1. Engineering Analysis Methodology

When developing its engineering analysis for distribution transformers, DOE divided the covered equipment into equipment classes. As discussed, distribution transformers are classified by insulation type (liquid immersed or dry type), number of phases (single or three), primary voltage (low voltage or medium voltage for dry-type distribution transformers) and basic impulse insulation level (BIL) rating (for dry types). Using these transformer design characteristics, DOE developed ten equipment classes. Within each of these equipment classes, DOE further classified distribution transformers by their kilovolt-ampere (kVA) rating. These kVA ratings are essentially size categories, indicating the power handling capacity of the transformers. For DOE's rulemaking, there are over 100 kVA ratings across all ten equipment classes.

DOE recognized that it would be impractical to conduct a detailed engineering analysis on all kVA ratings, so it sought to develop an approach that simplified the analysis while retaining reasonable levels of accuracy. DOE consulted with industry representatives and transformer design engineers to develop an understanding of the construction principles for distribution transformers. It found that many of the units share similar designs and construction methods. Thus, DOE simplified the analysis by creating engineering design lines (DLs), which group kVA ratings based on similar principles of design and construction. The DLs subdivide the equipment classes in order to improve the accuracy of the engineering analysis. These DLs differentiate the transformers by insulation type (liquid immersed or dry type), number of phases (single or three), and primary insulation levels for medium-voltage dry-type distribution transformers (three different BIL levels).

After developing its DLs, DOE then selected one representative unit from each DL for study, greatly reducing the number of units for direct analysis. For each representative unit, DOE generated hundreds of unique designs by contracting with Optimized Program Services, Inc. (OPS), a software company specializing in transformer design since 1969. The OPS software used three primary inputs that it received from DOE: (1) A design option combination, which included core steel grade, primary and secondary conductor material, and core configuration; (2) a loss valuation combination; and (3) material prices. For each representative unit, DOE examined anywhere from 9 to 16 design option combinations and for each design option combination, the OPS software generated 518 designs based on unique loss valuation combinations. These loss valuation combinations are known in industry as A and B evaluation combinations and represent a customer's present value of future losses in a transformer core and winding, respectively. For each design option combination and A and B combination, the OPS software generated an optimized transformer design based on the material prices that were also part of the inputs. Consequently, DOE obtained thousands of transformer designs for each representative unit. The performance of these designs ranged in efficiency from a baseline level, equivalent to the current distribution transformer energy conservation standards, to a theoretical max-tech efficiency level.

After generating each design, DOE used the outputs of the OPS software to help create a manufacturer selling price (MSP). The material cost outputs of the OPS software, along with labor estimates, were marked up for scrap factors, factory overhead, shipping, and non-production costs to generate a MSP for each design. Thus, DOE obtained a cost versus efficiency relationship for each representative unit. Finally, after DOE had generated the MSPs versus efficiency relationship for each representative unit, it extrapolated the results to the other, unanalyzed, kVA ratings within that same engineering design line.

FEMCO commented that DOE generated too many designs, and that many were impractical or unlikely to sell. (FEMCO, No. 180 at p. 1) EMS Consulting made an opposite remark, that DOE's chosen methodology omits many possible solutions. (EMS, No. 170 at p. 5) Finally, NEMA commented that the "steepness" of some of DOE's curves were lower than was shown by some manufacturers, ABB in particular. (NEMA, No. 170 at p. 4, p. 3) In other words, NEMA questioned whether cost might rise more quickly with efficiency than DOE's analysis suggested. Conversely, ATI Allegheny commented that DOE did excellent work on the engineering analysis. (ATI, No. 191 at p. 1)

DOE acknowledges both that it may not have analyzed every possible design and that, conversely, some designs would be unlikely to be considered by many purchasers, but notes that the goal of the engineering analysis is to both explore the limits of design possibility and establish a cost/efficiency behavior. The Life-Cycle Cost and Payback Period Analysis, in turn, examines which of the designs would be cost-effective for individual purchasers. It would not be practical to attempt to analyze every possible physical design. Regarding NEMA's comments, DOE is always seeking constructive feedback to aid in the accuracy of its engineering analysis, but cautions that comparisons between designs must be made carefully in order to be sure that they remain valid across a wide variety of market forces and construction techniques. A manufacturer's cost of producing higher-efficiency units in today's market may be different than the cost of meeting those same efficiencies after establishment of energy conservation standards, which may lead to production at higher volumes.

2. Representative Units

For the preliminary analysis, DOE analyzed 13 DLs that cover the range of equipment classes within the distribution transformer market. Within each DL, DOE selected a representative unit to analyze in the engineering analysis. A representative unit is meant to be an idealized unit typical of those used in high volume applications.

In view of comments received from stakeholders throughout the analysis period, DOE slightly modified its representative units for the NOPR analysis. For the NOPR, DOE analyzed the same 13 representative units as in the preliminary analysis, but also added a design line, and therefore representative unit, by splitting the former design line 13 into two new design lines, 13A and 13B. This new representative unit allows DOE's analysis to better reflect the behavior of high kVA, high BIL medium-voltage dry-type units and is shown in Table IV.5. The representative units selected by DOE were chosen because they comprise high volume segments of the market for their respective design lines and also provide, in DOE's view, a reasonable basis for scaling to the unanalyzed kVA ratings. DOE chooses certain designs to analyze as representative of a particular design line or design lines because it is impractical to analyze all possible designs in the scope of coverage for this rulemaking.

DOE also notes that as a part of the negotiations process, DOE worked directly with multiple interested parties to develop a new scaling methodology for the NOPR that addresses some of the interested party concerns regarding scaling.

TABLE IV.5—ENGINEERING DESIGN LINES (DLS) AND REPRESENTATIVE UNITS FOR NOPR ANALYSIS

EC*	DL	Type of distribution transformer	kVA range	Representative unit for this engineering design line
1	1	Liquid-immersed, single-phase, rectangular tank.	10–167	50 kVA, 65 °C, single-phase, 60Hz, 14400V primary, 240/120V secondary, rectangular tank, 95kV BIL.
	2	Liquid-immersed, single-phase, round tank.	10–167	25 kVA, 65 °C, single-phase, 60Hz, 14400V primary, 120/240V secondary, round tank, 125 kV BIL.
	3	Liquid-immersed, single-phase	250–833	500 kVA, 65 °C, single-phase, 60Hz, 14400V primary, 277V secondary, 150kV BIL.
2	4	Liquid-immersed, three-phase	15–500	150 kVA, 65 °C, three-phase, 60Hz, 12470Y/7200V primary, 208Y/120V secondary, 95kV BIL.
	5	Liquid-immersed, three-phase	750–2500	1500 kVA, 65 °C, three-phase, 60Hz, 24940GrdY/14400V primary, 480Y/277V secondary, 125 kV BIL.
3	6	Dry-type, low-voltage, single-phase	15–333	25 kVA, 150 °C, single-phase, 60Hz, 480V primary, 120/240V secondary, 10kV BIL.
4	7	Dry-type, low-voltage, three-phase	15–150	75 kVA, 150 °C, three-phase, 60Hz, 480V primary, 208Y/120V secondary, 10kV BIL.
	8	Dry-type, low-voltage, three-phase	225–1000	300 kVA, 150 °C, three-phase, 60Hz, 480V Delta primary, 208Y/120V secondary, 10kV BIL.
6	9	Dry-type, medium-voltage, three-phase, 20–45kV BIL.	15–500	300 kVA, 150 °C, three-phase, 60Hz, 4160V Delta primary, 480Y/277V secondary, 45kV BIL.
	10	Dry-type, medium-voltage, three-phase, 20–45kV BIL.	750–2500	1500 kVA, 150 °C, three-phase, 60Hz, 4160V primary, 480Y/277V secondary, 45kV BIL.
8	11	Dry-type, medium-voltage, three-phase, 46–95kV BIL.	15–500	300 kVA, 150 °C, three-phase, 60Hz, 12470V primary, 480Y/277V secondary, 95kV BIL.
	12	Dry-type, medium-voltage, three-phase, 46–95kV BIL.	750–2500	1500 kVA, 150 °C, three-phase, 60Hz, 12470V primary, 480Y/277V secondary, 95kV BIL.
10	13A	Dry-type, medium-voltage, three-phase, 96–150kV BIL.	75–833	300 kVA, 150 °C, three-phase, 60Hz, 24940V primary, 480Y/277V secondary, 125kV BIL.
	13B	Dry-type, medium-voltage, three-phase, 96–150kV BIL.	225–2500	2000 kVA, 150 °C, three-phase, 60Hz, 24940V primary, 480Y/277V secondary, 125kV BIL.

* EC means equipment class (see Chapter 3 of the TSD). DOE did not select any representative units from the single-phase medium-voltage equipment classes (EC5, EC7 and EC9), but calculated the analytical results for EC5, EC7, and EC9 based on the results for their three-phase counterparts.

For a full version of the Department of Energy final rule for distribution transformer standards

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