Distribution Transformer Standards Rulemaking

Draft Report for Review

Dry-type Distribution Transformers, Life Cycle Cost Analysis on Design Line 9

Prepared for:

Building Technology Program
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

October 4, 2002

Lawrence Berkeley National Laboratory
Building 90-4000
1 Cyclotron Road
Berkeley, CA 94720

FOREWORD

The U.S. Department of Energy (the Department or DOE) is determining minimum efficiency levels for distribution transformers sold in the United States. The purpose of this draft report is to present the methodology and structure of the Life Cycle Cost (LCC) Analysis for dry-type transformers. On June 6, 2002, the Department published a similar draft report on a representative liquid-type unit. This present report presents preliminary results from the life cycle cost analysis on Design Line 9, a 300 kVA, three-phase, dry-type at 45kV BIL transformer. This design line represents a common dry-type unit being manufactured in the U.S. On August 23, 2002, the Department released a related draft engineering report for comment, *Engineering Analysis for Dry-type Distribution Transformers and Results on Design Line 9*, which presents detailed cost and efficiency information. All distribution transformer reports are available on the Department's web site:

http://www.eren.doe.gov/buildings/codes_standards/applbrf/dist_transformer.html.

The Department is making this draft report public in the spirit of early consultation with all stakeholders. This is just one of several opportunities that stakeholders have to provide the Department with data, recommendations, and other comments.

The Department requests public review and comment on the assumptions, methodology, and draft results presented in this draft report. Comments will be entered into the docket for the distribution transformers rulemaking. Please submit comments by 4 p.m. October 28, 2002, to:

Antonio Bouza
Project Manager
"Energy Conservation Standards for Distribution Transformers, Docket No. EE-RM/STD-00-550"
EE-2J / Forrestal Building
US Department of Energy
1000 Independence Avenue SW
Washington DC 20585-0121

Email: Antonio.Bouza@ee.doe.gov

Please note that for all comments submitted, DOE requires that a signed, original document be mailed to the address above for inclusion in the docket. However, due to possible security screening delays in DOE's processing of mail sent through the U.S. Postal Service, DOE encourages stakeholders to also submit comments electronically (via email) to ensure timely receipt.

TABLE OF CONTENTS

1. SETTING THE CONTEXT 1
2. OVERVIEW 3
   - 2.1 Content Overview 3
   - 2.2 Overview of Methodological Intent 3

3. LCC SPREADSHEET 5
   - 3.1 LCC Equation 5
   - 3.2 LCC Spreadsheet Key Steps 5
   - 3.3 LCC INPUTS 7
     - 3.3.1 A and B Transformer Selection Parameters and Usage Rates 7
     - 3.3.2 Database of Transformer Designs 8
     - 3.3.3 Markup and Installation Costs 8
     - 3.3.4 Transformer Loading 9
     - 3.3.5 Utility Tariffs 10
     - 3.3.6 Load Growth Rate 11
     - 3.3.7 Electricity Price Trends 11
     - 3.3.8 Discount Rates 12
     - 3.3.10 Transformer Service Life 13
     - 3.3.11 Maintenance Costs 13
     - 3.3.12 Power Factor 13
   - 3.4 LCC Computational Flow 14
     - 3.4.1 Step #1: Select A & B 14
     - 3.4.2 Step #2: Select Design 15
     - 3.4.3 Step #3: Load and Price Profile 15
     - 3.4.4 Step #4: Calculate Cost of Losses 15
     - 3.4.5 Step #5: Project Losses and Costs into the Future 16
     - 3.4.6 Step #6: Select Discount Rate 16
     - 3.4.7 Step #7: Calculate Present Value of Future Cost of Losses 16
     - 3.4.8 Step #8: Results Reported 16
     - 3.4.9 Step #9: Results of Distribution of Transformers 16
     - 3.4.10 Step #10: Results for “Average” Scenario 17
     - 3.4.11 Repeat Process 17
4. LCC DRAFT RESULTS 18
   - 4.1 Monte-Carlo Simulations 19
5. USER INSTRUCTIONS 25
   - 5.1 Software and Hardware Requirements 25
   - 5.2 LCC Spreadsheets 25
     - 5.2.1 Sheet Overview 25
     - 5.2.2 User-Selectable Variables 26
     - 5.2.3 Monte-Carlo Simulation Using Crystal Ball 26

APPENDIX A. MARKUPS AND INSTALLATION COSTS FOR DRY-TYPE TRANSFORMERS A-1

REFERENCES R-1

LIST OF TABLES

Table 3.1 A and B Distributions: Three Scenarios with Usage Percentages 8
Table 3.2 Markups 9
Table 4.1 Summary of the LCC Savings Results Presented in Figures 4.2 - 4.11 19

LIST OF FIGURES

Figure 3.1 Transformer LCC Spreadsheet Model Flowchart 6
Figure 3.2 Electricity Price Scenarios 11
Figure 3.3 Distribution of Discount Rates Used in the LCC Analysis 12
Figure 4.1 Design Level Losses (LL) versus No-load Losses (NL) for TP1-2002 18
Figure 4.2 LCC Savings for Standard Level 1 (TP 1): Frequency Chart 20
Figure 4.3 LCC Savings for Standard Level 1 (TP 1): Cumulative Chart 20
Figure 4.4 LCC Savings for Standard Level 2 (TP 1 + 0.2%): Frequency Chart 21
Figure 4.5 LCC Savings for Standard Level 2 (TP 1 + 0.2%): Cumulative Chart 21
Figure 4.6 LCC Savings for Standard Level 3 (TP 1 + 0.4%): Frequency Chart 22
Figure 4.7 LCC Savings for Standard Level 3 (TP 1 + 0.4%): Cumulative Chart 22
Figure 4.8 LCC Savings for Standard Level 4 (TP 1 + 0.6%): Frequency Chart 23
Figure 4.9 LCC Savings for Standard Level 4 (TP 1 + 0.6%): Cumulative Chart 23
Figure 4.10 LCC Savings for Standard Level 5 (TP 1 + 0.7%): Frequency Chart 24
Figure 4.11 LCC Savings for Standard Level 5 (TP 1 + 0.7%): Cumulative Chart 24

ACKNOWLEDGMENTS

We would like to acknowledge and thank several individuals who provided guidance and input to the draft report: Antonio M. Bouza and Linda Graves of the U.S. Department of Energy's Office of Building Technologies, Michael Scholand and Michael Rivest of Navigant Consulting, Inc., and Stanley Merritt of Merritt and Associates.

ACRONYMS AND ABBREVIATIONS

ANOPR	Advance Notice of Proposed Rulemaking
AEO	DOE/EIA's *Annual Energy Outlook*
BIL	Basic Impulse Insulation Level
DOE	U.S. Department of Energy
DL#9	Design Line # 9
Hz	Hertz
kV	kilovolt
kVA	kilovolt-Ampere (transformer size rating)
LBNL	Lawrence Berkeley National Laboratory
LCC	life cycle cost
LL	load losses
NEMA	National Electrical Manufacturers Association
NL	no-load losses
NOPR	Notice of Proposed Rulemaking
OPS	Optimized Program Services, Inc
ORNL	Oak Ridge National Laboratory
NCI	Navigant Consulting, Inc.
TOC	Total Owning Cost

1. SETTING THE CONTEXT

On November 1, 2000, the Department held a public meeting in Washington, D.C., to discuss the *Framework Document for Distribution Transformer Energy Conservation Standards Rulemaking*. An electronic copy of that document is available on the Department's web site at http://www.eren.doe.gov/buildings/codes_standards/applbrf/dist_transformer.html.

The Framework Document describes the procedural and analytical approaches the Department is using as it considers energy conservation standards for distribution transformers. The formal rulemaking process for developing energy conservation standards includes three Federal Register notices: the Advance Notice of Proposed Rulemaking (ANOPR), the Notice of Proposed Rulemaking (NOPR), and the Notice of Final Rulemaking. With the release of this draft report, the Department is in what is commonly called the "pre-ANOPR" stage, meaning that the Department is presently conducting the analysis that it will publish for the ANOPR Federal Register notice and its public workshop.

Since it would be impractical to conduct detailed analyses of all seventy-three product classes identified in the National Electrical Manufacturers Association (NEMA)'s TP 1-2002 document (*Guide for Determining Energy Efficiency for Distribution Transformers*),[1] the Department has created thirteen "design lines" that group transformers based on their engineering similarities. The Department selected one model from each design line for analysis and will extrapolate the findings to the other models in that design line. The Department will analyze each of the design lines with a specific LCC spreadsheet for that grouping of distribution transformers. The Department has divided the thirteen representative design lines into two generic types: liquid and dry (five design lines describe liquid-type and eight describe dry-type transformers). The methodology and structure of the LCC Analysis for these two transformer types differ due to their unique economic environments. Electric utilities dominate the purchaser market for the liquid type, while commercial and industrial entities are the dominant purchasers of the dry-type distribution transformers.

On June 6, 2002, the Department posted for comment the LCC spreadsheet for Design Line #1 (DL#1) as the prototype design line for all liquid-type representative units. The present draft report focuses on the LCC spreadsheet for Design Line #9 (DL #9) as the prototype design line for all dry-type representative units. The representative unit for DL #9, as established in the Engineering Analysis, is a 300 kVA, three-phase, dry-type at 45kV BIL transformer. The Department assumes for the dry-type LCC analyses that a commercial or industrial entity installs, maintains, and owns these transformers.

The LCC spreadsheet compares the life cycle costs for a representative unit from the baseline scenario with life cycle costs for more efficient units. Baseline units are those designs that customers would choose in the absence of a new efficiency standard. Identifying a specific baseline for transformers is complicated for two reasons: (1) the lack of existing mandatory efficiency standards, and (2) the wide variability at any given efficiency level in designs available to potential purchasers.

In order to address these issues, the Department developed an LCC model that uses distributions of inputs to produce a representative range of transformer costs and efficiencies. That representative distribution of costs and efficiencies determines the baseline LCC scenario.

The Department will use the LCC spreadsheet to determine the effects of more efficient units on operating expenses (usually decreased) and changes in purchase prices (usually increased) of distribution transformers. The LCC spreadsheet focuses on a distribution of potential transformer designs for selected efficiency levels (see the *Engineering Analysis for Dry-type Distribution Transformers and Results on Design Line 9* for a discussion of the potential designs). These designs differ in cost, no-load losses, and load losses. Using the LCC spreadsheet, the Department will calculate operating costs, taking into account distributions in loading and marginal electricity prices, and will compare several potential energy efficiency standards levels.

2. OVERVIEW

2.1 Content Overview

In addition to providing draft results on DL#9, this report presents detailed descriptions of the assumptions and methodology of LCC analysis for all dry-type units. Figure 3.1 provides a graphical overview of the basic flow of the LCC spreadsheet. Section 3.3 provides definitions of the inputs, and Section 4 contains the draft results.

The Department is especially interested in detailed stakeholder comments regarding this draft LCC report and its accompanying spreadsheet. Those with specific questions on using the LCC spreadsheet should contact John Stoops at Lawrence Berkeley National Laboratory (LBNL), phone: 510.486.6114, or e-mail JLStoops@lbl.gov.

2.2 Overview of Methodological Intent

The Department by law must evaluate the economic impact of any potential energy efficiency standard (EPCA (Energy Policy Conservation Act), Section 325(o)(2)(A), 42 U.S.C. 6295 (o)(2)(A)). The effects of energy efficiency standards include changes in operating expenses (usually decreased) and changes in purchase price (usually increased). The LCC analysis captures these expenses for the service life of a transformer. LCC calculations include the installed cost (purchase price plus installation cost), operating expenses (energy and maintenance costs), service lifetime of the product, and the application of a discount rate. The LCC decreases, thereby resulting in net savings, if the savings from reduced operating expenses of a more efficient transformer are greater than any increase in the installed cost.

The Department developed an LCC spreadsheet model to calculate the economic impacts of more efficient distribution transformers. The LCC spreadsheet estimates the economic impacts on the owner of a transformer by calculating the difference between pairs of transformers. In these pairs, one transformer is a baseline model representing a typical transformer that would be purchased in the current environment (i.e., without an efficiency standard). The other transformer model is selected in two ways: For those purchasers conducting Total Owning Cost (TOC) evaluations, the transformer corresponds to the lowest-TOC design that meets a particular energy efficiency standard; for those purchasers not basing their purchase decisions on TOC evaluation, the transformer is the one with minimum first cost. The Department expects to incorporate additional enhancements in the model as it receives stakeholders' comments. These enhancements will aid the Department in preparing the evaluation runs for the ANOPR.

Transformer design, efficiency, and economics are characterized by a large degree of diversity, which is represented in the LCC spreadsheet by distributions. There are many possible transformer designs with different loss and efficiency characteristics. Commercial and industrial customers may purchase electricity from more than three thousand retail utilities, which may charge different tariffs and prices. As part of a distribution system with varying load factors, system loads,

and electricity costs, all transformers are exposed to dynamic loads. Each of these elements affects the economics of improving transformer efficiency. The LCC spreadsheet captures these effects by utilizing probability distributions instead of point values as inputs. Custom distributions are derived from available data to characterize economic parameters such as discount rates and electricity tariffs. When detailed data are unavailable, the Department uses theoretical formulas for probability distribution functions that have mean values and variances consistent with the available data.

The LCC spreadsheet uses several data sets as sources for these distributions. Potential transformer designs come from a distribution of more than two thousand potential designs from the engineering analysis by Navigant Consulting Inc. (NCI), formerly Arthur D. Little, Inc., *Engineering Analysis for Dry-type Distribution Transformers and Results on Design Line 9*. Utility economics consist of a sample of more than fifty utilities. Hourly loads come from more than two thousand three hundred transformer load profiles based on simulations from actual system loads. The Department calculates customer bills from a statistically representative sample of tariffs from eighty utilities. Since many of the inputs to the LCC are distributions rather than point values, the LCC results are also distributions. The LCC model produces results through ten thousand iterations of a Monte-Carlo simulation tool.

3. LCC SPREADSHEET

3.1 LCC Equation

An important part of the LCC analysis and spreadsheet model is the LCC equation. The LCC equation reflects both the first costs of an item and the present value of the operating costs over the service life of the equipment.

The LCC equation is

$$LCC = IC + SUM_{n=1,Lifetime} [OC_n/(1+Drate)^n]$$

Where:

- IC is the initial installed cost;
- SUM is the sum over service life;
- n is the index for the year of operation;
- Lifetime is the service life of the transformer;
- OC_n is the operating costs in year n; and
- Drate is the discount rate applied to the calculation.

The initial installed costs include the purchase price and installation cost of the transformer, while the operating costs include the value of the losses and maintenance costs. The Department calculates the value of the losses as part of representative customer bills using transformer loading and utility tariffs, as explained below.

3.2 LCC Spreadsheet Key Steps

While the LCC equation is a simple equation, the LCC spreadsheet model takes into account the dynamic nature of inputs over the service life of a transformer. A simplified flowchart (Figure 3.1) illustrates the key steps implemented in the LCC spreadsheet: inputs, computational steps, and outputs.

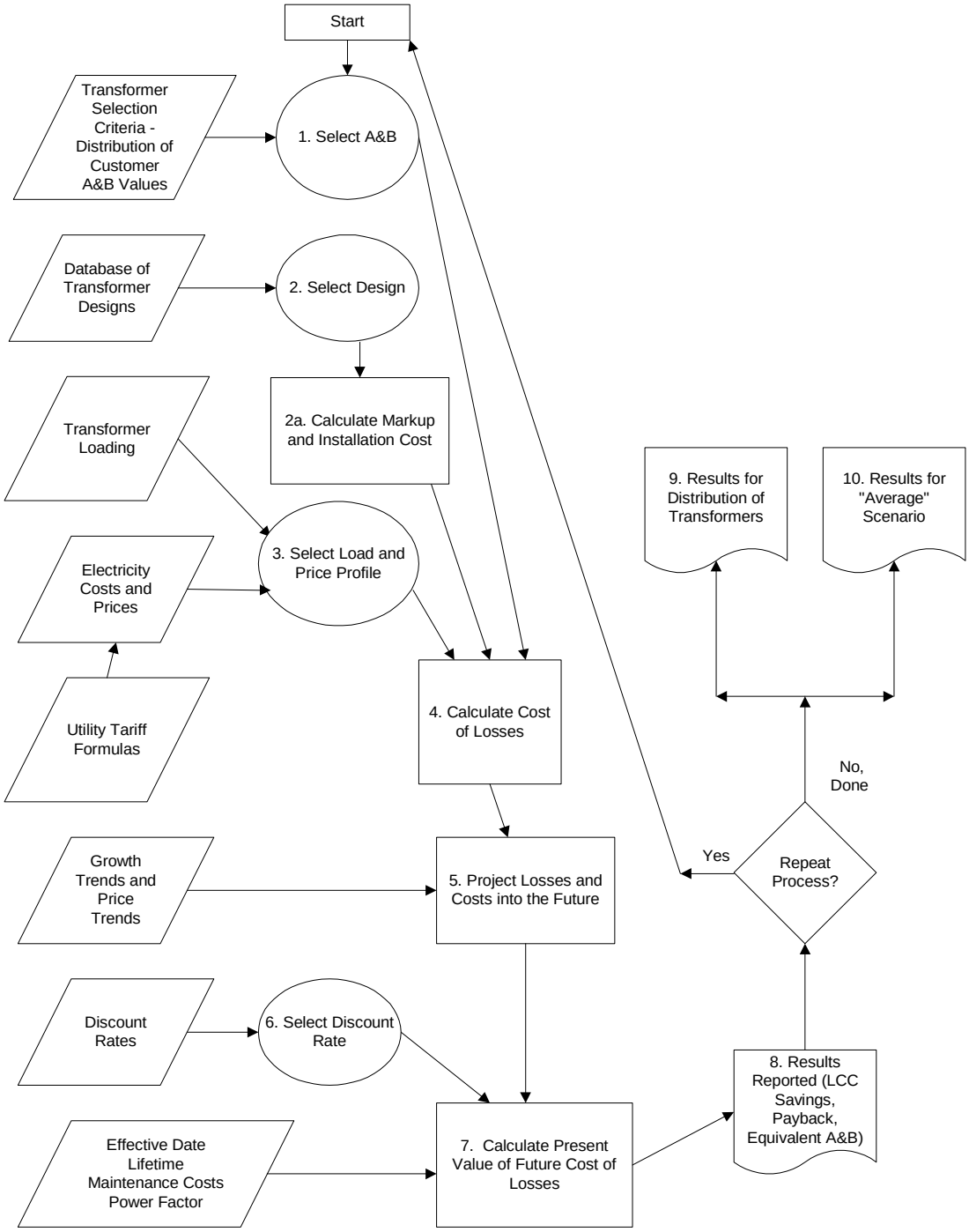

Figure 3.1 Transformer LCC Spreadsheet Model Flowchart

3.3 LCC INPUTS

This section presents the LCC inputs for the spreadsheet model; it provides definitions and data sources for each component. The Department recognizes that the LCC inputs in this draft report may not adequately reflect all DL#9 customers and requests that reviewers, particularly commercial and industrial customers, review and comment on these inputs.

3.3.1 A and B Transformer Selection Parameters and Usage Rates

Utilities and commercial and industrial customers use A and B factors in their calculations of Total Owning Cost (TOC). In the TOC method, the A parameter is the no-load loss valuation multiplier and the B parameter is the load loss valuation multiplier. Commercial and industrial customers may tend to purchase dry-type transformers without the explicit use of the utility TOC methodology for transformer selection. Present value calculation of the value of losses will implicitly yield a value per watt for both no-load and load losses that is equivalent to A and B parameters. Therefore, DOE uses distributions of A and B parameters to characterize customer choices.

DOE developed three A and B usage distributions, differing in the percent of transformers evaluated. The scenario representing non-evaluation by all purchasers is 0% while the scenario representing evaluation by all purchasers is 100%. For this dry-type design line, few purchasers evaluate, so DOE developed a medium scenario with 10% of purchasers evaluating. Table 3.1, taken directly from the LCC spreadsheet for DL#9, provides the exact usage rates for the different A and B combinations. The default scenario, representing current practice for this design line, is the medium evaluation rate of 10%, which is consistent with Table 4.2 in Report ORNL-6925 *Supplement to the "Determination Analysis"* .[2] The 0% and 100% evaluation scenarios are available to test the LCC sensitivity to changes in the percentage of transformer purchasers using evaluation to select transformers.

Table 3.1 A and B Distributions: Three Scenarios with Usage Percentages

0% Non Evaluating Usage Rate

A	B	Rate (%)
0.00	0.00	100.00

10% Med Evaluating Usage Rate

A	B	Rate (%)
0.00	0.00	90.00
0.63	0.22	0.19
1.25	0.44	0.37
1.88	0.66	0.56
2.50	0.88	0.75
3.13	1.09	0.87
3.75	1.31	1.00
4.38	1.53	1.00
5.00	1.75	1.00
5.63	1.97	0.90
6.25	2.19	0.80
6.88	2.41	0.66
7.50	2.63	0.53
8.13	2.84	0.42
8.75	3.06	0.30
9.38	3.28	0.23
10.00	3.50	0.15
10.63	3.72	0.11
11.25	3.94	0.07
11.88	4.16	0.05
12.50	4.38	0.03
13.13	4.59	0.02
13.75	4.81	0.01

100% High Evaluating Usage Rate

A	B	Rate (%)
0.00	0.00	0.00
0.63	0.22	1.87
1.25	0.44	3.74
1.88	0.66	5.61
2.50	0.88	7.47
3.13	1.09	8.72
3.75	1.31	9.96
4.38	1.53	9.96
5.00	1.75	9.96
5.63	1.97	8.97
6.25	2.19	7.97
6.88	2.41	6.64
7.50	2.63	5.31
8.13	2.84	4.18
8.75	3.06	3.04
9.38	3.28	2.28
10.00	3.50	1.52
10.63	3.72	1.10
11.25	3.94	0.67
11.88	4.16	0.47
12.50	4.38	0.27
13.13	4.59	0.18
13.75	4.81	0.10

3.3.2 Database of Transformer Designs

As an integral part of the rulemaking process, the Engineering Analysis captures the cost-efficiency relationship. For transformers, this relationship is in the form of a database of selling prices, no-load losses, and load losses for a wide range of realistic transformer designs contained in the LCC spreadsheet for DL#9. Navigant Consulting, Inc. used a transformer design software company, Optimized Program Service Inc. (OPS), and its software to create the database of designs. The database consists of a wide range of efficiencies and manufacturer sale prices (including a predetermined markup) to represent the variability of designs in the marketplace. The Engineering Analysis provides more detail on the structure and methodology used to generate this database of transformer designs.

3.3.3 Markup and Installation Costs

Markup and installation costs are the costs associated with bringing a manufactured transformer into service as an installed piece of electrical equipment. The manufacturing costs of dry-type transformers are subjected to four price markups: manufacturer markup, distributor markup, contractor markup, and sales tax.

DOE estimated these markups (expressed as average multipliers) using *RS Means Electrical Cost Data 2002*[3] and NCI inputs. Table 3.2 lists the average markups used in this draft report.

Table 3.2 Markups

Markup	Average Multiplier
Manufacturer	1.32
Distributor	1.34
Contractor	1.25
Sales Tax	1.056

The manufacturer markup converts the manufacturing cost to a manufacturer selling price that covers the overhead and profit for the manufacturer. After the transformer leaves the manufacturer, the distributor applies a markup to the manufacturer selling price to arrive at a distributor price, which is the price paid by the electrical contractor. This distributor price covers the cost of the distribution business including sales labor, transportation, warehousing, overhead, and profit for the distributor.

The contractor then applies a markup on the distributor price to cover overhead and profit on both labor and materials, and adds an installation cost. The installation cost is based on transformer weight using several empirical equations developed for this analysis. Finally, a sales tax added to the installation cost covers local taxes; the sum is the total installed cost to the purchaser. Appendix A of this draft report contains more detail on the development of these markups and the relationship between transformer weight and installation cost.

3.3.4 Transformer Loading

Transformer loading is the amount of electrical current that a transformer carries. DOE created a statistical load simulation model to calculate the hourly loads on individual transformers from system loads. There are five main inputs to the statistical load simulation model:

(1) An estimate of the annual peak load;
(2) A relationship between peak load and load factor;
(3) A relationship between the load factor and the load distribution function;
(4) The hourly system load; and
(5) The correlation between hourly system load and an individual transformer load.

From the rated size (kVA) of the transformer, the model estimates the annual peak load from a distribution of peak loads that range from 50% to 130% of rated load with a mean

of 85% of the rated peak load of the transformer. (The 85% average loading provides some room for load growth and a safety margin for the loading of the transformer. The limits of the range approximate the point at which one would move to a different size category of transformer.) The load model derives a scaling relationship between peak load and load factor from available hourly load monitoring data. The load distribution of the estimated load has this scaled load factor. The Department obtained the hourly system load from data on Federal Energy Regulatory Commission (FERC) Form 714, and derived hourly loads from analysis of End-Use Load and Consumer Assessment Program (ELCAP)[4] hourly load data and proprietary hourly load data. The Department took the correlation between transformer load and system load from distributions of correlation coefficients for commercial and residential customers from hourly load monitoring data available to the Department. The output of the load model is a monthly series of usage demand and root mean square usage from which the Department calculates customer bills, with and without transformer losses.

3.3.5 Utility Tariffs

The calculation of monthly customer incremental electricity costs from transformer losses uses a representative set of actual utility tariff formulas from the year 2002. Utility tariffs include fixed charges, energy (per kWh) charges, and demand (per kW) charges. Utilities typically arrange the rates for the different charges by blocks defined by levels of energy use and demand. The tariff formulas contain a series of blocks and several parameters per block defining the charges in that block of use. The spreadsheet contains a customer bill calculator that calculates customer bills based on information collected from a representative set of utility tariffs, seasonal charges, their blocks, and the fixed, energy, and demand charges in each block. The customer bill calculator is a custom Visual Basic for Application (VBA) function. The bill calculator function is a piece of VBA code included with the LCC Spreadsheet. Users can view the source code for the bill calculation function by going to Tools-->Macro-->Visual Basic Editor. The source code is in Module 3. DOE collected published utility tariffs to provide the data for the bill calculator. The tariff data is located in the “tariffs” and “components” worksheets. The bill calculator includes two hundred and eighteen tariffs from ninety utilities and includes fixed, usage, demand, and seasonal charges extracted from published utility tariffs.

3.3.6 Load Growth Rate

The Department is using as the default scenario a 1% per year load growth, i.e., a medium rate, as identified in ORNL-6847, *Determination Analysis of Energy Conservation Standards for Distribution Transformers*[5]. The 1% annual load growth trend from ORNL-6847 is consistent with the average electricity use growth per customer during the 1990s determined by the Energy Information Administration (EIA) at DOE. The Department applies a 1% load growth trend to each transformer beginning in 2007, the expected effective date of the standard (see Section 3.3.9) .

3.3.7 Electricity Price Trends

For the relative change in electricity prices for future years, the Department is using the price trends from three *Annual Energy Outlook 2002* (*AEO 2002*) forecast scenarios from EIA.[6] LCC spreadsheet users have the choice of these three scenarios:

(1) *AEO 2002* Low Growth scenario;
(2) *AEO 2002* Reference scenario; and
(3) *AEO 2002* High Growth scenario.

The current draft LCC analysis uses the trend from the Reference scenario as its "medium" scenario. The EIA's projections in *AEO 2002* extend through the year 2020. Until it is superseded by future *AEO* forecasts, the current EIA forecast recommends that electricity prices beyond the year 2020 should be held constant at 2020 levels, assuming that the period of transition to a restructured electricity industry will be complete (see Figure 3.2).

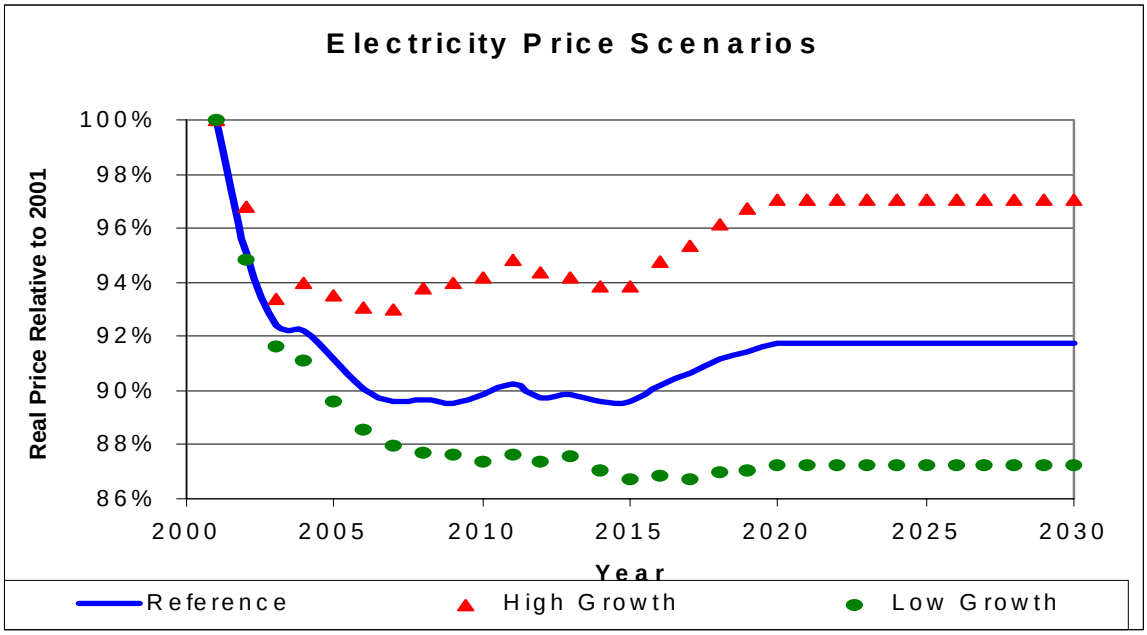

Figure 3.2 Electricity Price Scenarios

3.3.8 Discount Rates

The discount rate is the rate at which future expenditures are discounted to estimate their present value. Based on contemporary financial theory, the Department assumes that discount rates are equal to the cost of capital. The cost of capital is a combination of debt interest rates and the cost of equity capital to the affected firms and industries. Figure 3.3 shows a distribution of discount rates from the LCC spreadsheet. The Department divided the ownership for each transformer design line into several classes of potential owners. The Department determined from an online investment survey (http: //pages.stern.nyu.edu/~adamodar/) that each class of potential owners has a distribution of discount rates. The discount rate distribution for each design line is a weighted sample, combining the ownership percentages and their respective discount rate distributions.

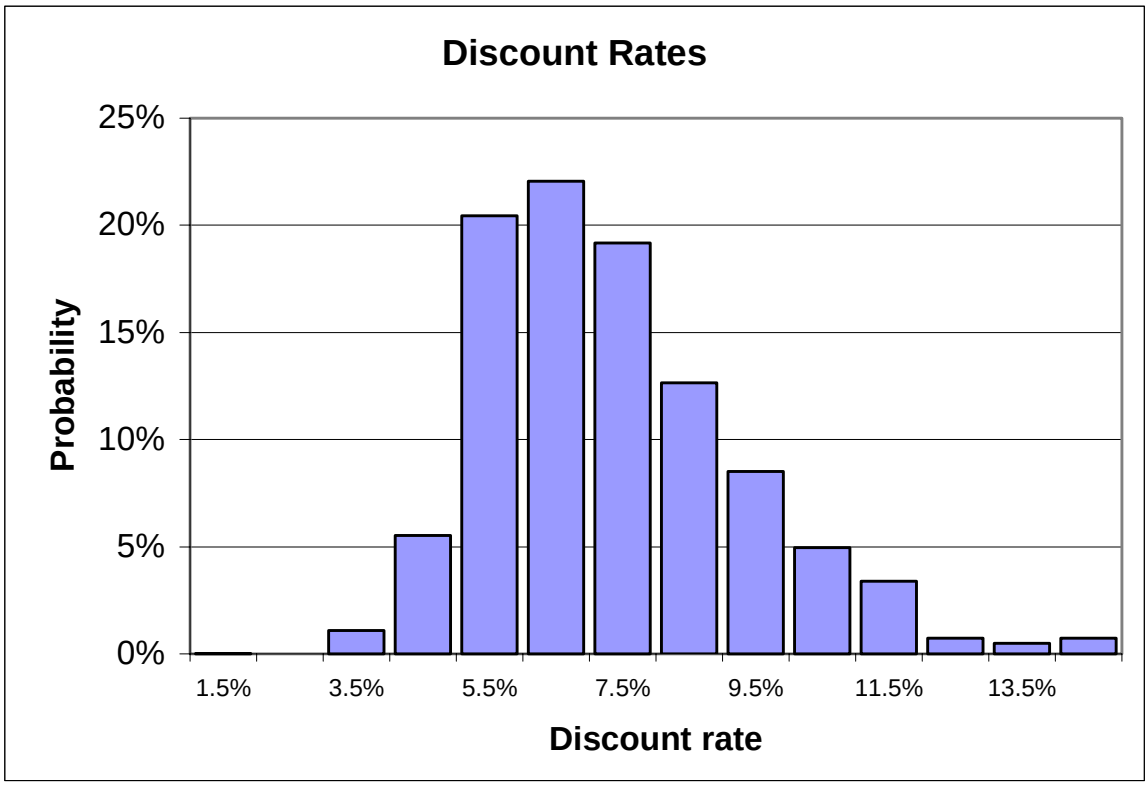

Figure 3.3 Distribution of Discount Rates Used in the LCC Analysis

3.3.9 Effective Date of Standard

The effective date of the new energy efficiency standard for distribution transformers is three years after the final rule. The Department assumes that the final rule will be issued

in 2004 and that, therefore, the new standard will take effect in 2007. The Department calculates the LCC for all users as if each new distribution transformer purchase occurs in the year the standard takes effect. The Department bases the cost of the equipment on that year; however, the Department expresses all dollar values in 2001 dollars.

3.3.10 Transformer Service Life

The Department defines distribution transformer service life as the age at which the transformer retires from service. The Department assumes, based on ORNL-6847, *Determination Analysis of Energy Conservation Standards for Distribution Transformers*, that the average life of distribution transformers is thirty-two years.[5] This lifetime assumption includes a constant failure rate of 0.5%/year due to lightning and other random failures unrelated to transformer age, and an additional corrosive failure rate of 0.5%/year at year fifteen and beyond. DOE adjusts the retirement distribution to maintain an average life of thirty-two years.

3.3.11 Maintenance Costs

The Department assumes that the cost for general maintenance will not change with increased efficiency. In practice, there is little scheduled maintenance for DL#9 transformers. Maintenance consists of brief annual checks for dust buildup, vermin infestation, and accident or lightning damage.

3.3.12 Power Factor

The power factor is the real power divided by the apparent power. Real power is the time average of the instantaneous product of voltage and current. Apparent power is the product of the root mean square voltage times the root mean square current. When specifying transformer efficiency, specifications such as NEMA's TP-1 2002 (see para. 1.3) assume a power factor of 1.0. Thus the Department used a power factor of 1.0 in calculating the efficiency levels for its Engineering Analysis, and will use a power factor of 1.0 when it prepares trial standard levels for the ANOPR.

However, in real world installations, the loads experienced by distribution transformers are likely to have power factors of less than 1.0. Because the LCC analysis models transformers installed and operating in the field, DOE created the spreadsheet with an adjustable power factor, enabling the LCC to run at lower values. In the absence of any specific data or guidance on the appropriate power factor, the Department used 1.0 for this draft LCC analysis. The Department requests specific stakeholder comment on this assumption.

3.4 LCC Computational Flow

The LCC spreadsheet uses the inputs as defined in Section 3.3 to perform the basic LCC calculation as defined in Section 3.1. Figure 3.1 is a graphical representation of the computational flow, consisting of inputs, computational steps, and outputs. The outputs are basically LCC results from different input assumptions; Chapter 4 of this report provides examples. This section (3.4) briefly discusses the ten steps of the computational flow as illustrated in Figure 3.1. Subsections 3.4.1 and 3.4.2 describe the first two steps in the LCC process in greater detail to provide additional guidance on these two key computations. Refer to the process flow chart, Figure 3.1, as needed to help place the following discussion in context.

3.4.1 Step #1: Select A & B

Step#1: Select Customer Choice A and B parameters from the choices on the "A & B Dist" worksheet.

The Department assumes that those commercial and industrial customers who evaluate transformer decisions use the same process as electric utilities, because it is the only specifically documented transformer economic evaluation process identified. It is standard practice for some electric utilities to provide manufacturers with economic "A and B factors," where A and B are the equivalent first costs of the no-load and load losses (in $/watt). The LCC spreadsheet simulates commercial and industrial customers' transformer purchase evaluation scenarios with three different A and B distributions through the use of the "Customer Decision As & Bs" pull-down menu on the "Summary" worksheet. These three scenarios represent using A and B factors 0%, 10%, and 100% of the time, respectively, in the selection process. These three scenarios are tabulated in the "A & B Dist" worksheet and in Section 3.3.1 of this report.

The first and third scenarios are the low and high bounds on the use of A and B factors, while the second scenario is intended to be more representative of the full mix of purchasers. The first scenario covers transformer purchasers who do not conduct an economic evaluation of transformer losses and purchase primarily on the basis of least first cost. These customers have 0% usage of A and B factors. The medium scenario for transformers of this design line is represented with a 10% usage rate of A and B factors in evaluating losses. The third scenario represents the case in which 100% of transformer purchasers evaluate using A and B factors. The Department uses the medium scenario as the default in the LCC spreadsheet, which is consistent with the evaluation rate estimated in ORNL-6925.

3.4.2 Step #2: Select Design

Step #2: Choose a standard level from the pull-down menu on the Summary Worksheet.

The key input for this step is the Transformer design (Transformer prices and ranges of NL and LL). The Department's Engineering Analysis yields a cost-efficiency relationship in the form of selling prices, no-load losses (NL), and load losses (LL) for a wide range of realistic transformer designs. This data set provides the LCC model with a distribution of transformer design choices. (See the “Design Table" worksheet, a condensed version of the Engineering Analysis output.) The manufacturer selling prices are in column C.

Step #2a: Calculate Markup and Installation Cost. These costs consist of a manufacturer markup, distribution markup, contractor markup, installation costs, and sales tax. The two key inputs for this step are Transformer Cost Markup and Installation Costs.

3.4.3 Step #3: Load and Price Profile

Step #3: The spreadsheet model selects a sample transformer load profile from the choices of load profiles on the "Demand and Usage" worksheet.

This step estimates customer demand and usage both with, and without, transformer losses. The LCC for each transformer uses monthly demand usage and root mean square usage estimates to calculate customer bills for baseline and standards scenarios in the “'Baseline LCC” and “Standard Option LCC” worksheets, respectively. The Department estimates monthly energy data using a statistical hourly load simulation model. The load simulation model provides hourly loads based on an estimate of the customer load factor, and an estimate of the customer load correlation with the utility system load. The model calculates transformer losses from the resulting customer usage, demand, and RMS usage estimates.

3.4.4 Step #4: Calculate Cost of Losses

Step #4: The spreadsheet model calculates the incremental impacts of no-load and load losses from the loss coefficients of the design, the monthly customer load characteristics (demand, usage and RMS usage), and the customer's tariff.

A customer bill calculator function calculates customer monthly bills both with, and without, transformer losses. The model presents the monthly bills in tables of monthly charges in the “Baseline LCC” and “Standard Option LCC” worksheets. The difference in the customer bills with, and without, transformer losses provides the marginal cost of transformer losses. The customer bill calculation function uses published tariff data from ninety utilities for two hundred eighteen tariffs. The Department stores the data on the tariff characteristics and charges in the “tariffs” and “components” worksheets, respectively.

3.4.5 Step #5: Project Losses and Costs into the Future

Step #5: The spreadsheet model projects losses and costs into the future based on load growth assumptions and a forecast of future changes in electricity price.

The model applies specific growth and price trends (the LCC user can select different growth and price options) to the current cost of losses calculated in step #4. This results in a projection of those losses and costs into the future.

3.4.6 Step #6: Select Discount Rate

Step #6: The spreadsheet model selects a discount rate from the discount rate distribution.

To discount the future stream of costs into a present value, it is necessary to select a discount rate. The LCC spreadsheet selects a discount rate from the weighted sample of discount rate inputs.

3.4.7 Step #7: Calculate Present Value of Future Cost of Losses

Step #7: The spreadsheet model calculates the present value of future operating costs and losses and the present worth per watt of no-load and load-losses.

This calculation step applies the basic time value of money discount methodology to express the future stream of costs in a single, present value. The calculation uses as inputs: the effective date of the standard, the transformer lifetime, maintenance costs, and power factor, in addition to the future costs of losses from Step #5.

3.4.8 Step #8: Results Reported

Step #8: The spreadsheet model records the LCC, LCC savings, payback period, and other results for inclusion in the distribution of results.

This is a reporting step. The model used the inputs in a set of calculations and reports the results. Depending on the application, different kinds of results can be reported, for example, LCC savings, payback periods, or equivalent A and B values.

3.4.9 Step #9: Results of Distribution of Transformers

Step #9: The spreadsheet model repeats the calculation until reaching the specified maximum number of samples.

When applying a Monte-Carlo simulation process, the model will perform a user-defined number of iterations and report the results as distributions. Based on the Department's experience with prior rulemakings using results expressed as distributions, ten thousand iterations in a Monte- Carlo simulation captures sufficient variability.

3.4.10 Step #10: Results for "Average" Scenario

Step #10: The spreadsheet model reports the results of the calculation for the "Average" scenario on the "Summary" worksheet.

The "Average" scenario allows users of the spreadsheet to produce provisional answers without performing a Monte-Carlo simulation. The Summary Worksheet of the LCC spreadsheet shows the results from this scenario. The Department extracted the marginal demand charge and marginal energy charge used in the average scenario calculation from an LCC spreadsheet Monte- Carlo simulation conducted during spreadsheet development.

3.4.11 Repeat Process

The specific number of iterations required for the Monte-Carlo simulation is implemented through the Repeat Process decision box. Each pass though the computational process registers a tick in a tabulation table. When the desired number of iterations has been reached, the model ends the simulation process and generates result reports.

4. LCC DRAFT RESULTS

One of the primary impacts of an energy efficiency standard is the change it produces in the set of transformer designs available for purchase and their corresponding loss characteristics, load losses (LL), and no-load losses (NL). The LL versus NL graph (fourth from right worksheet) illustrates this impact. Figure 4.1 provides an illustration of the LL versus NL graph copied from the LCC spreadsheet. The indicated standard level in this case is TP 1-2002.[1] This graph plots an example of a Crystal Ball LCC run. (Crystal Ball is an add-in to the Excel spreadsheet program; see Section 5.1 for details on Crystal Ball). It shows different sets of designs by their load losses at rated load and their no-load losses. The graph shows potential designs as both small blue dots and small purple squares. The thick blue line illustrates the standard level (those designs that satisfy the standard are to the left of this line). The red triangles are selected designs not subject to standard constraints. The green dots represent designs subject to standards constraints. As the standard level increases, the thick blue line moves parallel to the left (to the area of the graph with lower losses) and so does the set of constrained designs. Users can select the standard level using the corresponding pull-down menu on the "Summary" sheet. The graph shows some of the selected designs (especially those with higher load losses) meeting the standard to the right of the blue line. This is because the efficiency rating and design assumptions use different percent loading definitions. The graph defines the efficiency level at 50% loading while nameplate loading (100%) defines the load and no-load losses.

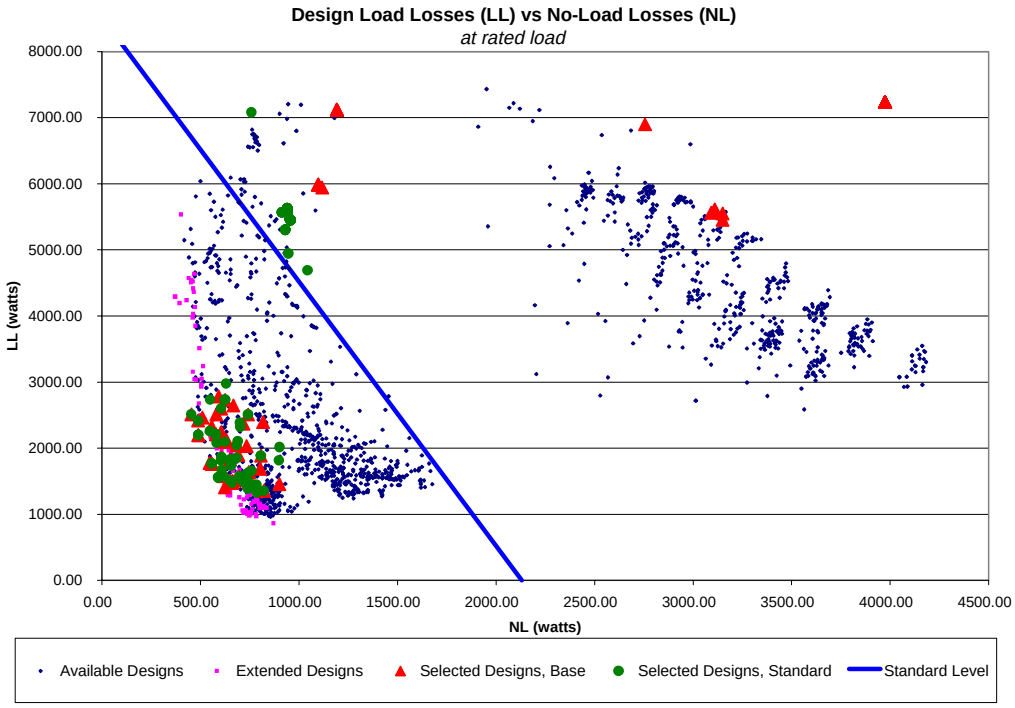

Figure 4.1 Design Load Losses (LL) versus No-load Losses (NL) for TP1-2002

The Department encourages stakeholders to conduct their own LCC simulation runs using their own specific sets of assumptions. Crystal Ball can illustrate the impact on LCC results of changes in different variables.

4.1 Monte-Carlo Simulations

The Monte-Carlo statistical method captures the effects of the values, relative weights, and distribution of the input variables on the LCC. The Department ran Monte-Carlo simulations using different possible standard levels 1 through 5 to illustrate the LCC analysis. The following set of charts (Figures 4.2- 4.11) provides stakeholders with an example of the results of these Monte-Carlo simulations. The charts represent LCC savings for different possible standard levels compared to the baseline LCC. Table 4.1 shows a summary of the results from the possible standard levels. All of the simulations are based on the Department's default assumptions for the input variables, which is the medium scenario in each case. The Department based each simulation on ten thousand iterations.

Two types of graphs present the results for each possible standard level: a Frequency Chart and a Cumulative Chart. On all of the graphs, the x-axis represents LCC savings, the difference between base case LCC and standards case LCC. Positive values represent reductions in LCC due to the standards and negative values represent increases in LCC due to the standards. Zero means no difference in LCC due to the standards. In the Frequency charts, the y-axis is equal to frequency. In the Cumulative Charts, the y-axis is equal to the cumulative frequency.

Table 4.1 Summary of the LCC Savings Results Presented in Figures 4.2 - 4.11

Standard Level	Mean LCC Savings per transformer	% of transformers having LCC Savings ≥ $0	Maximum LCC Savings	Minimum LCC Savings
1	$3999	~99.3	$47662	$-1400
2	$5565	~97.8	$55651	$-12820
3	$6794	~98.8	$78808	$-2176
4	$9780	~95.8	$101079	$-2187
5	$9921	~89.0	$109831	$-4024

Mean LCC per transformer in the base case is $33,310.

In evaluating possible standard levels and scenarios, the Department will conduct a large number of similar Monte-Carlo simulations. The Department encourages interested stakeholders to do likewise – to explore areas where they have a particular interest and to report those results back to the Department.

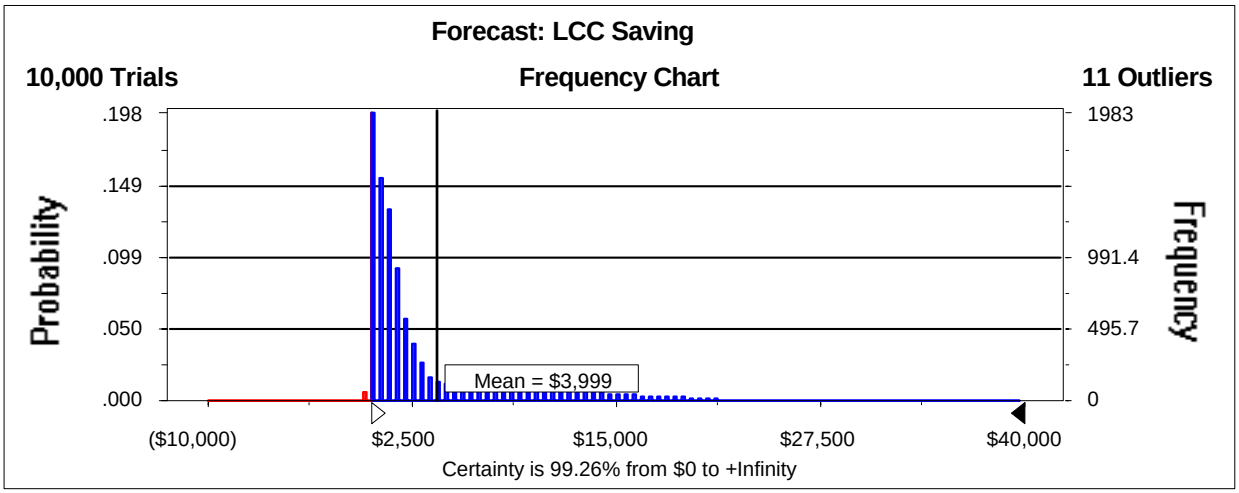

Figure 4.2 LCC Savings for Standard Level 1 (TP 1): Frequency Chart

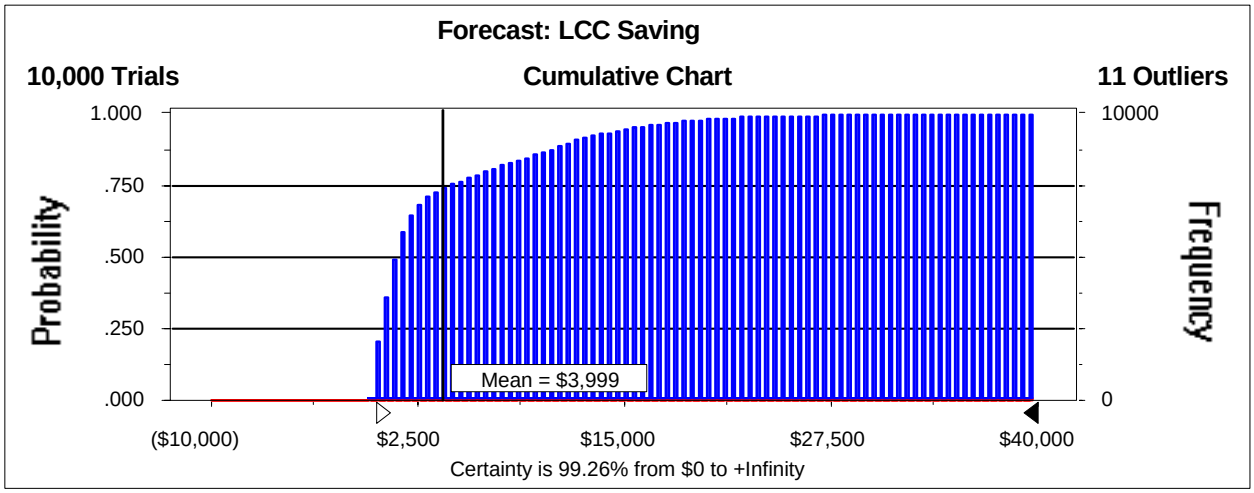

Figure 4.3 LCC Savings for Standard Level 1 (TP 1): Cumulative Chart

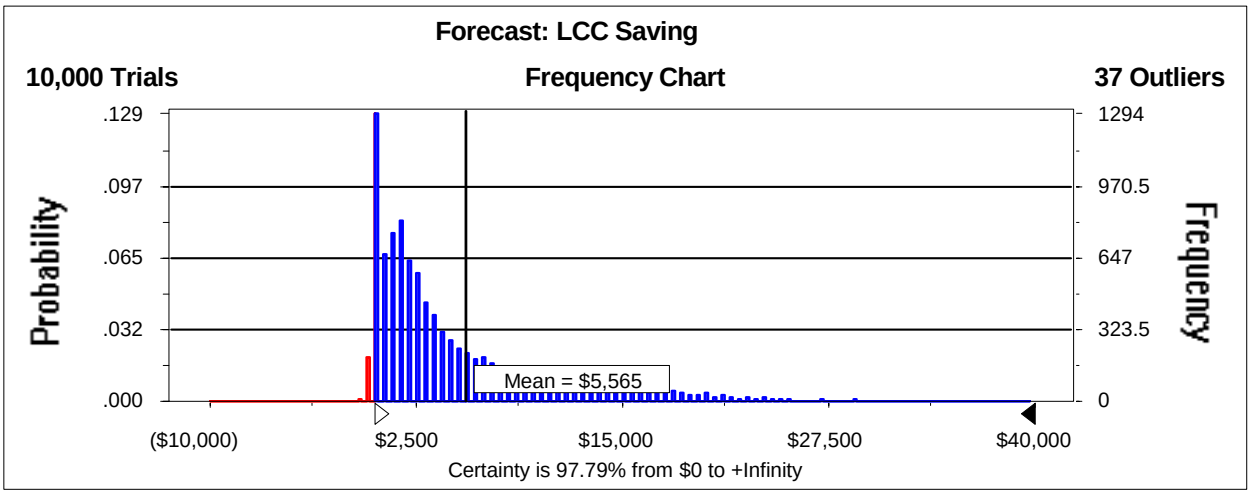

Figure 4.4 LCC Savings for Standard Level 2 (TP 1 + 0.2%): Frequency Chart

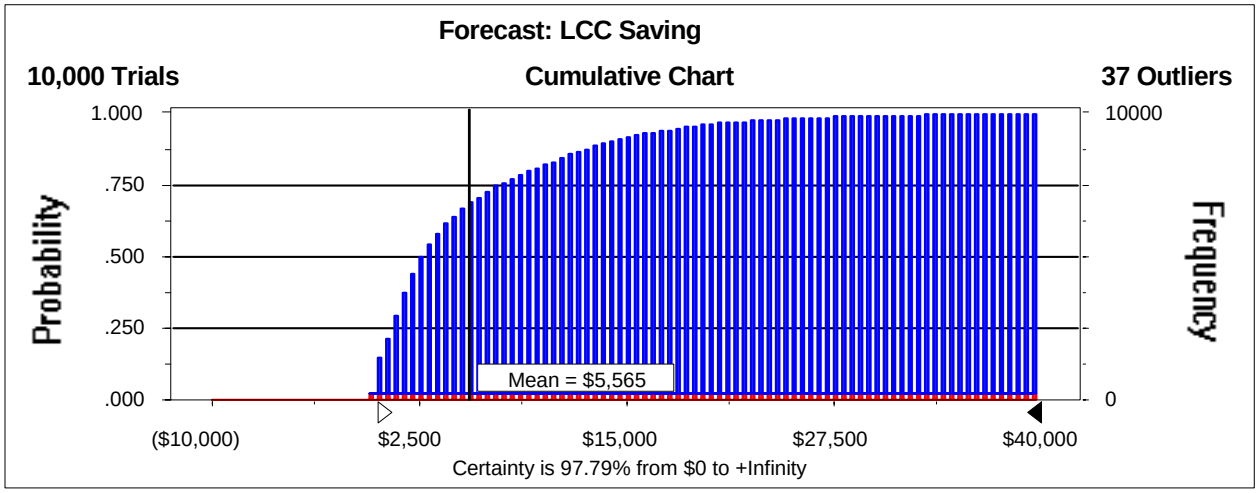

Figure 4.5 LCC Savings for Standard Level 2 (TP 1 + 0.2%): Cumulative Chart

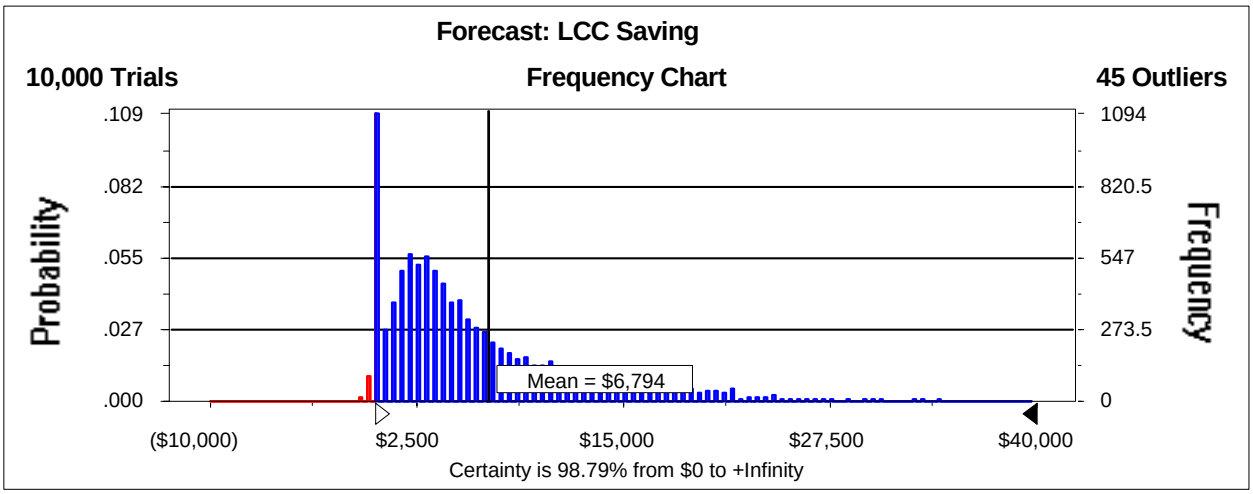

Figure 4.6 LCC Savings for Standard Level 3 (TP 1 + 0.4%): Frequency Chart

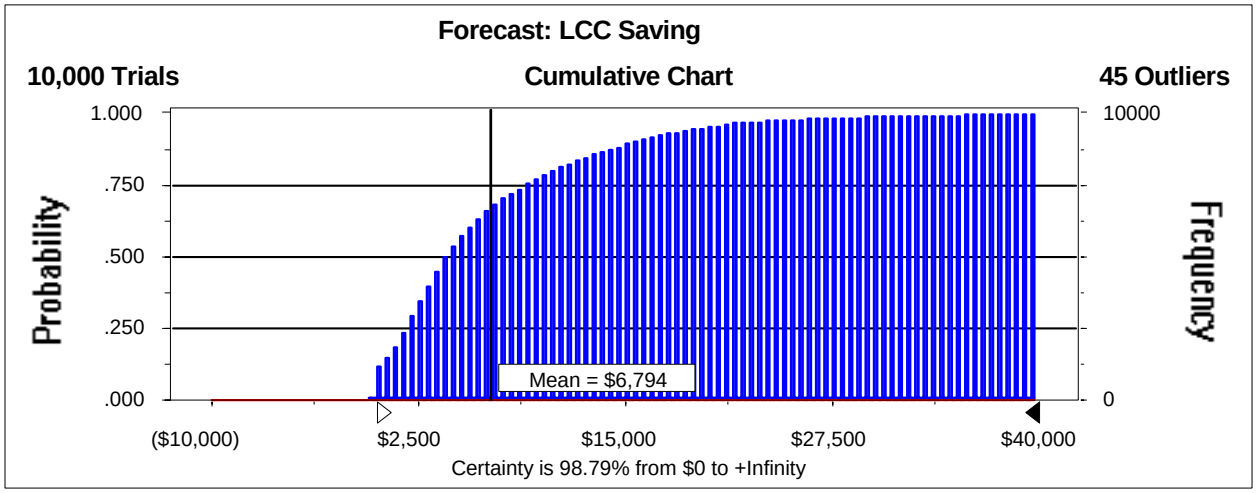

Figure 4.7 LCC Savings for Standard Level 3 (TP 1 + 0.4%): Cumulative Chart

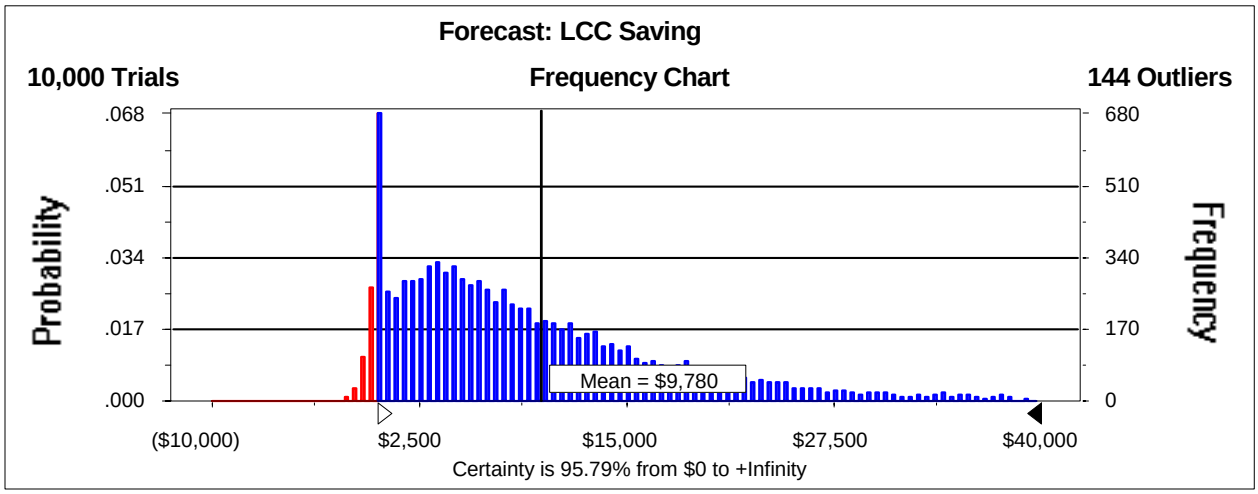

Figure 4.8 LCC Savings for Standard Level 4 (TP 1 + 0.6%): Frequency Chart

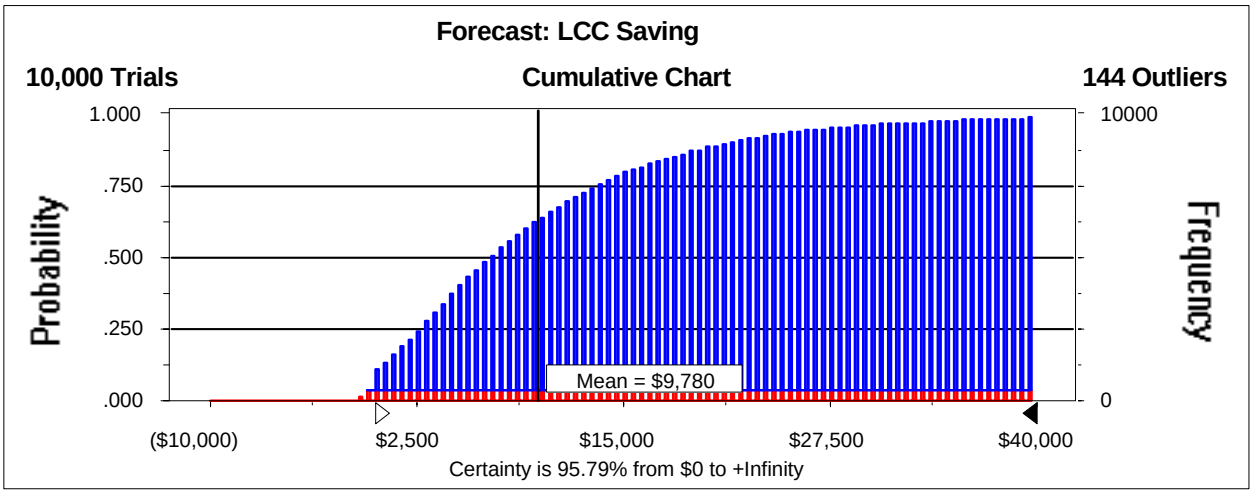

Figure 4.9 LCC Savings for Standard Level 4 (TP 1 + 0.6%): Cumulative Chart

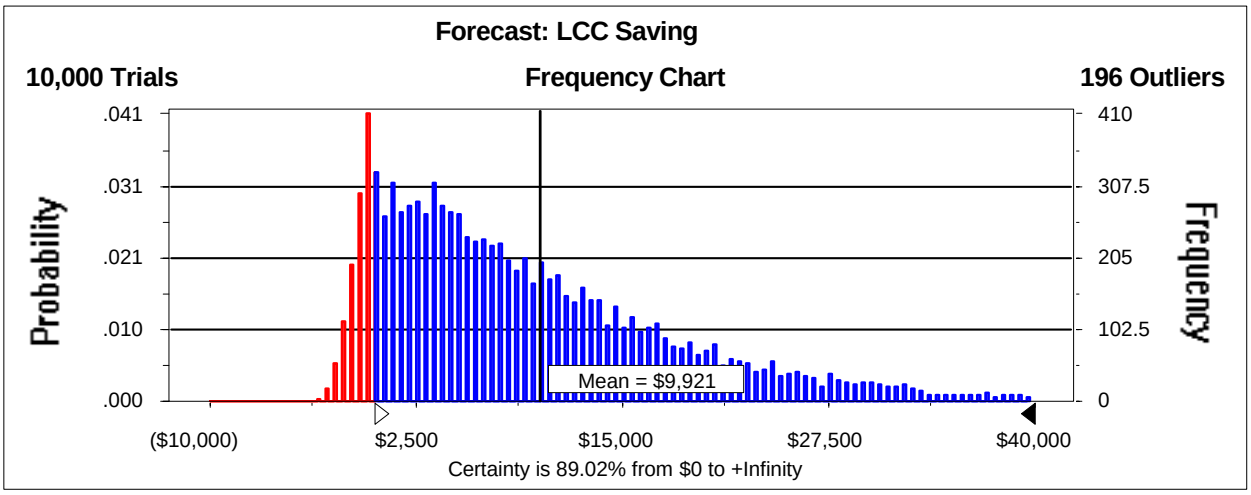

Figure 4.10 LCC Savings for Standard Level 5 (TP 1 + 0.7%): Frequency Chart

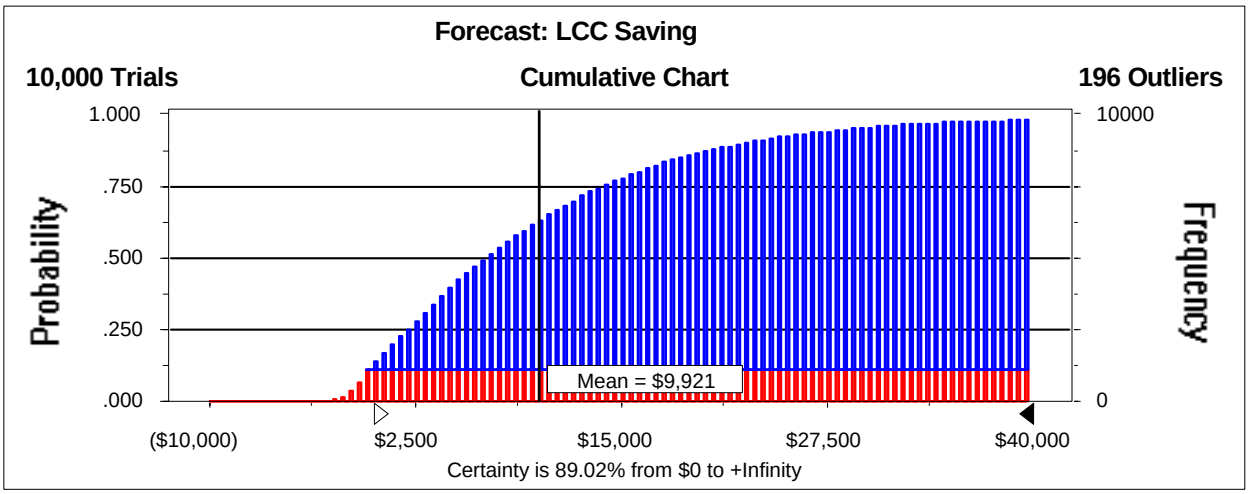

Figure 4.11 LCC Savings for Standard Level 5 (TP 1 + 0.7%): Cumulative Chart

5. USER INSTRUCTIONS

5.1 Software and Hardware Requirements

To execute the LCC spreadsheet, the user must have the appropriate software tools running under the Windows operating system on a PC. At a minimum, users need Microsoft Excel to execute the spreadsheet. For full functionality, advanced users should have a copy of Crystal Ball, a spreadsheet add-in to Excel, to run Monte-Carlo simulations. Without Crystal Ball, one can still run the LCC spreadsheet model but the run will be limited to using the "average transformer" for that scenario. The user can, however, view approximate results from a sample calculation that uses average values for the inputs and outputs, as displayed in the "Summary" worksheet.

5.2 LCC Spreadsheets

5.2.1 Sheet Overview

The LCC spreadsheet file is a stored Excel file. Each computer system will have a unique setup for loading a file. Users should refer to their software manuals if they have a problem loading the spreadsheet file.

The LCC spreadsheet is organized into the following sixteen worksheets:

- Description
- Summary
- A & B Distribution
- Design Table
- Demand and Usage
- Utilities
- Discount Rate
- Annual Energy Price Forecast
- Baseline LCC
- Design Option LCC
- Lifetime
- Results—LL vs NL
- LL vs NL
- Tariffs
- Components
- Options

Most of the worksheets consist of the data inputs used in the spreadsheet calculations. To maximize functionality while maintaining reasonable size, the Department has pre-processed certain variables into representative equations.

Users should read this document in its entirety and also review the “Description" shown on the first (far left) worksheet before using the spreadsheet. The spreadsheet/user interface is centered in the “Summary" worksheet. The Department used an example of a Monte-Carlo run to produce “Results —LL vs. NL", shown graphically as “LL vs NL." Selecting different standard levels in the “Summary" worksheet will produce a different graphical result on the “LL vs NL" sheet.

5.2.2 User-Selectable Variables

Several items on the “Summary” worksheet provide the user with selectable options in evaluating various standard alternatives. One can select “User Options” from a menu for each of the following variables:

- Standard Level;
- Transformer Load Growth/Year;
- Transformer Loading (relative to current estimates);
- Electricity Prices (relative to current estimates);
- Customer Decision As & Bs; and
- Future Energy Price Trend.

The user can change the effective year of the standard from the default of 2007. A “Reset” button brings all variables back to the starting default values.

The right side of the “Summary” sheet illustrates a sample LCC result using average values. Results utilizing the full distribution of inputs included with the spreadsheet requires a Monte-Carlo simulation. On some computers, it will be necessary to click on the “Init” button to initiate the average calculations.

5.2.3 Monte-Carlo Simulation Using Crystal Ball

The Monte-Carlo method estimates probability distributions of results by repetitively sampling from probability distributions of input parameters. For each sampled set of input parameters/data, the simulation calculates a weight and a set of output results. The set of output results together with their weights define the probability distribution of outcomes.

Crystal Ball is a spreadsheet add-in that allows one to perform Monte-Carlo simulations from within an Excel spreadsheet. Spreadsheet users must have both Excel and Crystal Ball to run the Monte-Carlo simulations. As noted above, approximate results are provided through a sample calculation that uses average values for the inputs and is displayed on the “Summary” sheet. Making a Crystal Ball simulation is relatively easy. First, the user selects a representative set of assumptions to test by modifying the User Options on the “Summary” sheet. When configured with Crystal Ball, the top line of the Excel menu bar includes the entry <Run> which activates Crystal Ball. The user should refer to the Crystal Ball instruction manual for more complete information on conducting a simulation run.

APPENDIX A. MARKUPS AND INSTALLATION COSTS FOR DRY-TYPE TRANSFORMERS

This appendix provides details on the development of the empirical equations and markup multipliers upon which the LCC spreadsheet relies for DL#9. The Department derived the basic data from *RS Means*.[3]

To estimate installation costs and contractor markups on transformers, *RS Means* electrical cost data [3] is fitted to a linear cost function. The *RS Means* data provides a breakdown of the total installed cost of transformers in terms of four cost components:

1. Materials: the cost of the transformer including mounting hardware.
2. Labor: the labor required for installation including unloading and uncrating, hauling within 200 feet of the loading dock, setting in place, and testing.
3. Equipment: equipment rentals necessary for completion of the installation.
4. Overhead and Profit: overhead and profit expenses for the contractor.

To disaggregate the installation costs into those costs that are associated with the installation and those costs that consist of the markup on the transformer cost, the direct installation costs, which include labor and equipment (i.e., equipment rental), are aggregated. *RS Means* lists the transformer cost as the "material" cost. A regression of the overhead and profit costs is used to disaggregate the overhead and profit associated with installation labor and equipment from the overhead and profit associated with the transformer (material) cost. The regression equation is:

$$O\&P = a * Mat + b * L\&E + c \qquad \textbf{(Eq. A.1)}$$

where O&P is the overhead and profit expense, Mat is the material cost (i.e., transformer and hardware), L&E is the direct labor and equipment costs of installation and a, b, and c are the computed linear regression coefficients.

DOE the used these computed coefficients to define labor and equipment costs as a function of the transformer weight. This relationship is justified because the weight (and the correlated size) of the transformer is a very significant factor in the labor and equipment required for transformer installation. The Department inferred the approximate weight of the kVA capacity because the *RS Means* data does not specify the weight of the transformer.

The Department derived the weight versus capacity relationship for typical transformers from the design data produced by the Engineering Analysis. It then used the weight versus capacity relationship to estimate the transformer weight corresponding to the transformer costs reported in *RS Means*. The Department empirically extracted the scaling relationship between transformer weight and direct installation labor and equipment costs by fitting the correlation between weight and installation costs to a power law equation.

The method for deriving the weight versus capacity relationship is to record the minimum and maximum transformer weights for the selection of designs in the Engineering Analysis, and then select the "typical" transformer weight as the minimum weight plus 20% times the weight range. From this data, DOE obtained the following power law relationship of the weight of the transformer as a function of capacity and BIL rating:

$$\text{Weight} = 13.13 * \text{kVA}^{0.765} * \text{BIL}^{0.244} \qquad \textbf{(Eq. A.2)}$$

where Weight is the weight of the transformer in pounds, kVA is the capacity of the transformer in kVA, and BIL is the BIL rating of the transformer in kilovolts (kV).

RS Means does not provide transformer weights, but does provide the capacity and primary voltage of the transformer. The Department uses the primary voltage of the transformer to estimate the BIL rating and then uses the BIL and capacity to estimate the weight. DOE compares the weight to the direct installation costs from labor and equipment to obtain a power law relationship between transformer weight and direct installation costs.

The first regression is the installation direct labor and equipment costs as a function of transformer weight. The result, using data for all 115 transformers listed in *RS Means* categories 16270-200, 16270-600, and 16270-610, is:

$$\text{L\&E} = 42.08 * \text{Weight}^{0.46} \qquad \textbf{(Eq. A.3)}$$

where L&E is the installation, direct labor, and equipment costs in dollars, Weight is the transformer weight in pounds, and the regression is obtained from a power law trend line fit in Excel with a R-square of 0.95.

Next DOE performed a regression to explain overhead and profit expenses of the contract in terms of a markup on materials (i.e., the transformer) and labor and equipment (i.e., direct installation). The linear regression was performed with a constant term. The Department, finding that the constant term was not significantly different from zero, reran the regression assuming a constant of zero and obtained the equation:

$$\text{O\&P} = 0.10 * \text{Mat} + 0.52 * \text{L\&E} \qquad \textbf{(Eq. A.4)}$$

DOE used the above equation to allocate overhead and profit expenses to a markup on the transformer cost and a separate markup on the direct labor and equipment costs for installation.

The result of these analytical steps is a total installed cost equation for transformers that provides the cost of the transformer to the customer as a function of the manufacturer selling price and the weight of the transformer:

$$\text{Installed_Price} = 1.056 * (1.52*(42.08 * \text{Weight}^{0.46}) + 1.10 * 1.34 * \text{ ManPrice}) \qquad \textbf{(Eq. A.5)}$$

where Installed_Price is the final installed price of the transformer in dollars, Weight is the transformer weight in pounds, 1.056 is the factor that accounts for sales tax, 1.52 is the factor that accounts for the markup on direct installation labor and equipment costs, 1.10 is the factor that accounts for the contractor markup on the purchase of the transformer from the distributor, and 1.34 is the average distributor markup factor.

REFERENCES

1. National Electrical Manufacturers Association, *NEMA Standards Publication TP 1-2002; Guide for Determining Energy Efficiency for Distribution Transformers*, 2002, NEMA. Rosslyn, VA. Report No. TP 1-2002.
2. Barnes, P.R., S. Das, B. W. McConnell, and J. W. Van Dyke, *Supplement to the "Determination Analysis" (ORNL-6847) and Analysis of the NEMA Efficiency Standard for Distribution Transformers*, September, 1997. Oak Ridge National Laboratory. Oak Ridge, TN. Report No. ORNL-6925
3. RS Means Company Inc., *Electrical Cost Data*, 25th Annual Edition, 2002, RS Means Company, Inc. Kinston, MA.
4. Taylor, Z. T. and R. G. Pratt, *Description of Electric Energy Use in Commercial Buildings in the Pacific Northwest*, 1989, Bonneville Power Administration. Portland, OR. Report No. DOE/BP-13795-22.
5. Barnes, P. R., J. W. Van Dyke, B. W. McConnell, and S. Das, *Determination Analysis of Energy Conservation Standards for Distribution Transformers*, 1996, Oak Ridge National Laboratory. Oak Ridge, TN. Report No. ORNL-6847.
6. U.S. Department of Energy - Energy Information Administration, *Annual Energy Outlook 2002: With Projections Through 2020*, December, 2001. Washington, DC. Report No. DOE/EIA-0383(2002). <http://www.eia.doe.gov/oiaf/aeo/>