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Advancing Free Trade
for Asia-Pacific Prosperity

Reducing Losses in Power Distribution through Improved Efficiency of Distribution Transformers

APEC Energy Working Group

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1 EXECUTIVE SUMMARY

This report was prepared for the Asia-Pacific Economic Secretariat (the "APEC Secretariat") under the "EWG 05 2016A – Reducing Losses in Power Distribution through Improved Efficiency of Distribution Transformers" project. The specific objectives of the project are:

- To build the capacity of policy makers in understanding impacts of adopting IEC[1] 60076-20 technical specification for their economies in terms of electricity distribution loss reductions and Greenhouse Gas (GHG) emission reductions; and
- To come up with key policy recommendations in consultation with key stakeholders, such as utilities, manufacturers, standard making bodies etc.

Distribution Transformers in the Global and APEC Context

Distribution transformers (DTs) are the critical components of the electricity system powering our modern society and they help lower voltages in distribution networks to the levels that are needed by end users. Compared with other electrical equipment, DTs are generally very efficient, typically incurring losses of just 2% to 3% in transforming electricity from one voltage level to another. However, DTs' performance has major impacts on electricity use given the non-stop operation of the equipment over its long service life, typically over 20 years.

Varying from economy to economy, technical losses in electricity networks range from a few percent to 15% to 20% of the total energy transported. On an average roughly one-third of these losses occur in DTs. According to the U4E Policy Guide for Energy-Efficient Transformers[2], using more efficient transformers in transmission and distribution networks can save nearly 5% of global electricity consumption. By 2040, annual electricity savings of over 750 TWh are possible (equivalent to the annual electricity generated by over 100 coal-fired power plants with a capacity of 1,000 MW), saving more than 450 million tonnes of GHG emissions.

APEC has 21 member economies, and the word 'economies' is used to describe APEC member economies because the APEC cooperative process is predominantly concerned with trade and economic issues, with member economies engaging with one another as economic entities. To date, 10 APEC member economies have established the Minimum Energy Performance Standards (MEPS) for DTs and the two major energy performance evaluation methods for DTs adopted by these APEC member economies are: maximum no-load and load losses and efficiency values at a specific loading factor (typically at 50% loading factor). Based on the LBNL study conducted in 2012[3], improvements of the MEPS requirements for DTs in APEC economies could save up to 19% of DT losses by 2030, equivalent to 30 TWh of electricity or 17 million tonnes of GHG emissions per year.

IEC 60076-20 Technical Specification

IEC 60076-20 technical specification, published in January 2017, gives methods of specifying a transformer with an appropriate level of energy efficiency according to the loading and operating conditions. The IEC technical specification document proposes two methods for defining an energy efficiency index, i.e.,: Efficiency Index Method A (EI_A)[4], and Efficiency Index Method B (EI_B)[5], and introduces three methods for specifying energy performance of a transformer, i.e., : 1) Peak Energy

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[1] The International Electrotechnical Commission (IEC) is the world's leading organization for the preparation and publication of international standards for electrical, electronic and related technologies.

[2] http://united4efficiency.org/wp-content/uploads/2017/11/U4E-TransformersGuide-201711-Final.pdf

[3] APEC EWG 15/2012A: APEC Distribution Transformers Survey: Estimate of Energy Savings Potential from Increase in MEPS

[4] Efficiency Index Method A (EI_A): ratio of the transmitted apparent power of a transformer minus electrical losses including the power consumed by the cooling to the transmitted apparent power of the transformer for a given load factor.

[5] Efficiency Index Method B (EI_B): ratio of the transmitted apparent power of a transformer to the transmitted apparent power of the transformer plus electrical losses for a given load factor.

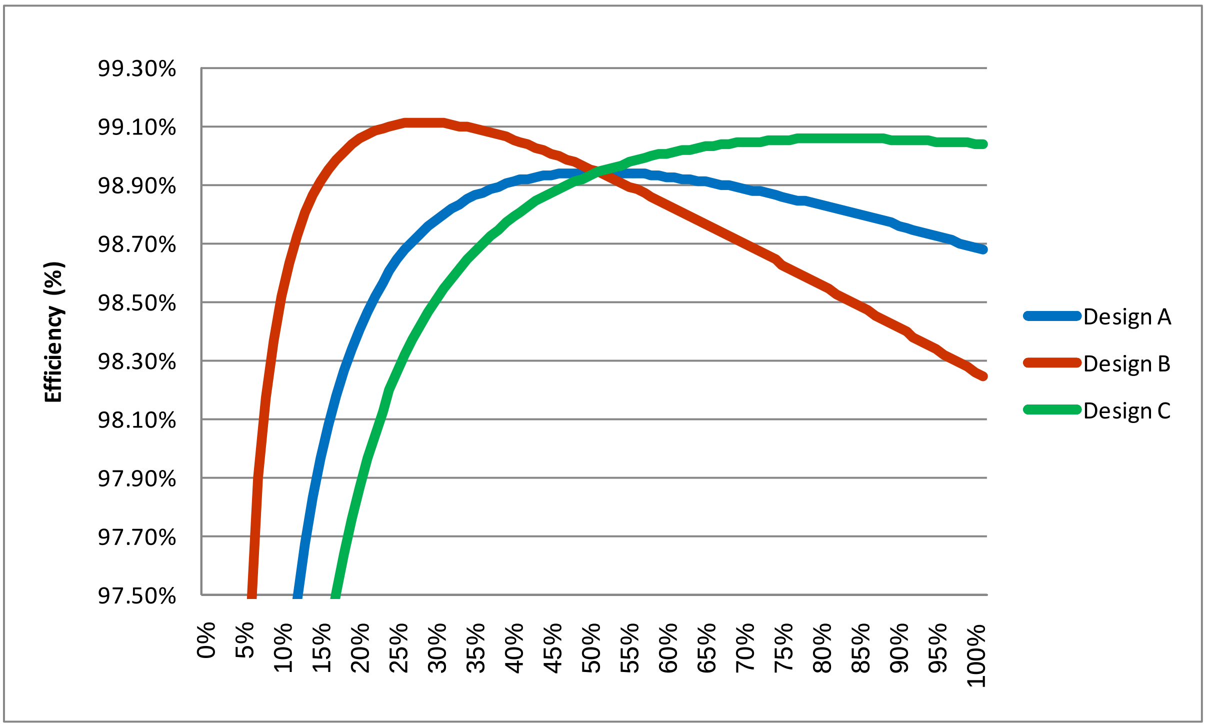
Index (PEI); 2) Maximum no-load and load losses; and 3) Efficiency index at a load factor of 50%. Under each energy performance method, the IEC technical specification document provides two levels of energy performance requirements:

- Level 1 recommendations are defined as “basic energy performance” requirements; and
- Level 2 recommendations are defined as “high energy performance” requirements.

It should be noted that the above energy performance recommendations for 50 Hz and 60 Hz DTs are not fully harmonized, as only PEI values (computed by method A) can be applied for both frequencies. The recommended maximum no-load and load losses cover only 50 Hz DTs, while efficiency index values (computed by method B) for 50 Hz and 60 Hz DTs are neither identical nor comparable. As for the 60 Hz transformers, level 1 values are in compliance with the United States Department of Energy (US DOE) ruling 2010 and level 2 are compliant with the amended ruling 2016. In addition to the 3 methods of defining energy performance of DTs, IEC 60076-20 technical specification also provides details on a loss capitalization (or total cost of ownership – TCO) and suggestion on additional requirements on energy performance parameters, e.g., total losses, efficiency at another load factor and/or power factor.

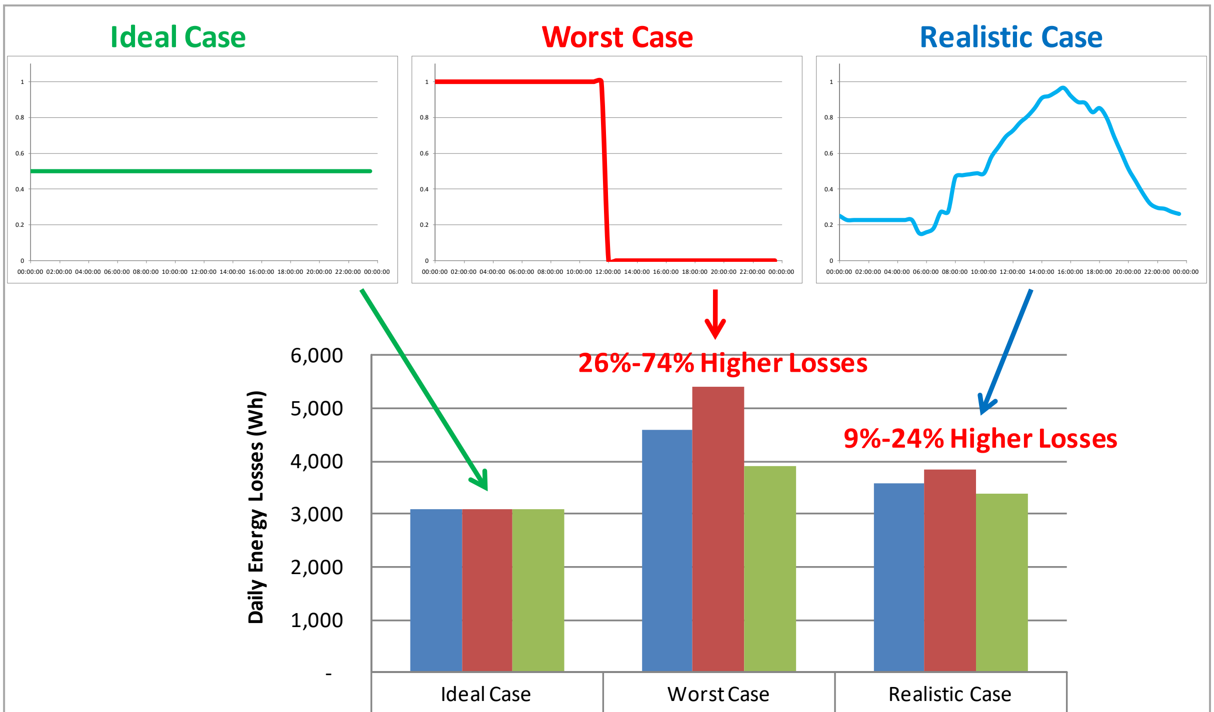
Analysis Approach and Methodology

Energy losses incurred in a particular DT are highly dependent on the load-efficiency curve and operating patterns. Each DT has a unique load-efficiency curve depending on its no-load and load losses. These loss values depend on the choices of core materials and winding which directly impact cost of DTs. DT designers can design DTs with different no-load and load losses but deliver the same efficiency value at a specific loading factor, e.g., 50% or EI_{B50}, as Design A, B and C shown in the figure below.



Source: Analysis by IIEC

For utility-owned DTs, operating patterns of a specific kVA rating depend on types and behaviors of customers connected to that particular DT. For example, during weekdays, residential customers tend to use more electricity before and after working hours, while office buildings generally use more electricity during office hours. Different operating patterns and load-efficiency curves of DTs could result great variations of energy loss estimations, ranging from 9% to 74% higher losses compared with the ideal flat load curve, as illustrated in the diagram on the following page.



	Ideal Case	Worst Case	Realistic Case
Design A (NL=66W, LL=264W)	3,102	4,587	3,588
Design B (NL=30W, LL=408W)	3,102	5,397	3,854
Design C (NL=96W, LL=144W)	3,102	3,912	3,367

Source: Estimation by ICA

The previous studies on potential energy loss reduction from energy efficient DTs did not consider impacts of load-efficiency design curves and daily load profiles (or load curves) of DTs. The analysis in this report takes into consideration different load-efficiency curves and daily load profiles when estimating energy losses of DTs. The most common kVA rating of DTs in the selected APEC economies was identified and annual energy losses were estimated based on 4 different load-efficiency design curves (baseline, Design A, B and C)[6] and 4 different daily load profiles (flat, residential, commercial and industrial)[7]. As a result, 16 combinations of per-unit annual energy losses were computed in each selected economy. National Energy Savings (NES) in each selected economy over the next 20 years were then projected based on comparison of the baseline model with Design A, B and C.

The proposed analysis approach and methodology require comprehensive data on DT population by kVA rating, market size and demand profiles of different end-use sectors. Despite the project team's relentless efforts in data gathering, only utility-owned DT data from the Philippines, Thailand, the USA and Viet Nam were obtained. Considering this, the analysis in this report focused on liquid-filled utility-owned DTs in these 4 economies.

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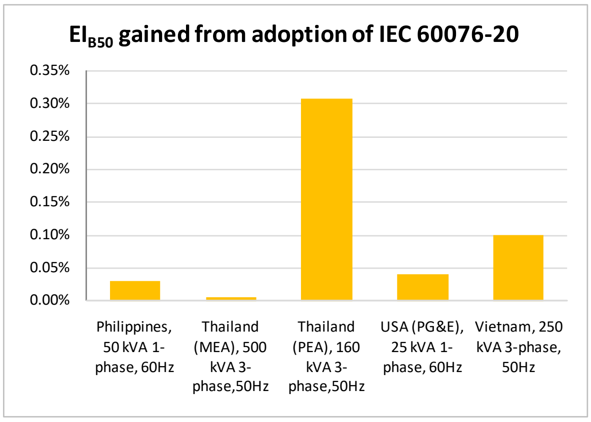
[6] 4 different load-efficiency design curves include: 1) Baseline model with typical no-load and load losses requirements or MEPS; 2) Design A model with IEC 60076-20 level 2 energy performance; 3) Design B model with low no-load losses and high load losses at IEC 60076-20 EI_{B50} level 2; and 4) Design C model with high no-load losses and low load losses at IEC 60076-20 EI_{B50} level 2.

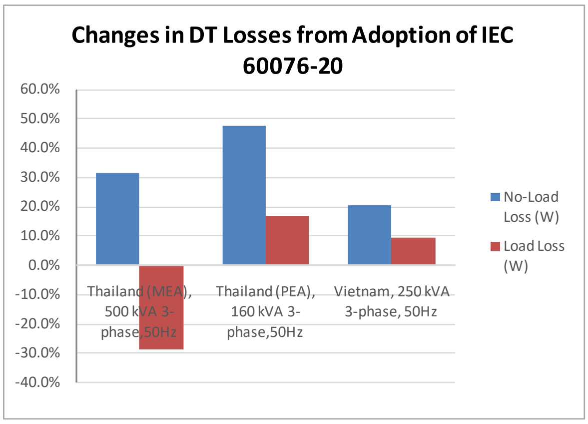
[7] 4 different daily load profiles include: 1) Flat load curve; 2) Residential load curve; 3) Commercial load curve; and 4) Industrial load curve. In each selected economy, the flat load curve has a loading factor equivalent to an annual average loading factor of the economy grid, while the residential, commercial and industrial load curves are based on the survey findings.

Key Findings of Data Collection and Analysis
Based on utility data from the 4 selected economies, the most common kVA ratings vary from economy to economy:

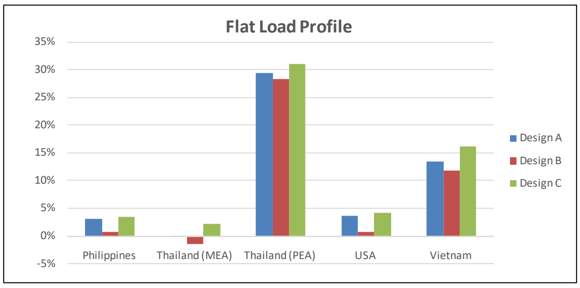
- The Philippines – 50 kVA single-phase 60 Hz
- Thailand (Metropolitan Electricity Authority) – 500 kVA three-phase 50 Hz
- Thailand (Provincial Electricity Authority) – 160 kVA three-phase 50 Hz
- The USA (PG&E) – 25 kVA single-phase 60 Hz
- Viet Nam – 250 kVA three-phase 50 Hz

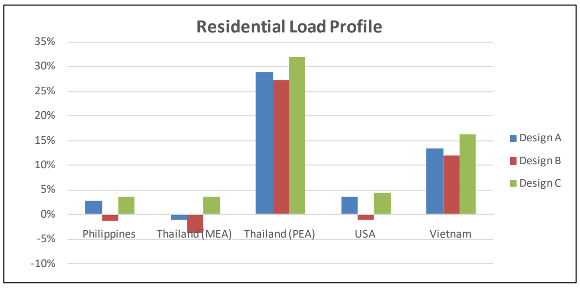
It is found that 60 Hz utility-owned DTs generally follow US DOE regulations on EI_{B50} for energy performance specifications, while 50 Hz utility-owned DTs normally use no-load and load losses as energy performance specifications. It is also found that the IEC 60076-20 level 2 "high energy performance" requirements are not necessarily more stringent than the existing utilities' procurement regulations for these common kVA ratings in the selected economies. As DTs are generally very efficient, improvements of DTs' efficiency are small, usually less than 1%. Therefore, adoption of IEC 60076-20 level 2 for utility-owned DTs delivers very marginal improvements in economies where utilities' procurement regulations are stringent, such as MEA in Thailand of which load losses requirements are actually more stringent than IEC 60076-20. However improvements can be more attractive in economies where utilities' procurement regulations are less stringent, for example PEA in Thailand and Viet Nam.

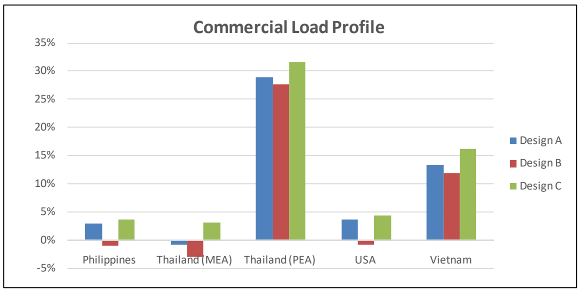


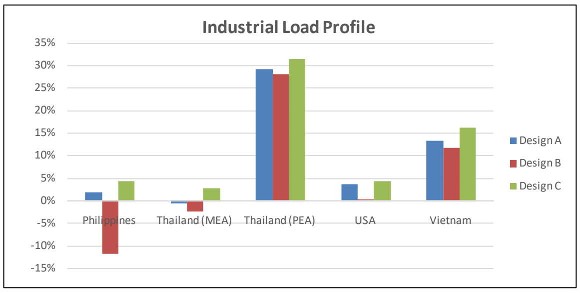


Analysis energy demand profiles in the selected economies reveals that total system load factors range from 66% to 88%, and daily load profiles of different end-use sectors vary greatly with maximum loading factors from 58% for residential end-use to 91% for industrial end-use. Applying different DT designs (Design A, B and C) that meet IEC 60076-20 level 2 EI_{B50} energy performance requirements in these different operating environments deliver combinations of positive and negative energy savings results, as illustrated below.









The analysis results also show that PEI and EI_{B50} cannot predict magnitudes of energy savings gained when DTs' loads deviate from the ideal case with loading factors are far greater or lower than the efficiency index measurement points. The analysis results reveal that Design C (with low load losses design) is the most suitable design as it is able to deliver positive energy savings under all operating environments in the selected economies.

Potential annual energy savings and GHG emissions resulting from adoption EI_{B50} level 2 Design C DTs for utility-owned DTs in the selected economies summarized in the table below. Considering that IEC energy performance levels for 50 Hz and 60 Hz DTs are neither identical nor comparable, it is not recommended to compare the saving results achieved from applying the same IEC energy performance level in 50 Hz and 60 Hz power supply systems.

Table 1: Summary of Annual Energy Savings and GHG Emission Reductions in selected APEC Economies

Economy	Popular Utility-Owned DTs	Utility Owned DT Installed Capacity (MVA)	EI_{B50} Level 2 (Design C)			
			Annual Energy Savings (GWh)		GHG Emission Reduction ($ktCO_2e$)	
			2030	2037	2030	2037
Philippines	Single-Phase, 60 Hz, 50 kVA	16,200 [1]	78	134	39	68
Thailand	Three-Phase, 50 Hz, 160 kVA (PEA) & 500 kVA (MEA)	47,655	1,394	2,210	795	1,260
USA	Single-Phase, 60 Hz, 25 kVA	186,000 [2]	652	1,012	402	624
Viet Nam	Three-Phase, 50 Hz, 250 kVA	41,015	1,578	2,503	890	1,412

Note: [1] Estimated installed capacity of DTs in three distribution utilities (two in Luzon, one large and one small, and one in Mindanao)
[2] Aggregated capacity of DTs installed in the PG&E system

Conclusions, Recommendations and Next Steps

Utilities and energy efficiency policy makers from APEC economies and ASEAN member economies participating in consultation workshops organized by the project agreed in principle that PEI and EI_{B50} are simple and easy-to-compare energy performance indicators. However energy losses of a DT at a specific loading factor cannot be estimated using PEI, and EI_{B50} will only be meaningful and more accurate for comparing DTs when loading factors are close to 50%. It is virtually impossible to predict uncertainty of EI_{B50} as it depends on DT designs (no-load and load loss values).

Considering that diversity of daily load profiles (or load curves) and loading factors for different end-use sectors (e.g., residential, commercial and industrial sectors) could result in great variations of energy losses in DTs with the same EI_{B50}, the workshops' participants acknowledged that no-load and load losses allow for better estimation of the actual energy losses of DTs under different operating conditions. The participants also acknowledge that IEC 60076-20 high energy performance (level 2) for no-load and load losses do not necessarily offer more stringent energy performance requirements for all utilities in APEC and ASEAN.

The analysis in this report found that variations of energy losses at a specific loading factor due to diversity of daily load profiles are generally less than 5%. Changes in the overall loading factor typically deliver a greater impact on DT energy losses than diversity of daily load profiles. Load profile data from the selected economies generally demonstrates high loading factors of more than 50%. DTs with lower load losses (Design C) are therefore more effective in reducing energy losses than adoption of DTs with lower no-load losses, higher PEI or higher EI_{B50} with high load losses.

Based on findings from the analysis, it is recommended that more stringent energy performance levels (specifically for no-load and load losses requirements which are the most favorable approach by APEC and ASEAN utilities) should be recommended by IEC 60076-20 to provide guidance for utilities, private sector users and policy makers to go beyond the current level 2 requirements. Development of more stringent recommendations should be carried out in consultation with the industry. Other general recommendations for utilities, private sector end-users and policy makers pertaining to adoption of IEC 60076-20 are as follows:

- With limited data on energy demand profiles, adoption maximum no-load and load losses requirements, using IEC 60076-20 as the guideline, for procurement of DTs is recommended. This approach gives flexibility in estimation of energy losses for different kVA rating DTs allocated for different types of consumers.
- Adoption of DTs with lower load losses will deliver greater energy savings for utilities in the selected APEC economies. However cost and benefit analysis should be conducted to understand the most economical DT designs under different operating environments.
- More resources are needed in collecting demand data and understanding typical loading factors of common kVA ratings used in different end-use sectors. These will assist in determination of the energy performance parameters for DTs that best reflect the actual situation.

Utility and non-utility policy makers can initiate the works on DT MEPS by focusing on the most common kVA rating, and the following key immediate steps are recommended for utility and non-utility policy makers in APEC and ASEAN to initiate the works on DT MEPS.

a) Establish a dedicated working group to manage data collection activities on demand profiles for utility-owned and privately-owned DTs in their responsible economy;
b) Conduct on-site measurements of DTs' load profiles and determine average loading in different end-use applications;
c) Coordinate with DT manufacturers to determine key design parameters for cost/benefit analysis of different DT designs for operation under different load profiles and loading factors;

2 INTRODUCTION

IEC 60076-20 technical specification for power transformer energy efficiency were recently issued in January 2017 and it specifies methods for evaluating energy performance of distribution transformers (DTs), as well as recommends energy performance levels for both 50 Hz and 60 Hz DTs. This technical and impact analysis report was prepared to provide: (1) an analysis of the technical of the differences and commonalities between the economy and utility standards for energy performance of DT and IEC 60076-20; and (2) an analysis of the impact of changing from the existing energy performance requirements or Minimum Energy Performance Standards (MEPS) in the selected APEC member economies (see Box 1) to the energy performance levels as recommended by IEC 60076-20 in terms of energy savings.

This report was prepared for the Asia-Pacific Economic Secretariat (the "APEC Secretariat") under the "EWG 05 2016A – Reducing Losses in Power Distribution through Improved Efficiency of Distribution Transformers" project. The specific objectives of the project are:

- To build the capacity of policy makers in understanding impacts of adopting IEC TS 60076-20 for their economies in terms of electricity distribution loss reductions and GHG emission reductions; and
- To come up with key policy recommendations in consultation with key stakeholders, such as utilities, manufacturers, standard making bodies etc.

Box 1: Asia Pacific Economic Cooperation (APEC)

APEC has 21 member economies (mentioned below). The word 'economies' is used to describe APEC member economies because the APEC cooperative process is predominantly concerned with trade and economic issues, with member economies engaging with one another as economic entities.

Australia	Japan	Philippines
Brunei Darussalam	Republic of Korea	Russia
Canada	Malaysia	Singapore
Chile	Mexico	Chinese Taipei
People's Republic of China	New Zealand	Thailand
Hong Kong, China	Papua New Guinea	United States
Indonesia	Peru	Viet Nam

2.1 BACKGROUND

Distribution transformers (DTs) are the critical components of the electricity system powering our modern society. By helping to lower voltages in distribution networks to the levels that are needed by end users, they comprise part of the voltage transformation system enabling high-voltage power transmission and distribution (T&D) necessary to lower overall network energy losses. A brief introduction on DT is given in Box 2.

Compared with other electrical equipment, DTs are generally very efficient, typically incurring losses of just 2–3% in transforming electricity from one voltage level to another. However, the fact that almost all electricity is passed through transformers prior to its final use means that opportunities to reduce losses in DT are highly significant for improving the efficiency of electricity networks as a whole. Varying from economy to economy, technical losses in electricity networks range from a few percent to 15-20% of the total energy transported. On an average roughly one-third of these losses occur in DTs[8].

Box 2: Characteristics of Distribution Transformer

The International Electrotechnical Commission (IEC) which is the international standard organization defines a transformer as an "electric energy converter without moving parts that changes voltages and currents associated with electric energy without change of frequency". While there are slight differences in the definition of a distribution transformer, most countries define them as transformers with a highest winding voltage at or below 36 kV. Additional information on characteristics of distribution transformers is given below:

- There are two main types of distribution transformers: liquid-immersed or liquid-filled and dry types. The liquid-immersed transformers are the more common ones as they tend to be more efficient and compact and are used in almost all distribution utility applications. The dry transformers are mostly used in commercial buildings and industrial customers, as well as electric utilities, largely in areas where electricity leaks are more costly.
- Losses in transformers are split into no-load losses and load losses. No-load losses are independent of load, implying that they do not increase with the increased loading on the transformer. Load losses, sometimes referred to as "winding losses" or "copper losses", are losses in the transformer windings when it is under load.
- The combination of no-load losses and load losses means that each transformer has an optimum loading point when it is most efficient and the actual losses incurred will increase or decrease non-linearly as the load moves away from the optimum point.

Electric utilities around the world have specifications on losses and efficiency of DTs installed in their distribution networks, approaches in measurement of DTs' losses and computation of DTs' efficiency generally follow either IEC standards for 50 Hz DTs or NEMA standards[9] for 60 Hz DTs, which are not fully compatible. Regardless of how losses and efficiency are measured, increasing the level of MEPS for DTs represent significant energy savings potential in electricity distribution networks.

As for the APEC economies, the existing MEPS requirements are specified as maximum no-load and load losses and efficiency values at different loading factors, as shown in Figure 2-1 (more details on MEPS requirements are given in Annex A). Based on the LBNL study conducted in 2012[10], improvements of the MEPS requirements for DTs in APEC could save up to 20% of DT losses by 2030, equivalent to 32 TWh of electricity per annum, reducing CO_2 emissions by 18 Mt.

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[8] PROPHET II: The potential for global energy savings from high-efficiency distribution transformers, Final report – November 2014, the European Copper Institute

[9] The National Electrical Manufacturers Association (NEMA) is the association of electrical equipment and medical imaging manufacturers based in the US. NEMA standards for electrical equipment are popular among countries with 60Hz supply.

[10] APEC EWG 15/2012A: APEC Distribution Transformers Survey: Estimate of Energy Savings Potential from Increase in MEPS

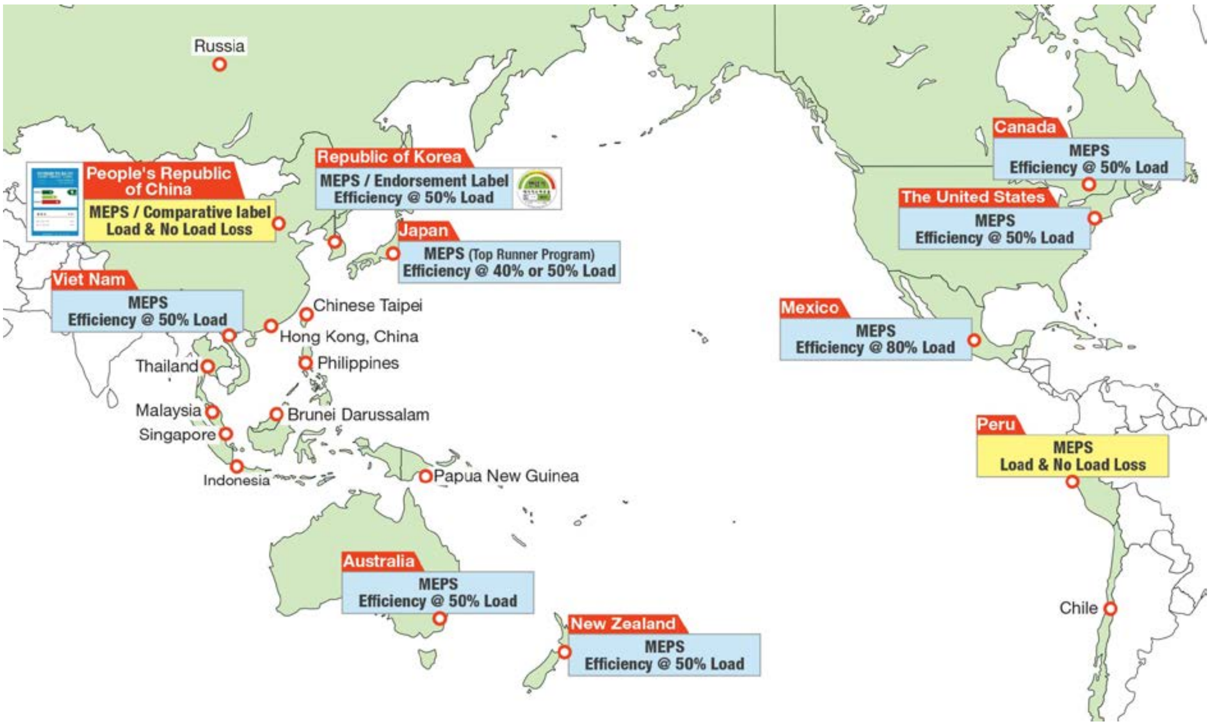


Figure 2-1: MEPS for Distribution Transformers in APEC Economies

2.2 OVERVIEW OF IEC 60076-20 TECHNICAL SPECIFICATION

IEC 60076-20 technical specification, published in January 2017, gives methods of specifying a transformer with an appropriate level of energy efficiency according to the loading and operating conditions. The technical specification document proposes two methods (A[11] and B[12]) of defining an energy efficiency index and introduces three methods to specify energy performance of a transformer as specified in Table 2-1.

Table 2-1: Three Methods of Specifying Energy Performance of a Transformer in IEC 60076-20

Method 1: Minimum PEIs	Method 2: No-load and Load Losses	Method 3: Efficiency Indexes at a Load Factor of 50%
The Peak Energy Index (PEI) is the highest value of efficiency index method A that can be achieved at the optimum value of load factor (when no-load loss equals load loss) PEI should be used in conjunction with either a total cost of ownership (TCO) approach or any other mean of specifying the load factor	The no-load and load losses at rated power for rationalization of transformer cores and coils for transformers generally produced in large volumes	The efficiency at a defined power factor and at a particular load factor (typically at 50%)

[11] Efficiency Index Method A (EI_A): ratio of the transmitted apparent power of a transformer minus electrical losses including the power consumed by the cooling to the transmitted apparent power of the transformer for a given load factor.

[12] Efficiency Index Method B (EI_B): ratio of the transmitted apparent power of a transformer to the transmitted apparent power of the transformer plus electrical losses for a given load factor.

For each method, the technical specification document provides two levels of energy performance requirements. Level 1 recommendations are defined as “basic energy performance” requirements, and level 2 recommendations are defined as “high energy performance” requirements. Recommended minimum PEI values have been developed from 50 Hz transformer data but they are also applicable to 60 Hz transformers, while recommended maximum no-load and load losses cover only 50 Hz transformers. As for the efficiency index, method B at 50% load factor, the technical specification document recommends two separate sets of efficiency indexes for 50 Hz and 60 Hz transformers. As for the 60 Hz transformers, level 1 values are in compliance with the United States Department of Energy (US DOE) ruling 2010 and level 2 are compliant with the amended ruling 2016. Summarized in the table below are applicability of IEC 60076-20 energy performance indicators for 50 Hz and 60 Hz DTs. More details on IEC recommendations on energy performance levels are given in Annex B.

Table 2-2: IEC 60076-20 Energy Performance Indicators for 50 Hz and 60 Hz Distribution Transformers

Energy Performance Indicator	50Hz DT	60Hz DT
Minimum PEI (Method A)	✓	✓
Maximum load losses & no-load losses	✓	✗
Minimum Efficiency Index at a load factor of 50% (Method B)	✓	✓

In addition, IEC 600076-20 also provides different levels of efficiency index values at 50% loading for single- and three-phase DTs, from 5 kVA to 1,000 kVA on single-phase and from 15 kVA to 3,150 kVA on three-phase. 5 Tiers of efficiency index, Tier 1 is the least efficient and Tier 5 is the most efficient, are calculated based on equations developed from the survey and analysis of existing world standards and regulations in 2013. Shown in the figure below are different efficiency Tiers for 50 Hz and 60 Hz three-phase DTs.

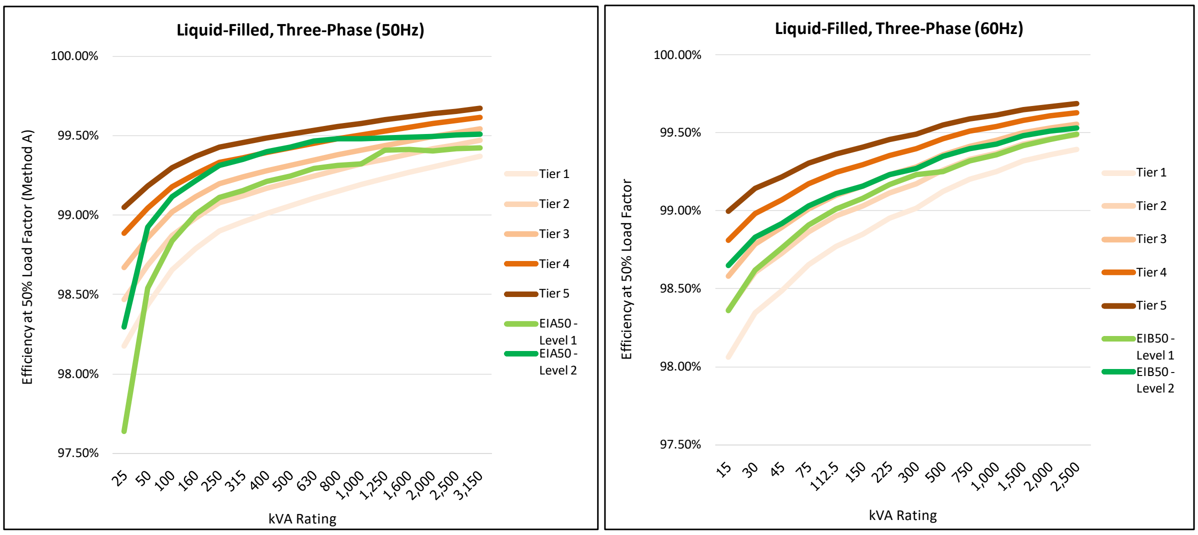


Figure 2-2: Efficiency of Three-Phase Distribution Transformers based on a Survey of World Practices

3 APPROACH AND METHODOLOGY

The project intended to cover all APEC member economies and non-APEC ASEAN member economies[13], i.e., Cambodia, Lao PDR and Myanmar, as additionally requested by ICA. The analysis on the impact of adoption of the IEC 60076-20 technical specifications was carried out using an Excel spreadsheet model which computes per unit annual energy losses of a selected kVA rating of DT under different daily load profiles and loading factors. The overall approach and methodology for the technical and impact analysis comprises several steps, as illustrated in Figure 3-1.

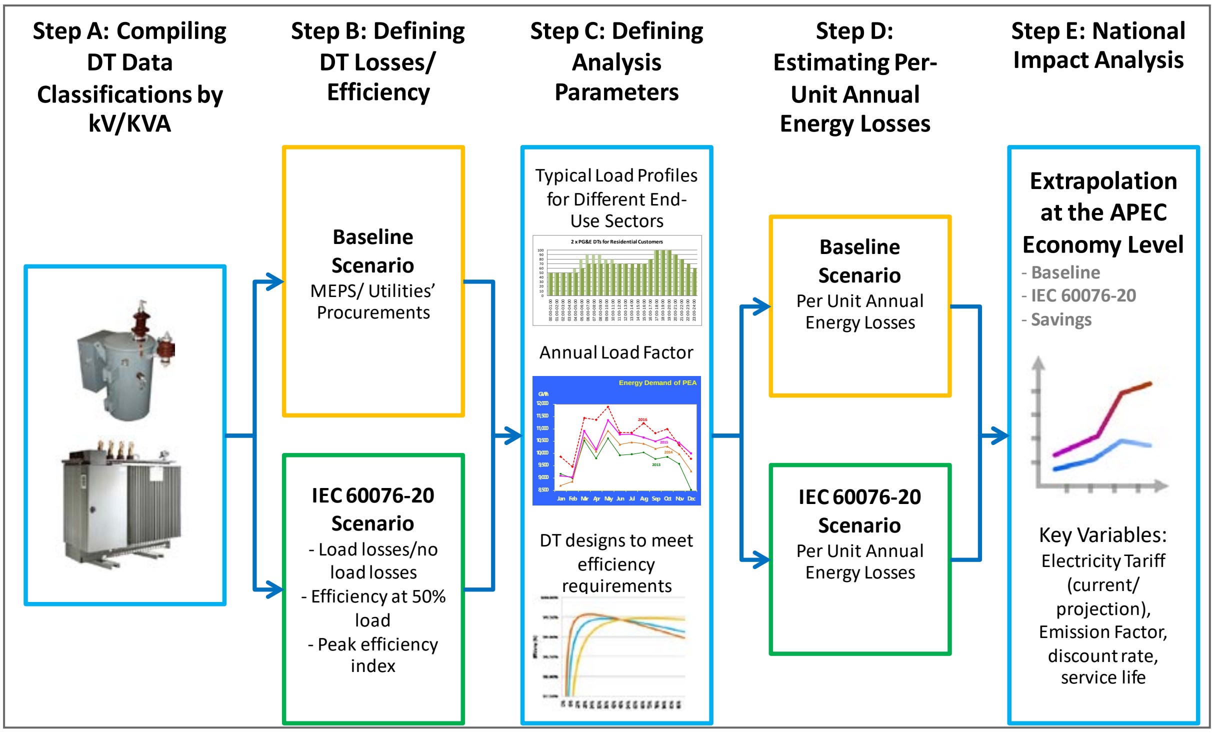


Figure 3-1: Overall Approach and Methodology for the Technical and Impact Analysis

3.1 STEP A – COMPILING DT DATA

The technical and impact analysis undertaken by this project required detailed inputs of several market and operating parameters in each economy, including but not limited to:

- Stock of installed DTs classified by kV and kVA;
- Popular kVA rating of DTs;
- Typical load profiles of different end-use sectors, seasonal variation and load factors;
- Average loading factor or average RMS loading;
- Current energy performance standards for DTs;
- Trend and projection of electricity tariff;
- Electricity emission factor;
- Expected service lifetime of DTs.

The project employed various data gathering methods including questionnaires distribution, direct interviews and secondary researches. The project was able to compile data from questionnaires and

[13] The Association of Southeast Asian Nations (ASEAN) is a regional intergovernmental organisation comprising ten Southeast Asian states, including Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand and Viet Nam.

direct interviews for Peru, the Philippines, the Chinese Taipei, Thailand and the United States. However data from Peru and the Chinese Taipei does not include current energy performance standards for DTs. Sufficient data for Viet Nam was also gathered from the recent studies commissioned by ICA and other secondary resources. The data shows that most utility-owned DTs in these countries are liquid-immersed DTs. In view of this, the analysis in this report will focus on existing energy efficiency requirements of utility-owned DTs in five countries, i.e., the Philippines, Thailand, the United States, and Viet Nam vis-à-vis the IEC 60076-20 technical specifications for liquid-immersed DTs.

3.2 STEP B – DEFINING DT LOSSES/EFFICIENCY

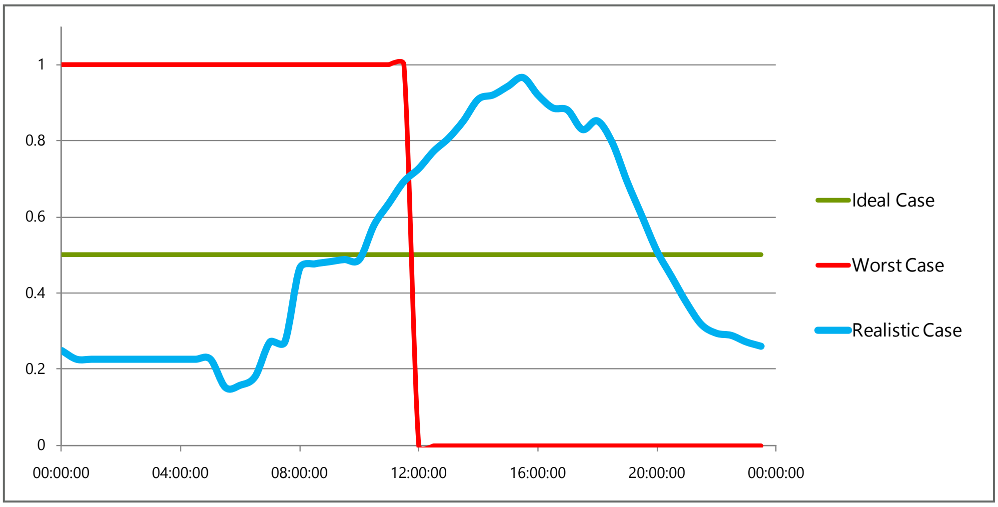
For the baseline scenario, maximum losses and efficiency values of DTs are based on either the economy's MEPS or values specified in the utilities' procurement documents. For the IEC 60076-20 scenario, level 2 energy performance recommendations on no-load and load losses and EI_{B50} will be used for 50 Hz DTs and only level 2 energy performance recommendations on EI_{B50} will be used for 60 Hz DTs. The PEI recommendations for 50 Hz are equivalent to the no-load and load losses recommendations hence the PEI values will not be referenced.

3.3 STEP C – DEFINING ANALYSIS PARAMETERS

Step C defines three sets of important parameters necessary for estimation of per-unit annual energy losses of a DT. These include: 1) typical daily load profiles for different end-use sectors; 2) annual load factor; and 3) typical DT designs to meet EI_{B50} requirements. Impacts of these parameters is discussed in the below sections.

3.3.1 Impacts of Daily Load Profile Diversity

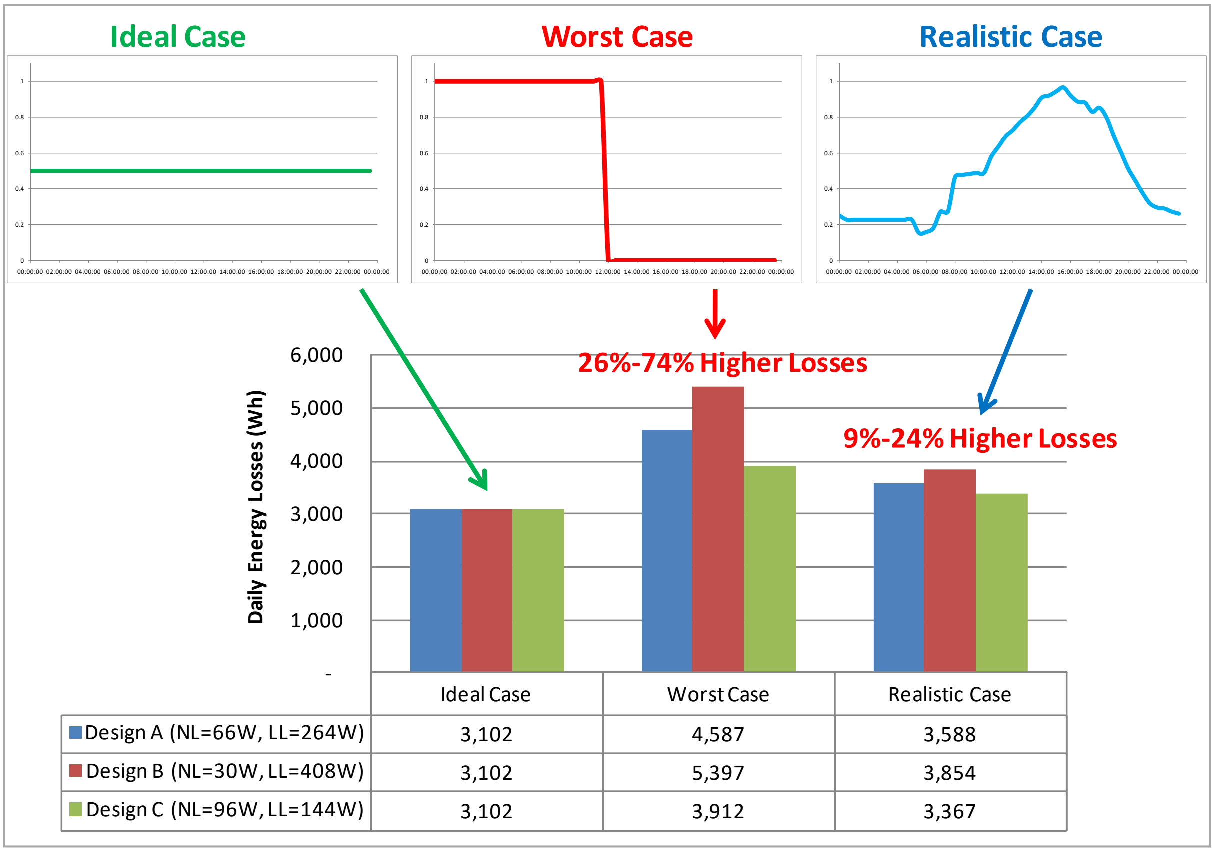
The technical and impact analysis in this report takes into consideration the impacts of different daily load profiles on energy losses incurred in DT. For utility-owned DTs, daily load profiles or load curves of a specific kVA rating depend on types and behaviors of customers connected to that particular DT. For example, during weekdays, residential customers tend to use more electricity before and after working hours, while office buildings generally use more electricity during office hours. Figure 3-2 illustrates three different daily load profiles, i.e., ideal, worst and realistic case, with an average loading factor of 50%.



Source: Presentation on EWG 05 2016A – Reducing Losses in Power Distribution through Improved Efficiency of Distribution Transformers, 48th Meeting of APEC-EGEE&C, Peru, September 2016

Figure 3-2: Different Daily Load Curves for a Typical Distribution Transformer

Applying the three different load profiles as shown in the figure above on a DT will result in three different sets of energy losses, and variations of energy losses depend on the designs or levels of no-load and load losses of DT. Under an extreme case, daily energy losses of a 25kVA DT could vary from 3,102 watts to 5,397 watt or an increase of 74%, as shown Figure 3-3. This could represent an uncertainty of the analysis of DT losses without consideration of the actual load profiles.



Source: Estimation by ICA

Figure 3-3: Daily Energy Losses under Different Load Curves

3.3.2 Impacts of DT Designs

Each DT has a unique load-efficiency curve depending on its no-load and load losses. These loss values depend on the choices of core materials and winding which directly impact product cost of DTs. DT designers can design DTs with different no-load and load losses (see Figure 3-3) but deliver the same efficiency value at a specific loading factor, e.g., 50% or EI_{B50}, as Design A, B and C shown in Figure 3-4.

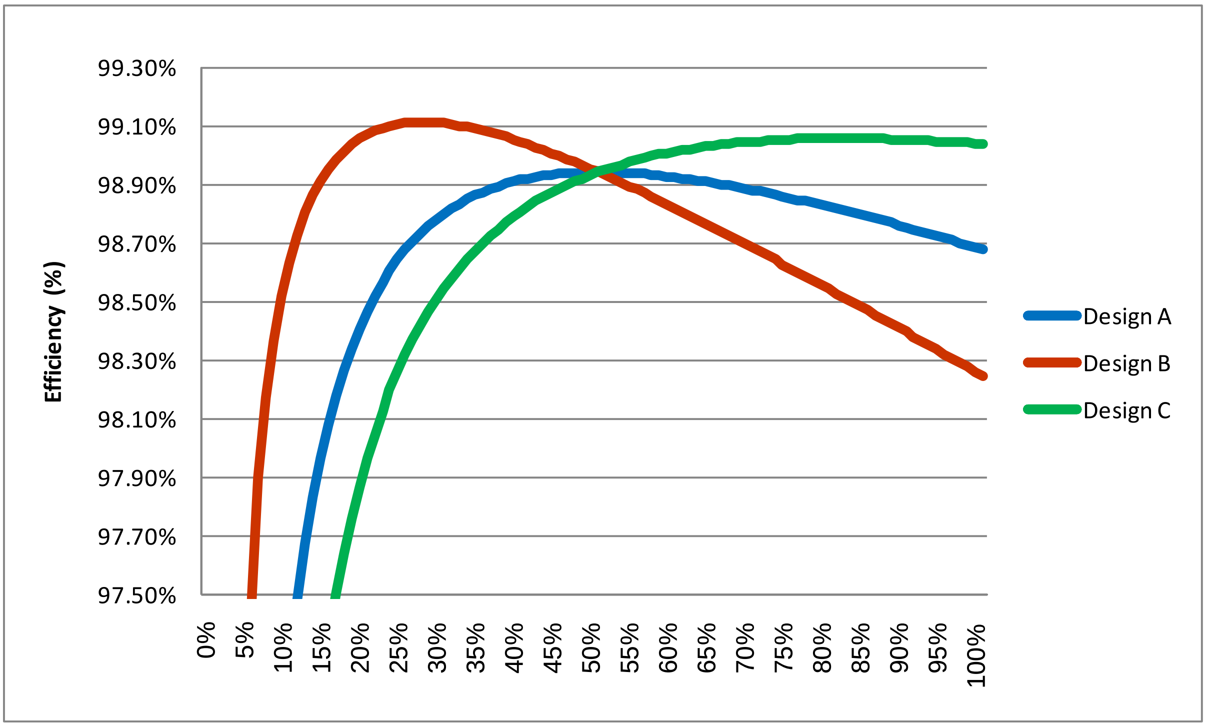


Figure 3-4: Different Designs of a 25 kVA Distribution Transformer at the same EI_{B50}

These DT designs are suitable for different operating conditions, for example, Design B with low no-load losses and high load losses is more suitable for an average loading factor of <50% than Design A and C. Design C with high no-load losses and low load losses is more suitable for an average loading factor of > 50% than Design A and 2, while Design A efficiency values are in between Design B and C, and may be suitable for the application where an average loading factor is not known.

3.4 STEP D – ESTIMATING PER-UNIT ANNUAL ENERGY LOSSES

3.4.1 Baseline Scenario

The analysis firstly constructed the baseline scenario based on the existing energy efficiency requirements specified by the utilities in the selected economies. In case the existing energy efficiency requirements of DTs in the selected economies are specified as % energy efficiency index, a typical design of DTs was chosen as a baseline model and a set of no-load/ load losses of this particular model was referenced in computation. Annual energy losses of the baseline model were anlyzed under different daily load profiles and % load factor. The analysis flowchart of the baseline scenario is shown in Figure 3-5.

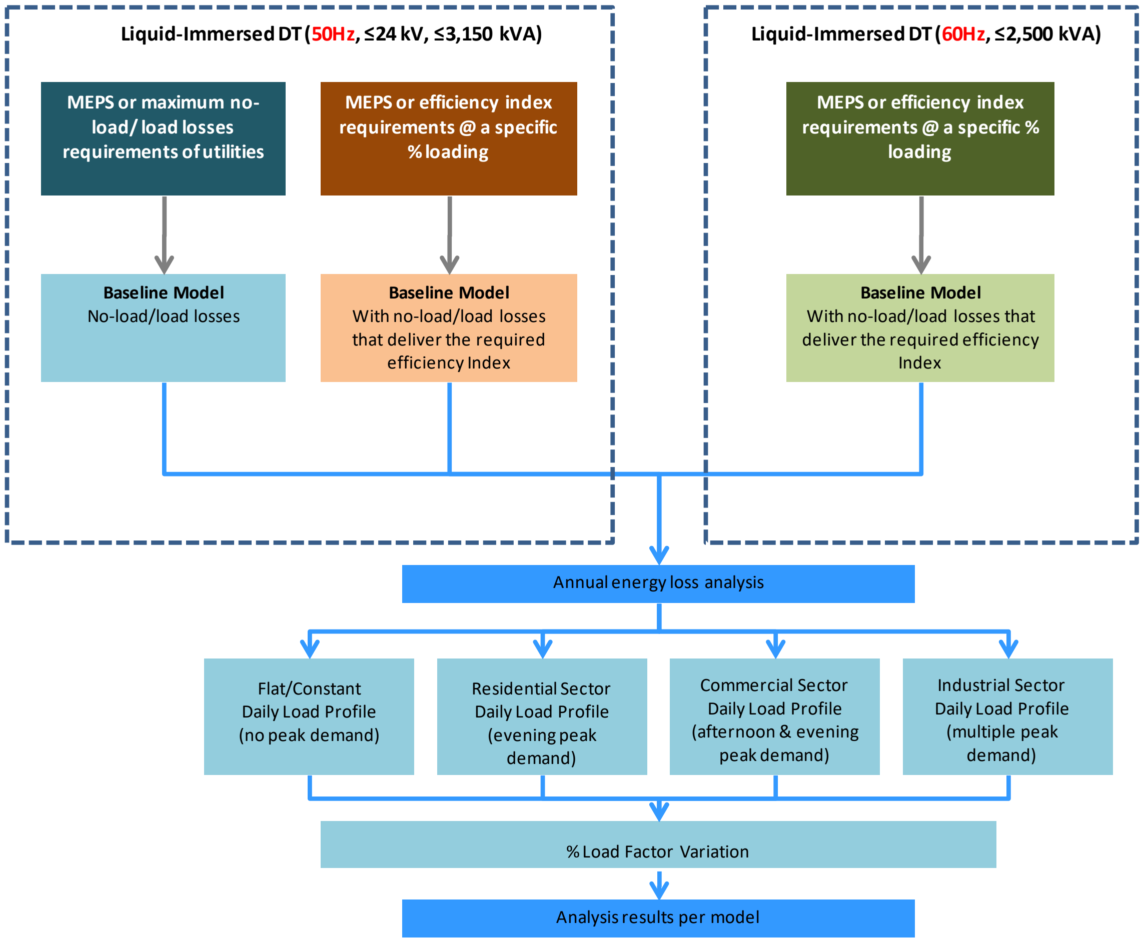


Figure 3-5: Estimation of Annual Energy Losses in Baseline Scenarios

3.4.2 Energy Efficiency/IEC 60076-20 Scenario

Analysis of annual energy losses in the IEC 60076-20 scenarios followed the similar approach as in the baseline scenarios. However, the IEC 60076-20 scenarios were more complex as IEC specifies different sets of technical specifications for 50Hz and 60Hz DTs, and for each level of efficiency index different designs of DT were constructed and annual energy losses under different daily load profiles and % load factor were computed. The approach for 50Hz and 60Hz DTs is outlined below.

1. **For the economy with 50Hz supply**, the analysis applied **IEC 60076-20 Maximum Load Losses and No-Load Losses Level 2**[14] and **IEC 60076-20 Efficiency Index Method B at 50% Loading (EI_{B50}) Level 2 for 50Hz**[15] and estimated per unit annual energy losses for the most common kVA rating. Under the EI_{B50} Level 2 for 50Hz analysis, two designs of DT with different load-efficiency curve (see Figure 3-4) were selected to evaluate impacts of load-efficiency curve design at the same EI_{B50} Level. Note that 50Hz DTs that meet the IEC 60076-20 maximum losses requirements will have the Peak Efficiency Index (PEI) values as specified in Table 2 of IEC 60076-20 specifications.

[14] Table 4, IEC 60076-20, Power transformers – Part 20: Energy Efficiency, Technical Specification, Edition 1.0, 2017-01

[15] Table 6, IEC 60076-20, Power transformers – Part 20: Energy Efficiency, Technical Specification, Edition 1.0, 2017-01

2. **For the economy with 60Hz supply**, the analysis applied **IEC 60076-20 EI_{B50} Level 2 for 60Hz**[16] and estimated per unit annual energy losses for the most common kVA rating. Under this scenario, three designs of DT with different load-efficiency curve (as shown in Figure 3-4) are considered to evaluate impacts of load-efficiency curve design at the same EI_{B50} Level for 60Hz.

The analysis flowchart of the IEC 60076-20 scenarios is shown in Figure 3-6.

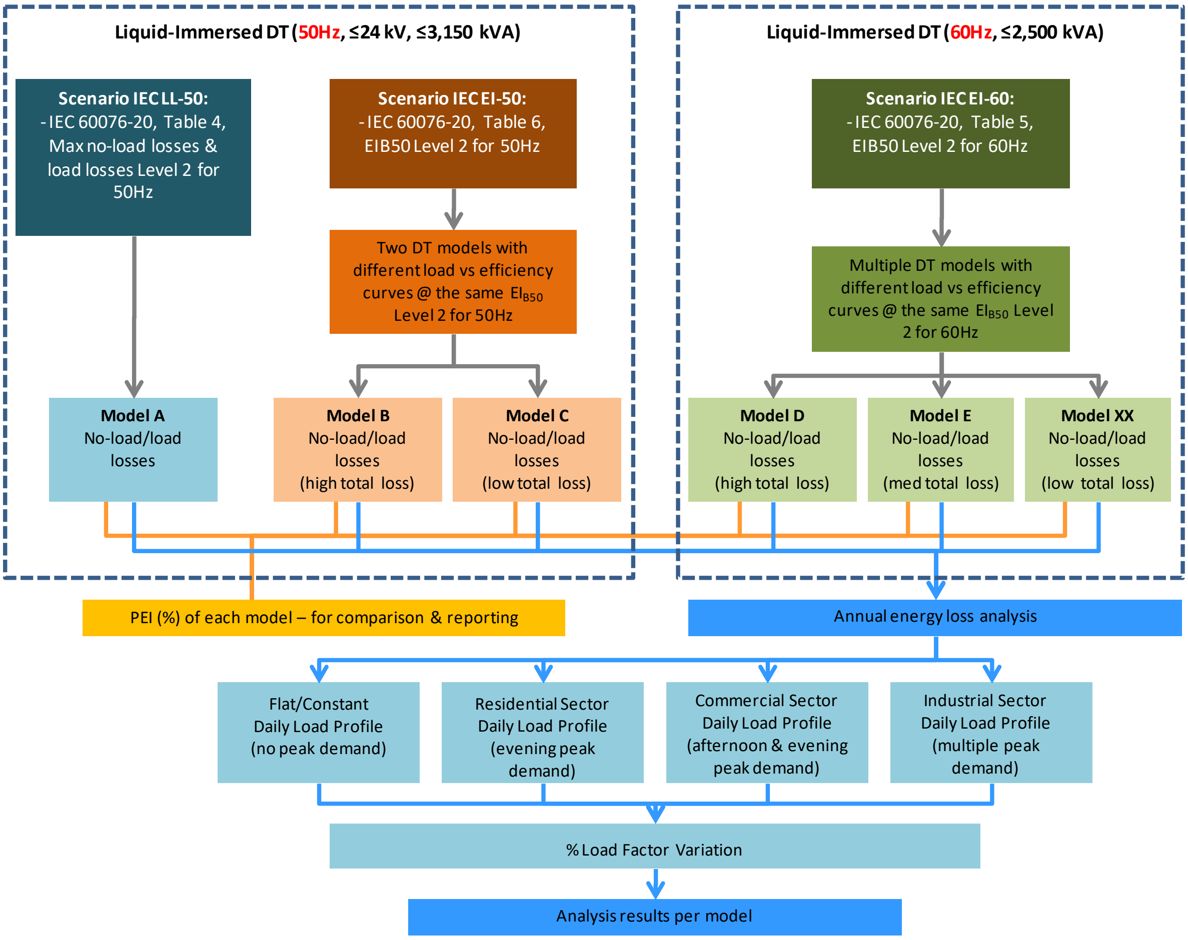


Figure 3-6: Estimation of Annual Energy Losses in IEC Scenarios

3.5 STEP E – ECONOMY IMPACT ANALYSIS

Analysis of the National Energy Savings (NES) from adoption of IEC 60076-20 in the selected economies is limited to utility owned DTs. For the economies where the economy-wide distribution networks are operated by a large number of utilities such as the Philippines and the US, the analysis has been confined to the areas where best data is available. Projection of energy savings and corresponding GHG emission reductions is calculated based on compliance with IEC 60076-20 for utilities' procurements of DTs for new installations and replacements from 2017 to 2037. Methods for calculation of energy savings and GHG emission reduction are described below.

[16] Table 5, IEC 60076-20, Power transformers – Part 20: Energy Efficiency, Technical Specification, Edition 1.0, 2017-01

Table 3-1: NES Analysis Methods

Indicator	Method
Energy savings from adoption of IEC 60076-20	NES is computed using estimated annual energy savings per kVA rating of different DT design models discussed in Step C. Annual energy savings per kVA are extrapolated to the total MVA installed for new and replacement DTs in a given year. Annual energy savings per kVA are calculated based on per unit annual energy savings of the three DT designs vs the baseline model, operating under different load profiles (i.e., residential, commercial, industrial and flat load profiles). The total MVA of new DTs installed in a given year is estimated using an average annual growth of DT stock in a selected economy. The total MVA of DTs replaced in a given year is estimated using an assumed replacement rate of 5% annually, based on the base year stock (2015). Energy savings are calculated in two scenarios: 1) Energy savings from new DTs installed; and 2) Energy savings from new DTs installed and replacement DTs.
GHG emissions reduction (CO_2e) as a result of energy savings	CO_2e is computed by multiplying energy savings with the emission factor for each economy.

3.5.1 Assumption and Data Input

There are a number of parameters required by the NES analysis, such as estimated installed DTs in the base year, an average life time and estimated annual sales for installation. Key assumptions and data inputs for the NES analysis are outlined in Table 3-2.

Table 3-2: Key Assumptions used in NES Analysis

Parameter	Assumption
Growth of DT Stock (annual sales for new installation)	The NES analysis assumes the average growth of annual sales for new installations over the next 20 years in the selected economy based on the past 5 years data or DT stock growth or annual electricity consumption growth. In case growth data is not available, a 3% annual growth rate is used.
Diversity of load profiles and load factors	The NES analysis assumes that diversity of load profiles and load factors remain unchanged throughout the 20-year projection period. DT stock in MVA for each load profile is allocated based on the percentage share in the total annual electricity consumption. All DTs are loaded 365 days per year.
Electricity Emission Factor (ton CO_2e/MWh	The NES analysis assumes a constant electricity emission factor over the next 20 years. Emission factors of APEC economies are given in Annex A.

4 FINDINGS FROM ANALYSIS

This section summarizes findings from the analysis of applying the IEC 60076-20 specifications for the most common kVA rating of utility-owned DTs in each selected economy and the impacts on energy savings and GHG emission reduction over the next 20 years. The estimated impacts under the IEC 60076-20 scenario were developed based on the similar regulatory and market environments being referenced by the baseline scenarios. It should be noted that IEC energy performance levels for 50 Hz and 60 Hz DTs are neither identical nor comparable, and it is not recommended to compare the saving results achieved from applying the same IEC energy performance level in 50 Hz and 60 Hz power supply systems. In addition, the IEC high energy performance levels (level 2) are not necessarily more stringent than the existing efficiency requirements being used in APEC economies.

Shown in Figure 4-1 are maximum no-load and load losses being specified in the procurement regulations of utilities in Thailand and Viet Nam. In general, maximum no-load losses requirements of IEC 60076-20 are more stringent than those of the Thai and Vietnamese utilities. However maximum load losses requirements of the Thai and Vietnamese utilities are somewhat comparable to the IEC ones. In fact, one of the Thai utilities, MEA, has already adopted more stringent load losses requirements than IEC 60076-20.

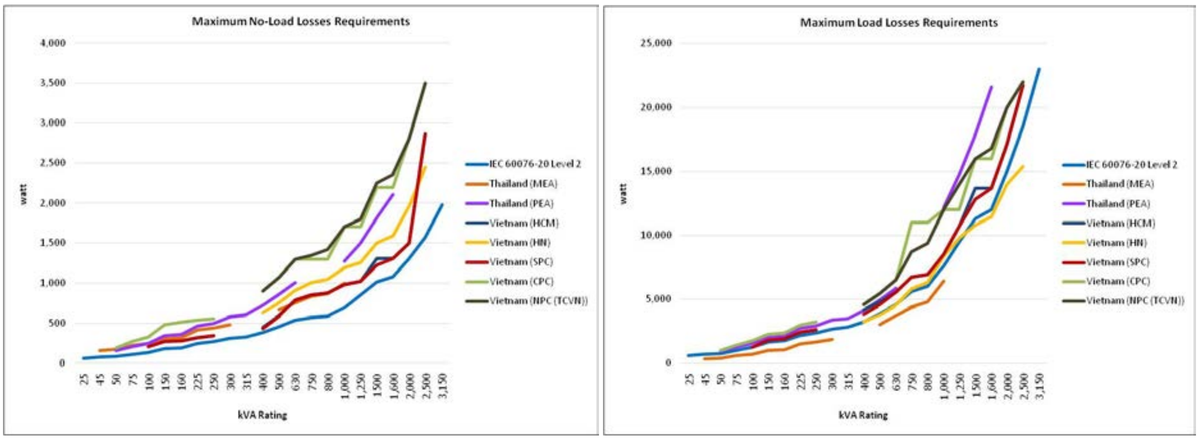


Figure 4-1: Maximum No-Load and Load Losses Requirements of IEC and Utilities in Thailand and Viet Nam

As for 60 Hz DTs, the IEC level 2 recommendations are generally more stringent than the existing requirement being adopted by the utilities in the Philippines and the US, as shown in Figure 4-2.

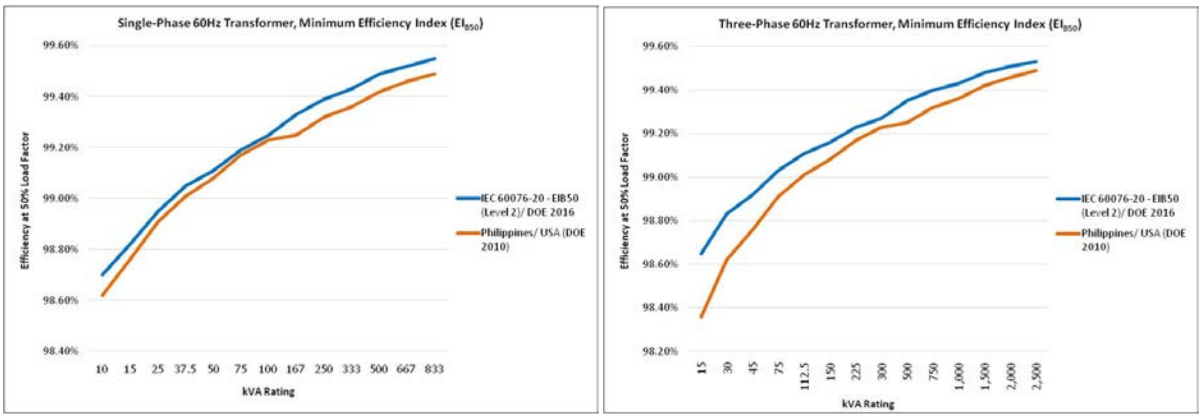


Figure 4-2: Minimum Efficiency Index of IEC and Utilities in the Philippines and the USA

Table 4-1 below summarizes the impacts of adoption the high energy performance requirements (level 2) for EI_{B50} (Design C) as specified in IEC 60076-20 technical specification.

Table 4-1: Summary of Annual Energy Savings and GHG Emission Reductions in selected APEC Economies

Economy	Popular Utility-Owned DTs	Utility Owned DT Installed Capacity (MVA)	EI_{B50} Level 2 (Design C)			
			Annual Energy Savings (GWh)		GHG Emission Reduction ($ktCO_2e$)	
			2030	2037	2030	2037
Philippines	Single-Phase, 60 Hz, 50 kVA	16,200 [1]	78	134	39	68
Thailand	Three-Phase, 50 Hz, 160 kVA (PEA) & 500 kVA (MEA)	47,655	1,394	2,210	795	1,260
The USA	Single-Phase, 60 Hz, 25 kVA	186,000 [2]	652	1,012	402	624
Viet Nam	Three-Phase, 50 Hz, 250 kVA	41,015	1,578	2,503	890	1,412

Note: [1] Estimated installed capacity of DTs in three distribution utilities (two in Luzon, one large and one small, and one in Mindanao)
[2] Aggregated capacity of DTs installed in the PG&E system

More details on the economy impact analysis for each selected economy are described below, and details of DTs and the analysis in each selected economy per the approach and methodology discussed in Section 2 are given in Annex B.

4.1 PHILIPPINES

The Philippines is the only economy in Southeast Asia with 60 Hz electrical system. Design and operation of the Philippine distribution network generally follow US standards and practices, including standards for DTs. As a result, single-phase, pole-mounted DTs are very common in the Philippines. Based on the market surveys and various secondary resources, it is believe that all DTs procured by most distribution utilities in the Philippines would meet the US DOE regulation of DT efficiency issued in 2010 (see more details in Annex).

Analysis of the NES and GHG emission reduction from adoption of the IEC 60076-20 high energy performance requirement (level 2) for 60 Hz utility owned DTs in the Philippines references the economy-specific parameters as summarized in Table 4-2.

Table 4-2: Economy-Specific Parameters for the Philippines, 2015

No.	Parameter	Value	Source/Note
1	Emission Factor (tCO_2/MWh)	0.508	IGES
2	Annual Growth (2015-2037)	5.6%	Annual electricity consumption statistics (2011-2015), Philippine DOE
3	DT Replacement Rate	5%	Assumption/Fixed Annual Replacement based on 2015 stock, commencing in 2018

No.	Parameter	Value	Source/Note
4	Utility Owned DT Stock (MVA)	15,300	IIEC Survey (three utilities in Luzon and Mindanao)
5	% Share of DTs with Flat Load	4%	Annual electricity consumption statistics (2015), Philippine DOE
6	% Share of DTs with Residential Load	34%	Annual electricity consumption statistics (2015), Philippine DOE
7	% Share of DTs with Commercial Load	30%	Annual electricity consumption statistics (2015), Philippine DOE
8	% Share of DTs with Industrial Load	33%	Annual electricity consumption statistics (2015), Philippine DOE

NES is computed using the estimated annual energy savings per kVA rating of different DT designs (Design A, B and C) operating under different daily load profiles (see Table 4-3). The annual energy savings per kVA are then extrapolated to the total MVA installed for new and replacement DTs in the Philippines. It should be noted that Design B shown in the table below is not suitable for the Philippines due to high annual average loading factor.

Table 4-3: Annual Energy Savings per kVA of 50 kVA DT in the Philippines

Daily Load Profile	Annual Energy Savings/kVA (kWh)		
	Design A: US DOE 2016	Design B: EI_{B50} Level 2 for 60 Hz (Low No-Load Losses/ High Load Losses)	Design C: EI_{B50} Level 2 for 60 Hz (High No-Load Losses/ Low Load Losses)
Flat	0.94	-16.14	4.05
Residential	1.07	-10.17	3.13
Commercial	1.23	-3.57	2.11
Industrial	1.18	-5.42	2.39

Based on the economy-specific parameters for the Philippines, projection of annual new installations, replacements and stock of baseline models of utility owned DTs over the next 20 years are shown in Figure 4-3. The results on NES and GHG emission reduction from adoption of the above three DT designs in new installations and replacements are summarized in Table 4-4.

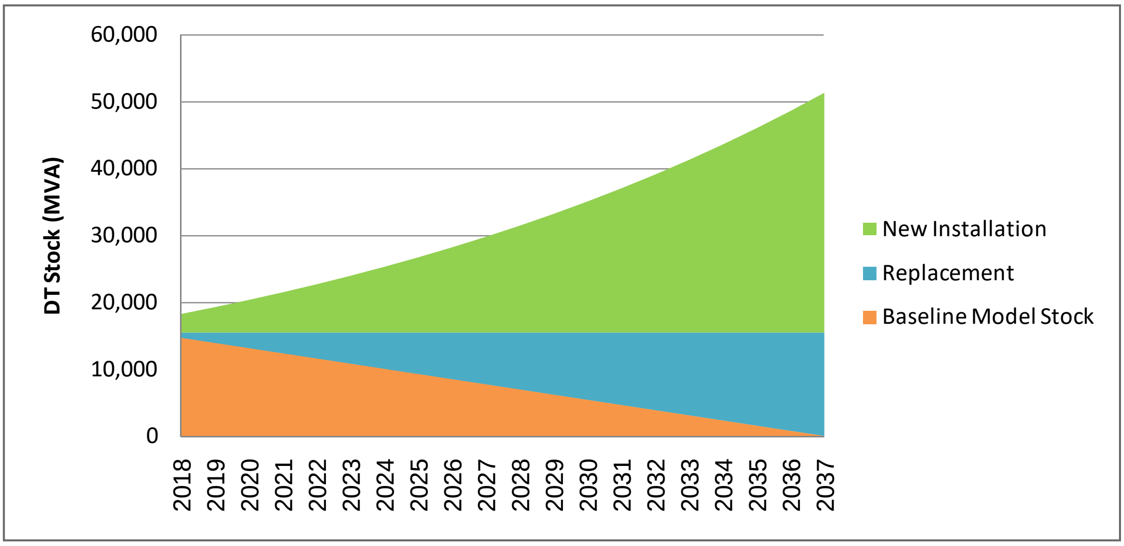


Figure 4-3: Profiles of Utility Owned DT Stock in the Philippines

Table 4-4: Impact Analysis Results from Adoption of IEC 60076-20 in New Installation and Replacement in the Philippines

Impacts	Year	Design A	Design B	Design C
Annual Energy Savings (GWh)	2020	8.22	N/A	18.76
	2025	19.96	N/A	45.55
	2030	33.99	N/A	77.56
	2037	58.87	N/A	134.34
Annual GHG Emission Reduction ($ktCO_2e$)	2020	4.18	N/A	9.53
	2025	10.14	N/A	23.14
	2030	17.27	N/A	39.40
	2037	29.91	N/A	68.24

Note: Although Design B has higher EI_{B50} than the baseline model, energy savings are negative due to high load losses design operating in a high loading factor condition in the Philippines.

4.2 THAILAND

Thailand does not have any energy efficiency standards for DTs, however all procurements by the only two distribution utilities in the economy, MEA and PEA, specify maximum no-load losses and load losses. It should be noted that MEA's no-load and load losses requirements for its DTs are relatively stringent in comparison with the IEC 60076-20 high energy performance recommendations (level 2). While PEA's no-load and load losses requirements are less stringent compared with the IEC 60076-20 level 2.

Analysis of the NES and GHG emission reduction from adoption of the IEC 60076-20 high energy performance requirement (level 2) for 50 Hz utility owned DTs in Thailand references the economy-specific parameters as summarized in Table 4-5.

Table 4-5: Economy-Specific Parameters for the Thailand, 2015

No.	Parameter	Value		Source/Note
		MEA	PEA	
1	Emission Factor (tCO_2/MWh)	0.570		IGES
2	Annual Growth (2015-2037)	2%	3%	Annual electricity consumption statistics (2011-2015), EPPO
3	DT Replacement Rate	5%		Assumption/Fixed Annual Replacement based on 2015 stock, commencing in 2018
4	Utility Owned DT Stock (MVA)	11400	36200	IIEC Survey
5	% Share of DTs with Flat Load	7%	3%	Annual electricity consumption statistics (2015), EPPO
6	% Share of DTs with Residential Load	25%	24%	Annual electricity consumption statistics (2015), EPPO
7	% Share of DTs with Commercial Load	40%	18%	Annual electricity consumption statistics (2015), EPPO
8	% Share of DTs with Industrial Load	28%	55%	Annual electricity consumption statistics (2015), EPPO

For utility-owned DTs, the most popular kVA ratings in terms of aggregated kVA installed are 500 kVA for MEA and 160 kVA for PEA. Considering its stringent no-load and load losses requirements and the average annual load factor of more than 60%, MEA will only benefit from Design C DTs. As for PEA, its DT's energy performance requirements are less stringent when compared with IEC 60076-20, and all DT designs meeting level 2 requirements of IEC 60076-20 will benefit PEA in terms of energy savings and corresponding GHG emission reduction.

NES is computed using the estimated annual energy savings per kVA rating of different DT designs (Design A, B and C) operating under different daily load profiles in MEA's and PEA's networks (see Table 4-6). The annual energy savings per kVA are then extrapolated to the total MVA installed for new and replacement DTs in Thailand.

Table 4-6: Annual Energy Savings per kVA of MEA's and PEA's DTs

Daily Load Profile	Annual Energy Savings/kVA (kWh)		
	Design A: IEC 60076-20, Max. No-Load/Load Losses Level 2	Design B: EI_{B50} Level 2 for 50 Hz (Low No-Load Losses/ High Load Losses)	Design C: EI_{B50} Level 2 for 50 Hz (High No-Load Losses/ Low Load Losses)
MEA's 500 kVA DT			
Flat	-2.94	-6.65	4.38
Residential	-1.58	-3.71	2.59
Commercial	-2.99	-6.75	4.44
Industrial	-2.99	-6.77	4.45
PEA's 160 kVA DT			
Flat	19.57	12.58	33.42
Residential	16.00	13.27	21.38
Commercial	19.74	12.55	33.98
Industrial	19.69	12.56	33.82

Based on the economy-specific parameters for the Philippines, projection of annual new installations, replacements and stock of baseline models of utility owned DTs over the next 20 years are shown in Figure 4-3. The results on NES and GHG emission reduction from adoption of the above three DT designs in new installations and replacements are summarized in Table 4-4.

Based on the economy-specific parameters for MEA and PEA, projection of annual new installations, replacements and stock of baseline models over the next 20 years of MEA and PEA are shown in Figure 4-4. The results on NES and GHG emission reduction from adoption of the above three DT designs in new installations and replacements are summarized in Table 4-7.

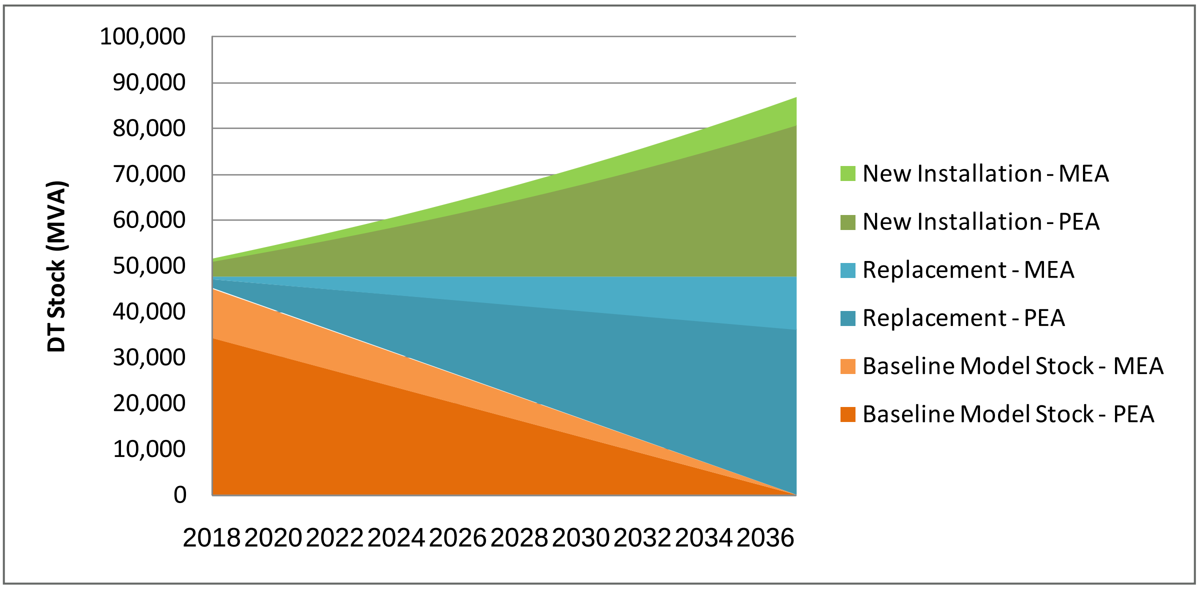


Figure 4-4: Profiles of Utility Owned DT Stock in Thailand

Table 4-7: Impact Analysis Results from Adoption of IEC 60076-20 in New Installation and Replacement in Thailand

Impacts	Year	Design A	Design B	Design C
Annual Energy Savings (GWh)	2020	210.60	142.51	356.89
	2025	506.57	342.78	858.81
	2030	822.57	556.60	1,394.11
	2037	1,304.78	882.89	2,209.84
Annual GHG Emission Reduction ($ktCO_2e$)	2020	120.04	81.23	203.43
	2025	288.75	195.38	489.52
	2030	468.87	317.26	794.64
	2037	743.73	503.25	1,259.61

Note: Impacts from adoption of Design A and B include only PEA, while impacts from adoption of Design C are combination of MEA and PEA.

4.3 UNITED STATES

There are more than 3,200 electric utilities in the US and the US Department of Energy (DOE) has been regulating the energy efficiency level of DTs since 2002. The new MEPS for liquid-immersed distribution transformers has been effective since January 1st, 2016 and the efficiency requirements are equivalent to the EI_{B50} recommendations for 60 Hz DTs specified in IEC 60076-20. The analysis for the US in this report focus on the PG&E's networks in California in which the most popular kVA rating in terms of units installed is 25 kVA single-phase DT. Considering that the new MEPS for liquid-immersed distribution transformers has recently been effective, the analysis reference the DOE 2010 MEPS as the baseline efficiency levels of DT in the US.

Analysis of the energy savings and GHG emission reduction from adoption of the IEC 60076-20 high energy performance requirement (level 2) DTs in PG&E's networks references the specific parameters as summarized in Table 4-8.

Table 4-8: Specific Parameters for PG&E's Networks, 2015

No.	Parameter	Value	Source/Note
1	Emission Factor (tCO_2/MWh)	0.616	E
2	Annual Growth (2015-2037)	2%	Assumption
3	DT Replacement Rate	5%	Assumption
4	Utility Owned DT Stock (MVA)	186000	IIEC Survey (PG&E Report)
5	% Share of DTs with Flat Load	9%	Annual Electricity Consumption, EIA
6	% Share of DTs with Residential Load	34%	Annual Electricity Consumption, EIA
7	% Share of DTs with Commercial Load	33%	Annual Electricity Consumption, EIA
8	% Share of DTs with Industrial Load	24%	Annual Electricity Consumption, EIA

Energy savings in the PG&E's networks are computed using the estimated annual energy savings per kVA rating of different DT designs (Design A, B and C) operating under different daily load profiles (see Table 4-9). The annual energy savings per kVA are then extrapolated to the total MVA installed for new and replacement DTs in the PG&E's networks. It should be noted that Design B shown in the table below is not suitable for the end-use sectors with high loading factor, e.g., commercial and industrial sectors.

Table 4-9: Annual Energy Savings per kVA of 25 kVA DT in PG&E's Networks

Daily Load Profile	Annual Energy Savings/kVA (kWh)		
	Design A: US DOE 2016	Design B: EI_{B50} Level 2 for 60 Hz (Low No-Load Losses/ High Load Losses)	Design C: EI_{B50} Level 2 for 60 Hz (High No-Load Losses/ Low Load Losses)
Flat	2.26	-16.94	5.74
Residential	1.70	6.02	0.92
Commercial	2.05	-8.41	3.95
Industrial	2.26	-17.13	5.78

Based on the specific parameters of PG&E's network, projection of annual new installations, replacements and stock of baseline models of utility owned DTs over the next 20 years are shown in Figure 4-5. The results on energy savings and GHG emission reduction from adoption of the IEC 60076-20 technical specifications in new installations and replacements are summarized in Table 4-10.

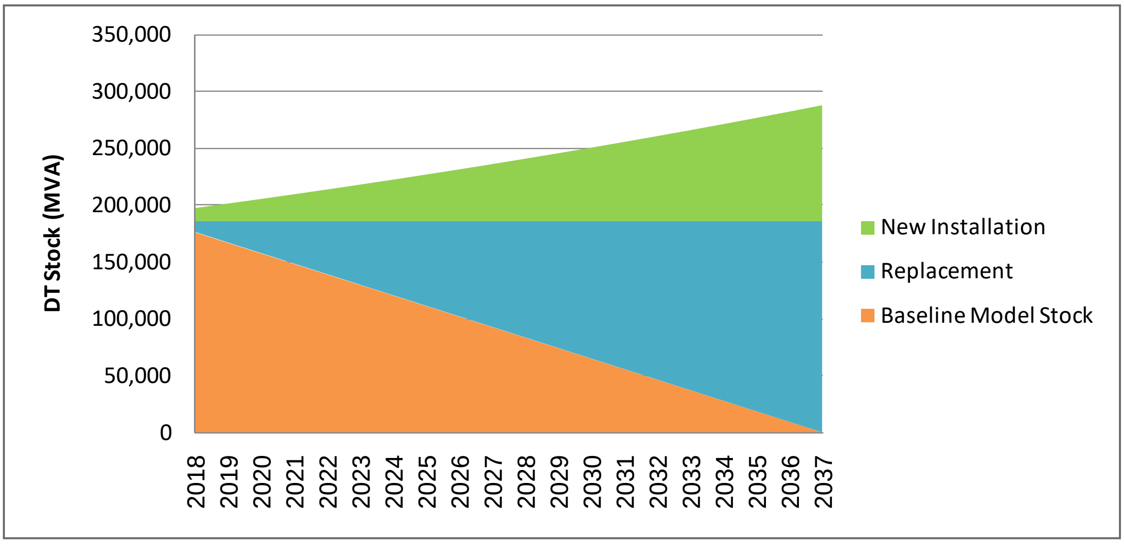


Figure 4-5: Profiles of DT Stock in PG&E Networks

Table 4-10: Impact Analysis Results from Adoption of IEC 60076-20 in New Installation and Replacement in PG&E's Networks

Impacts	Year	Design A	Design B	Design C
Annual Energy Savings (GWh)	2020	94.55	N/A	166.38
	2025	230.34	N/A	405.33
	2030	370.58	N/A	652.11
	2037	575.29	N/A	1012.33
Annual GHG Emission Reduction (ktCO2e)	2020	58.25	N/A	102.50
	2025	141.91	N/A	249.72
	2030	228.32	N/A	401.77
	2037	354.44	N/A	623.70

Note: Although Design B has higher EI_{B50} than the baseline model, energy savings are negative due to high load losses design and high load factor (over 50%) in non-residential sectors in PG&E's networks.

4.4 VIET NAM

There are five power distribution companies in Viet Nam, responsible for supplying power and for the maintenance of the distribution grid up to 110kV in North, Central, South, Hanoi, and Ho Chi Minh City. These distribution utilities specify maximum no-load and load losses when procuring their DTs, however these maximum losses requirements have not yet been harmonized. Viet Nam has also promulgated minimum energy performance standards for DTs based on EI_{B50} as specified in TCVN 8525:2015. However the efficiency values are less stringent compared with IEC 60076-20 and the existing utilities' procurement regulation.

Analysis of the NES and GHG emission reduction from adoption of the IEC 60076-20 high energy performance requirement (level 2) for 50 Hz utility owned DTs in Viet Nam references the economy-specific parameters as summarized in Table 4-11.

Table 4-11: Economy-Specific Parameters for Viet Nam, 2015

No.	Parameter	Value	Source/Note
1	Emission Factor (tCO_2/MWh)	0.564	IGES
2	Annual Growth (2015-2037)	3%	Utility owned DT growth (2014-2017 est.), ICA report
3	DT Replacement Rate	5%	Assumption/Fixed Annual Replacement based on 2015 stock, commencing in 2018
4	Utility Owned DT Stock (MVA)	41,000	IIEC Survey (ICA report)
5	% Share of DTs with Flat Load	6%	Annual electricity consumption statistics in 2013, ADB report
6	% Share of DTs with Residential Load	36%	Annual electricity consumption statistics in 2013, ADB report
7	% Share of DTs with Commercial Load	5%	Annual electricity consumption statistics in 2013, ADB report
8	% Share of DTs with Industrial Load	53%	Annual electricity consumption statistics in 2013, ADB report

The most common kVA rating of utility owned DTs in Viet Nam is 250 kVA three-phase DT. NES is computed using the estimated annual energy savings per kVA rating of different DT designs (Design A, B and C) operating under different daily load profiles in utilities' networks (see Table 4-12). The annual energy savings per kVA are then extrapolated to the total MVA installed for new and replacement DTs in Viet Nam.

Table 4-12: Annual Energy Savings per kVA of 250 kVA DT in Viet Nam

Daily Load Profile	Annual Energy Savings/kVA (kWh)		
	Design A: IEC 60076-20, Max. No-Load/Load Losses Level 2	Design B: EI_{B50} Level 2 for 50 Hz (Low No-Load Losses/ High Load Losses)	Design C: EI_{B50} Level 2 for 50 Hz (High No-Load Losses/ Low Load Losses)
Flat	9.24	-2.20	31.92
Residential	9.23	-2.19	31.89
Commercial	8.78	-1.56	29.27
Industrial	9.26	-2.24	32.07

Based on the economy-specific parameters of Viet Nam, projection of annual new installations, replacements and stock of baseline models of utility owned DTs over the next 20 years are shown in Figure 4-5. The results on energy savings and GHG emission reduction from adoption of the IEC 60076-20 technical specifications in new installations and replacements are summarized in Table 4-13.

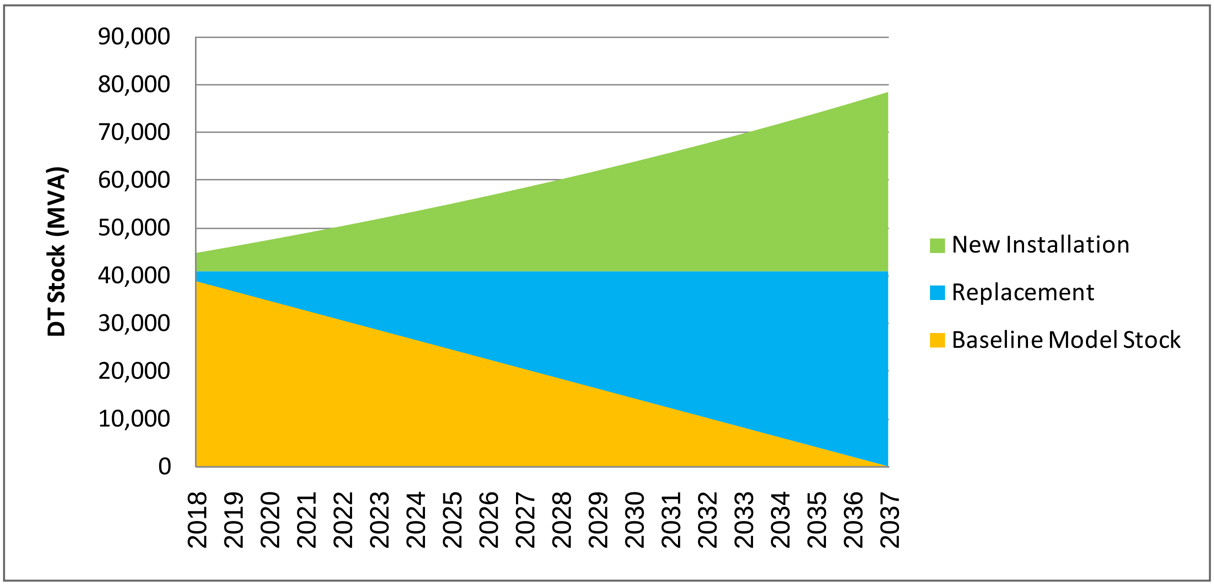


Figure 4-6: Profiles of Utility Owned DT Stock in Viet Nam

Table 4-13: Impact Analysis Results from Adoption of IEC 60076-20 in New Installation and Replacement in Viet Nam

Impacts	Year	Design A	Design B	Design C
Annual Energy Savings (GWh)	2020	116.99	N/A	403.96
	2025	281.41	N/A	971.68
	2030	456.94	N/A	1577.81
	2037	724.81	N/A	2502.75
Annual GHG Emission Reduction ($ktCO_2e$)	2020	65.98	N/A	227.84
	2025	158.71	N/A	548.03
	2030	257.72	N/A	889.88
	2037	408.80	N/A	1411.55

Note: Although Design B has higher EI_{B50} than the baseline model, energy savings are negative due to high load losses design and high load factor Viet Nam.

5 Conclusions and Recommendations

5.1 Conclusions

Utilities and energy efficiency policy makers from APEC economies and ASEAN member economies participating in consultation workshops organized by the project agreed in principle that PEI and EI_{B50} are simple and easy-to-compare energy performance indicators. However energy losses of a DT at a specific loading factor cannot be estimated using PEI, and EI_{B50} will only be meaningful and more accurate for comparing DTs when loading factors are close to 50%. It is virtually impossible to predict uncertainty of EI_{B50} as it depends on DT designs (no-load and load loss values).

Considering that diversity of daily load profiles (or load curves) and loading factors for different end-uses (e.g., residential, commercial and industrial applications) could result in great variations of energy losses in DTs with the same EI_{B50}, the workshops' participants acknowledged that no-load and load losses allow for better estimation of the actual energy losses of DTs under different operating conditions, and IEC 60076-20 high energy performance (level 2) for no-load and load losses do not necessarily improve energy performance requirements for all utilities in APEC and ASEAN.

The analysis in this report found that:

- Variations of energy losses at a specific loading factor due to diversity of daily load profiles are generally less than 5%. Changes in the overall loading factor normally deliver a greater impact on DT energy losses than diversity of daily load profiles.
- Different DT designs for a specific kVA rating can deliver the same level of EI_{B50}, however total energy losses and efficiency indexes at any other loading factors, either lower or higher than 50%, can be different depending on choices of no-load and load losses.
- Load profile data from the selected economies generally demonstrates high loading factors of more than 50%. DTs with lower load losses (Design C) are therefore more effective in reducing energy losses than adoption of DTs with lower no-load losses, higher PEI or higher EI_{B50} with high load losses.

5.2 Recommendations

Based on findings from the analysis, it is recommended that more stringent energy performance levels (specifically for no-load and load losses requirements which are the most favorable approach by utilities) should be recommended by IEC 60076-20 to provide guidance for utilities, private sector users and policy makers to go beyond the current level 2 requirements. Development of the more stringent recommendations should be carried out in consultation with the industry. Other general recommendations for utilities, private sector end-users and policy makers pertaining to adoption of IEC 60076-20 are as follows:

- With limited data on energy demand profiles, adoption maximum no-load and load losses requirements, using IEC 60076-20 as the guideline, for procurement of DTs is recommended. This approach gives flexibility in estimation of energy losses for different kVA rating DTs allocated for different types of consumers.
- Adoption of DTs with lower load losses will deliver greater energy savings for utilities in the selected APEC economies. However cost and benefit analysis should be conducted to understand the most economical DT designs under different operating environments.
- More resources are needed in collecting demand data and understanding typical loading factors of common kVA ratings used in major end-use sectors. These will assist in determination of the energy performance parameters for DTs that best reflect the actual situation.

Utility and non-utility policy makers can initiate the works on DT MEPS by focusing on the most common kVA rating. In addition to no-load and load losses requirements, policy makers should use IEC 60076-

20 as a guide, to determine the energy performance criteria that facilitate the impact assessment and respond to the typical load factors in their economies, for example: efficiency Index at two loading factors (e.g. 50% and 100%), use mix of losses, i.e. low no-load losses for light load ratings and low load losses for high load ratings. The following key immediate steps are recommended for utility and non-utility policy makers in APEC and ASEAN to initiate the works on DT MEPS.

a) Establish a dedicated working group to manage data collection activities on demand profiles for utility-owned and privately-owned DTs in their responsible economy;
b) Conduct on-site measurements of DTs' load profiles and determine average loading in different end-use applications;
c) Coordinate with DT manufacturers to determine key design parameters for cost/benefit analysis of different DT designs for operation under different load profiles and loading factors;

6 ANNEXES

6.1 ANNEX A – MEPS FOR DTS IN APEC ECONOMIES

Based on a report published by the European Copper Institute (ECI), there are thirteen countries around the world that have adopted MEPS for distribution transformers for their markets[17], and ten of which are APEC member economies. MEPS strategy is one of the most powerful tools to ensure that energy-efficient DTs are taken up in the market. Fundamentally, these mandatory regulations require that all DTs sold and installed meet or exceed the specified performance requirements. MEPS can help to facilitate a shift to higher levels of efficiency, particularly when they are combined with supporting policies including financial incentives and communication programs.

However, as discussed in the previous section, APEC economies have adopted both maximum no-load and load losses and efficiency at different loading factors as MEPS requirements, as summarized in the table below. For other APEC economies which are not shown in the table, electric utilities generally specify requirements on DTs' efficiency which may or may not cover privately-owned DTs. Analysis of baseline scenarios in this report referenced either MEPS or utilities' specifications on DTs' efficiency and the target APEC economies include: the Philippines, Thailand, the United States and Viet Nam.

Table 6-1: Energy Performance Requirements for DTs in APEC Economies

Economy	Type of Energy Performance Requirements	Mandatory / Voluntary	Definition of Performance
Australia	MEPS	Mandatory	Efficiency @ 50% Load
Canada	MEPS / Endorsement Label	Mandatory / Voluntary	Efficiency @ 50% Load
China	MEPS / Comparative label	Mandatory / Mandatory	No Load & Load Loss
Japan	MEPS (Top Runner Program)	Mandatory	Efficiency @ 40% OR 50% Load
Korea	MEPS / Endorsement Label	Mandatory / Voluntary	Efficiency @ 50% Load
Mexico	MEPS / Endorsement Label	Mandatory/ Voluntary	Efficiency @ 80% Load
New Zealand	MEPS	Mandatory	Efficiency @ 50% Load
Peru	MEPS	Mandatory	No Load & Load Loss
The USA	MEPS	Mandatory	Efficiency @ 50% Load
Viet Nam	MEPS	Mandatory	Efficiency @ 50% Load
EU see note	MEPS (Ecodesign)*	Mandatory	No Load & Load Loss

Note: EU is not a part of APEC but included as reference.

[17] Source: PROPHET II: The potential for global energy savings from high-efficiency distribution transformers, Final report – November 2014, the European Copper Institute

6.2 ANNEX B – IEC 60076-20 ENERGY PERFORMANCE LEVELS

Table 1 – PEI values for single-phase transformers with $U_m \leq 12$ kV and $S_r \leq 100$ kVA

Rated power kVA	PEI level 1 %	PEI level 2 %
15	98,38	98,48
25	98,50	98,65
33	98,61	98,80
50	98,73	98,89
100	98,90	99,08

Table 2 – PEI values for transformers with $U_m \leq 36$ kV and $S_r \leq 3150$ kVA

	$U_m \leq 24$ kV		24 kV < $U_m \leq 36$ kV	
Rated power kVA	PEI level 1 %	PEI level 2 %	PEI level 1 %	PEI level 2 %
≤25	97,992	98,445	97,742	98,251
50	98,741	99,014	98,584	98,891
100	98,993	99,194	98,867	99,093
160	99,122	99,281	99,012	99,191
250	99,210	99,363	99,112	99,283
315	99,248	99,395	99,154	99,320
400	99,297	99,439	99,209	99,369
500	99,330	99,465	99,247	99,398
630	99,373	99,500	99,295	99,437
800	99,416	99,532	99,343	99,473
1000	99,431	99,541	99,360	99,484
1250	99,483	99,544	99,418	99,487
1600	99,488	99,550	99,424	99,494
2000	99,495	99,558	99,432	99,502
2500	99,504	99,568	99,442	99,514
3150	99,506	99,572	99,445	99,518

NOTE Although the values in this table have been developed from 50 Hz transformer data, they are also applicable to 60 Hz transformers.

Table 3 – PEI values for transformers with U_m > 36 kV or S_r >3150 kVA

Rated power kVA	PEI level 1 %	PEI level 2 %
> 3150 and ≤ 4000	99,465	99,532
5000	99,483	99,548
6300	99,510	99,571
8000	99,535	99,593
10000	99,560	99,615
12500	99,588	99,640
16000	99,615	99,663
20000	99,639	99,684
25000	99,657	99,700
31500	99,671	99,712
40000	99,684	99,724
50000	99,696	99,734
63000	99,709	99,745
80000	99,723	99,758
≥ 100000	99,737	99,770

NOTE Although the values in this table have been developed from 50 Hz transformer data, they are also applicable to 60 Hz transformers.

Table 4 – Maximum load losses and maximum no load losses for transformers with rated frequency equal to 50 Hz

	Level 1		Level 2	
Rated power kVA	Maximum load losses (in W)	Maximum no-load losses (in W)	Maximum load losses (in W)	Maximum no-load losses (in W)
≤ 25	900	70	600	63
50	1 100	90	750	81
100	1 750	145	1 250	130
160	2 350	210	1 750	189
250	3 250	300	2 350	270
315	3 900	360	2 800	324
400	4 600	430	3 250	387
500	5 500	510	3 900	459
630	6 500	600	4 600	540
800	8 400	650	6 000	585
1 000	10 500	770	7 600	693
1 250	11 000	950	9 500	855
1 600	14 000	1 200	12 000	1 080
2 000	18 000	1 450	15 000	1 305
2 500	22 000	1 750	18 500	1 575
3 150	27 500	2 200	23 000	1 980

NOTE In some countries, higher losses are allowed in regulations for transformers outside the scope of this table, for example with a wider tapping range, dual LV windings or higher voltage.

Table 5 – EI_{B50} value for liquid-immersed 60 Hz transformers

Single phase			Three phase		
Rated power kVA	EI_{B50} % Level 1	EI_{B50} % Level 2	Rated power kVA	EI_{B50} % Level 1	EI_{B50} % Level 2
≤ 10	98,62	98,70	≤15	98,36	98,65
15	98,76	98,82	30	98,62	98,83
25	98,91	98,95	45	98,76	98,92
37,5	99,01	99,05	75	98,91	99,03
50	99,08	99,11	112,5	99,01	99,11
75	99,17	99,19	150	99,08	99,16
100	99,23	99,25	225	99,17	99,23
167	99,25	99,33	300	99,23	99,27
250	99,32	99,39	500	99,25	99,35
333	99,36	99,43	750	99,32	99,40
500	99,42	99,49	1 000	99,36	99,43
667	99,46	99,52	1 500	99,42	99,48
833	99,49	99,55	2 000	99,46	99,51
			2 500	99,49	99,53

NOTE Level 1 values are in compliance with the United States of America Department of Energy (DOE) ruling 2010 and level 2 values are in compliance with the amended ruling 2016.

Table 6 – EI_{B50} value for liquid-immersed 50 Hz transformers

Rated power kVA	EI_{B50} level 1 %	EI_{B50} level 2 %
≤ 25	97,849	98,429
50	98,657	99,004
100	98,925	99,178
160	99,078	99,271
250	99,175	99,360
315	99,214	99,394
400	99,267	99,440
500	99,300	99,464
630	99,344	99,499
800	99,364	99,515
1 000	99,372	99,518
1 250	99,451	99,520
1 600	99,455	99,526
2 000	99,459	99,530
2 500	99,463	99,539
3 150	99,466	99,544

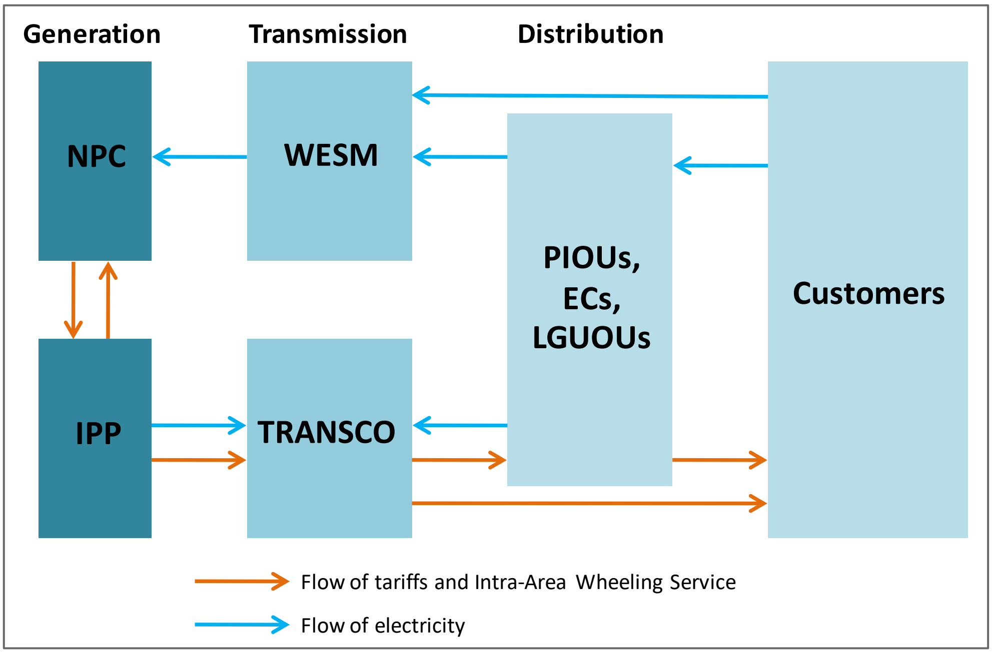
6.3 ANNEX C – ECONOMY ANALYSIS

6.3.1 The Philippines

6.3.1.1 Overview of the Power System

The electricity sector in the Philippines was restructured in 2001 when the Electric Power Industry Restructuring Act (EPIRA) was enacted and the transmission department of the National Power Corporation (NPC) became the National Transmission Corporation (TRASNCO). As a result, the generation business is operated by NPC and Independent Power Producers (IPPs), while the transmission business is run by TRANSCO. In 2006, the Wholesale Electricity Spot Market (WESM) was founded and has been operated in the Luzon area[18]. The Department of Energy (DOE) is responsible for supervise the development and usage of energy. After the enforcement of EPIRA, DOE is also in charge of the power development plan as well as energy planning.

Transmission and distribution networks in the Philippines are divided into three systems, one each for Luzon, the Visayas and Mindanao. Distribution of electricity in the Philippines is operated by the private sector. There are 16 Private Investor-Owned Utilities (PIOU), 199 Electric Cooperatives (ECs) and 8 Local Government Unit-Owned Utilities (LGUOU). ECs are non-for-profit electricity utilities, and have promoted electrification as a policy in the economy. The National Electrification Administration (NEA), a governmental organization, is responsible for managing and supervising ECs. NEA has also provided ECs with technical assistance and financial support for operation and expansion of facilities.



Source: System Loss Reduction for Philippine Electric Cooperatives (ECs) - Project Completion Report, JICA, 2013

Figure 6-1: Institutional Arrangement of the Power Sector in the Philippines

[18] The Philippines consists of about 7,600 islands that are categorized broadly under three main geographical divisions from north to south: Luzon, Visayas, and Mindanao.

6.3.1.2 Demand Characteristics

According to DOE[19], in 2016 total electricity consumption in the Philippines was about 91TWh. The residential sector accounted for the largest share, consuming about 28% of the total consumption, followed by the industrial sector at about 27% and the commercial sector at 24%. The remaining consumptions were met by other end-uses, such as public buildings, street lights, irrigation and agriculture. As shown in Figure 6-2, percentage shares of electricity consumption in the Philippines have been relatively constant over the past five years and the overall T&D losses in the Philippines in 2016 was about 9%.

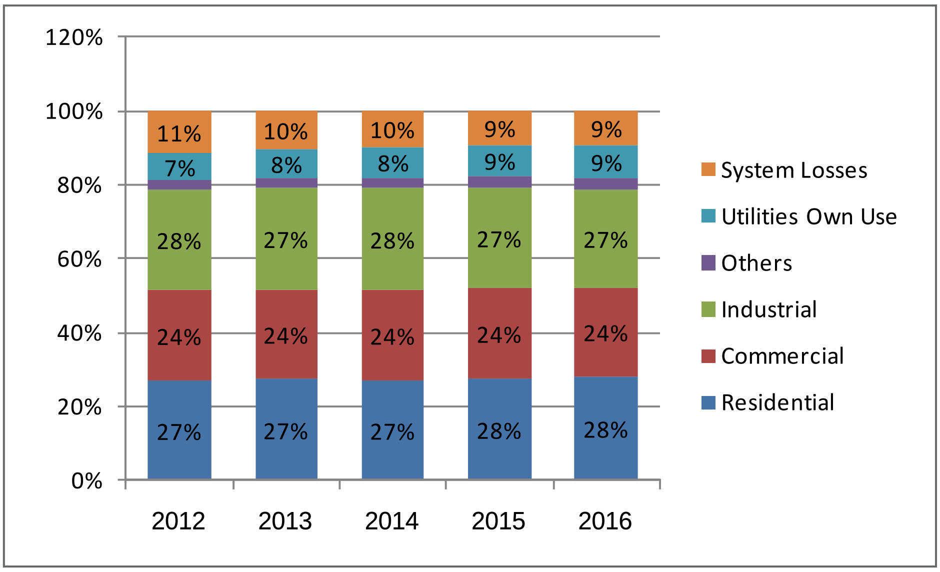


Figure 6-2: Electricity Consumption by End-Use Sector in the Philippines, 2012-2016

Annual peak demand profiles of Luzon, Visayas and Mindanao networks over the past five years, as shown in Figure 6-3, Figure 6-4 and Figure 6-5, reflect climatic conditions in different regions of the Philippines. In Luzon, the demands were typically peak during April, May and June, while the demands were low from January to March and then increased about 6% to 8% for the remaining months of the years. The average annual load factors of these networks were about 78% in 2016.

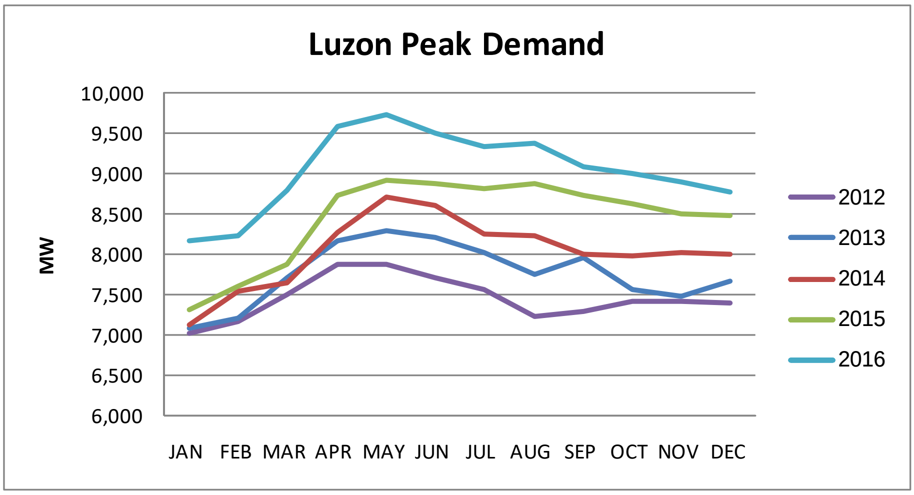


Figure 6-3: Monthly Peak Demand Profiles of Luzon Network

[19] https://www.doe.gov.ph/2016-philippine-power-statistics

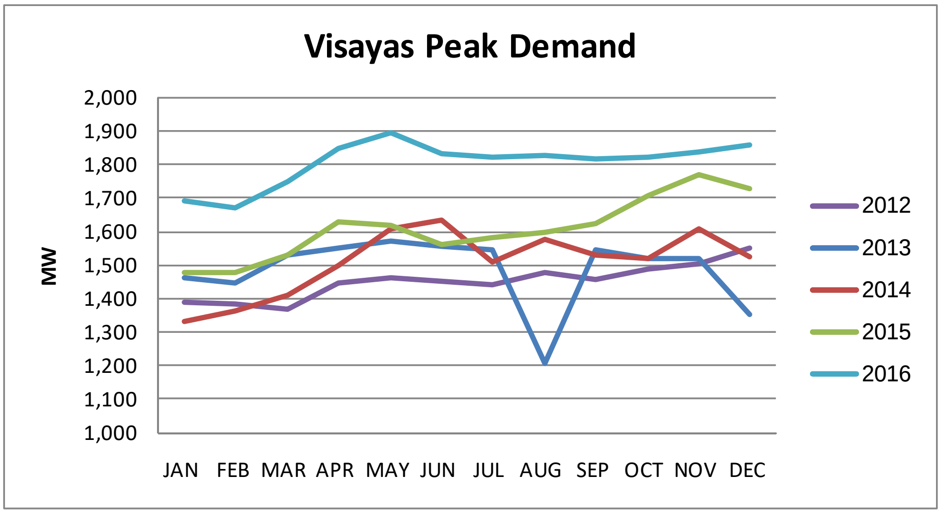


Figure 6-4: Monthly Peak Demand Profiles of Visayas Network

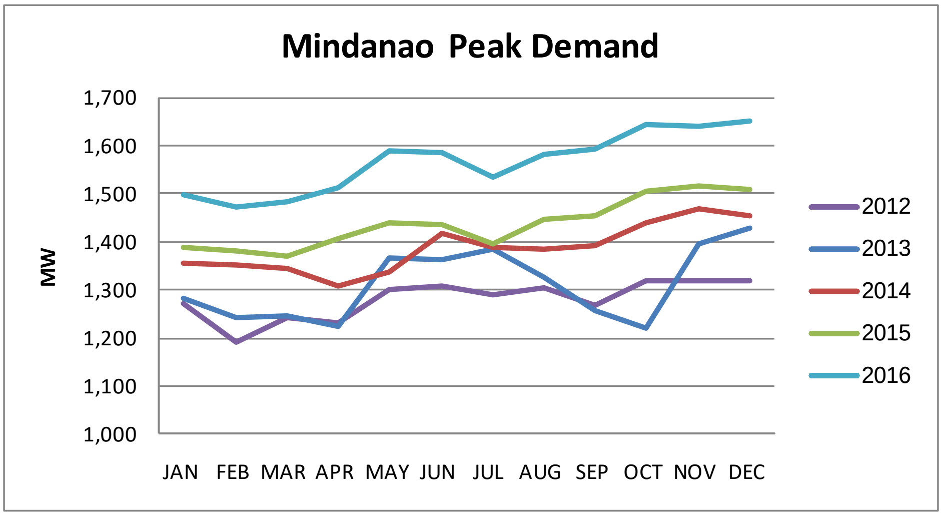


Figure 6-5: Monthly Peak Demand Profiles of Mindanao Network

Detailed data on daily load profiles of different end-use sectors in the Philippines was not available, however based on the data compiled by this study, daily load profiles of an electric utility in Mindanao are shown in Figure 6-6. Residential and commercial customers of this utility have similar consumption patterns, with an evening peak demand from 7-9pm, while electricity consumed by industrial customers reflects daily working hours from 8-9 am to 5-6 pm. This specific utility reported the average annual load factors for residential, commercial and industrial sectors at 65%, 56% and 50% respectively, and these figures are found to be corresponding with the daily load profiles.

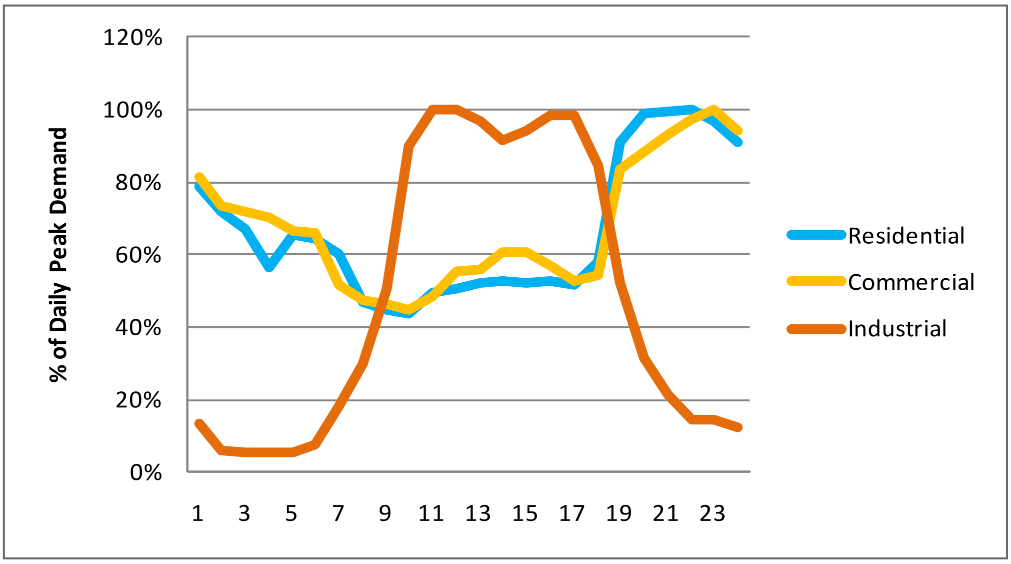
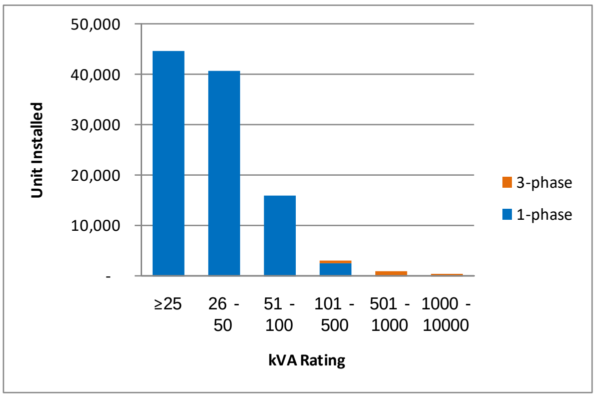


Figure 6-6: Daily Load Profile of an Electric Utility in Mindanao

6.3.1.3 Distribution Transformer Stock and Market

The Philippines is the only economy in Southeast Asia with 60 Hz electrical system. Design and operation of the Philippine distribution network generally follow US standards and practices, including standards for DTs. As a result, single-phase, pole-mounted DTs are very common in the Philippines. The previous APEC study on Energy Efficiency Potential for Distribution Transformers in the APEC Economies published in 2013 estimated the total distribution transformer stock in the Philippines at 0.21 million units with an aggregated installed capacity of 15,300 MVA, and annual sales at about 6,700 units. A more recent study on Copper – Intensive Technologies in the Philippines commissioned by the International Copper Association Southeast Asia (ICASEA) in 2016 estimated the market demand of DTs by distribution utilities and by commercial and industrial end-users at about 2,300 MVA and 1,600 MVA per year respectively. The survey questionnaires distributed by this project through the Philippine DOE were filled by three distribution utilities (two in Luzon, one large and one small, and one in Mindanao). The total installed capacity of DTs in these three networks is about 16,200 MVA, and the most popular kVA rating in terms of units and cumulative capacities installed is the single-phase 50 kVA DT. The overall profiles of DTs installed by these three distribution utilities are shown in the figure below.



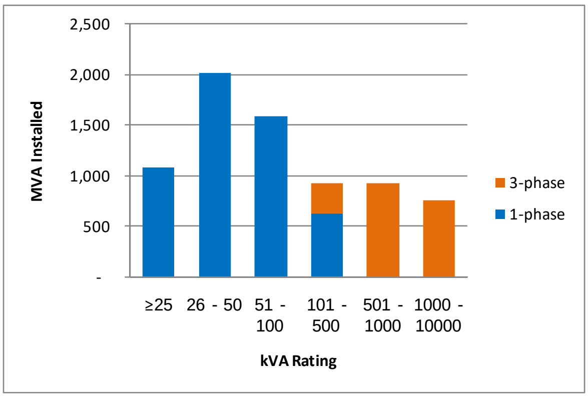


Figure 6-7: Profiles of Distribution Transformers installed in Three Distribution Utilities in Luzon and Mindanao

6.3.1.4 Efficiency Requirements for Distribution Transformers

Based on the survey feedback, distribution utilities in the Philippines generally follow the US standards. One of the distribution utilities in the Philippines specified that their DTs are in compliance with the NEMA energy efficiency requirements. It is believe that all DTs procured by most distribution utilities in the Philippines would meet the US DOE regulation of DT efficiency issued in 2010 as shown in Table 6-2. It should be noted that all efficiency values are at 50 percent of name plate rated load, determined according to the DOE Test Method for Measuring the Energy Consumption of Distribution Transformers under Appendix A to Subpart K of 10 CFR part 431, in which the efficiency calculation method is in line with Method B specified in IEC 60076-20. MERALCO which is the largest distribution utility in the Philippines evaluates procurements of their DTs based on the equipment's Total Owning Cost (TOC).

Table 6-2: Minimum Efficiency Values for Liquid-Immersed Distribution Transformers (DOE, 2010)

Single-Phase		Three-Phase	
Rating (kVA)	**Efficiency (%)**	**Rating (kVA)**	**Efficiency (%)**
10	98.62%	**15**	98.36%
15	98.76%	**30**	98.62%
25	98.91%	**45**	98.76%
37.5	99.01%	**75**	98.91%
50	99.08%	**112.5**	99.01%
75	99.17%	**150**	99.08%
100	99.23%	**225**	99.17%
167	99.25%	**300**	99.23%
250	99.32%	**500**	99.25%
333	99.36%	**750**	99.32%
500	99.42%	**1,000**	99.36%
667	99.46%	**1,500**	99.42%
833	99.49%	**2,000**	99.46%
		2,500	99.49%

In addition to the above minimum efficiency values, it is reported by ICASEA that ECs widely use the "Distribution Transformer Handbook for Electric Cooperatives" produced by NEA and ICA, in which the below maximum no-load and load losses are specified.

Table 6-3: Maximum No-Load and Load Losses for DTs procured by ECs

Rating	Silicon Steel Core		Amorphous Metal Core	
	No Load Losses, Watts	**Load Losses, Watts**	**No Load Losses, Watts**	**Load Losses , Watts**
3	9	45	8	45
5	19	75	8	75
10	36	120	12	120
15	50	195	15	195
25	80	290	18	290
37.5	105	360	30	360
50	135	500	32	500
75	190	650	45	650
100	210	850	50	850
167	350	1410	65	1410

Rating	Silicon Steel Core		Amorphous Metal Core	
	No Load Losses, Watts	Load Losses, Watts	No Load Losses, Watts	Load Losses , Watts
250	500	2000	90	2000
333	650	2500	120	2500

6.3.1.5 Baseline and Estimation of Per Unit Annual Energy Losses

Analysis of baseline energy losses in this report focus on annual energy losses by the most common kVA rating in the Philippines, i.e., 50 kVA single-phase distribution transformer. Considering that distribution utilities in the Philippines generally follow US standards, the baseline efficiency levels of distribution transformers in the Philippines in this report are based on the DOE 2010 MEPS (see Table 6-2) which specifies EI_{B50} for 50 kVA single-phase distribution transformer at 99.08%. It should be noted that DOE 2010 MEPS values are identical to EI_{B50} Level 1 as specified in Table 5 of IEC 60072-20.

The analysis model in this report uses no-load and load losses to estimate annual energy losses in kWh at different daily load profiles and also load factors. Distribution transformer designers have multiple choices to design transformers to meet the same EI_{B50} efficiency level but performing differently at light and heavy loading. No-load and load losses of the baseline 50 kVA model in this report were determined using a typical load-efficiency curve of a distribution transformer as per NEMA TP-1, as shown in Table 6-9, and no-load losses of 90W and load losses of 625W which deliver the efficiency of 99.08% at 50% loading were referenced in the analysis.

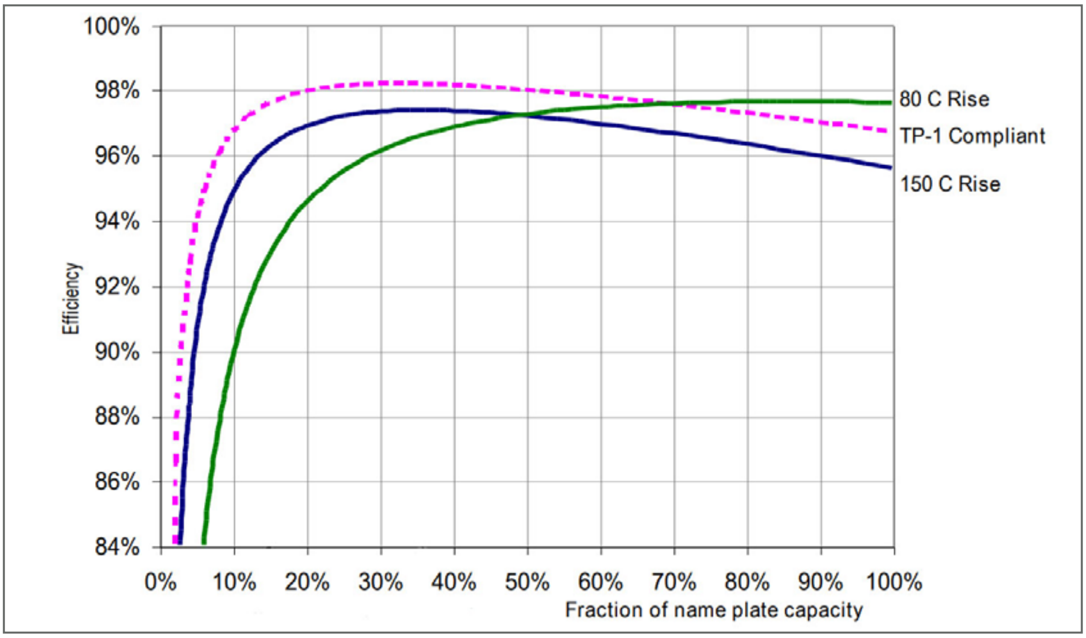
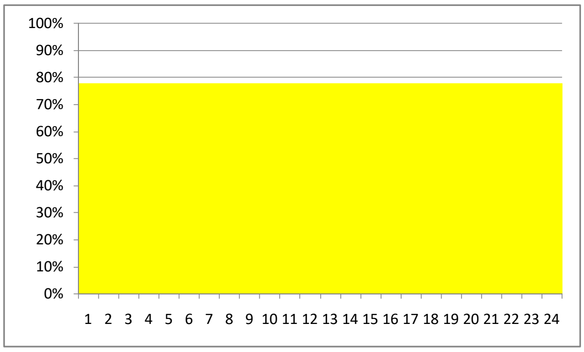
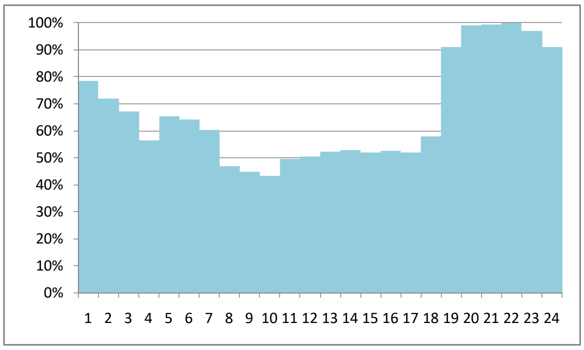


Figure 6-8: Typical Load-Efficiency Curve of NEMA TP-1 Compliant Distribution Transformer

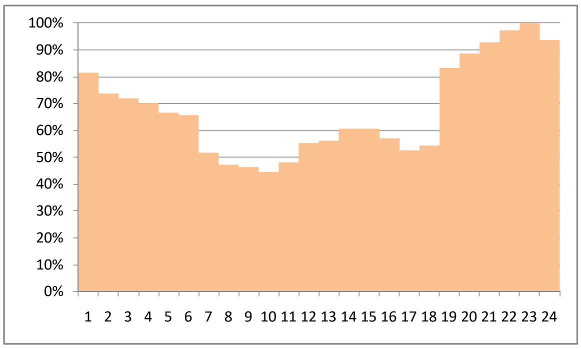
Data on daily load profiles of different end-use sector obtained from the survey was used to construct different daily load profiles for the analysis as shown in Table 6-10.



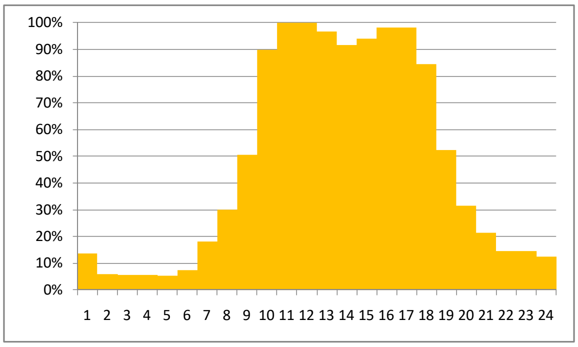
Load Profile: Flat;
Maximum Load Factor: 78%



Load Profile: Residential (evening peak);
Maximum Load Factor: 66%



Load Profile: Commerical (afternoon & evening peaks);
Maximum Load Factor: 68%



Load Profile: Industrial (morning & afternoon peaks);
Maximum Load Factor: 48%

Figure 6-9: Different Daily Load Profiles for the Philippines Baseline Analysis

The analyses under different daily load profiles and load factors of various end-uses, as shown above, as well as at 50% load factor for a 50 kVA single-phase DT were undertaken, and the analysis results are shown in the table below. Based on the analysis at 50% load factor, variations of baseline annual energy losses due to diversity of load profles in the Philippines range from 2,153 kWh (for the flat load profile) to 3,052 kWh (for the industrial load profile).

Table 6-4: Per Unit Baseline Annual Energy Losses of 50 kVA Single-Phase Distribution Transformer in the Philippines

Daily Load Profile	Average Load Factor (%)	Baseline Annual Energy Loss (kWh)	Average Load Factor (%)	Baseline Annual Energy Loss (kWh)
Flat	78%	4,119	50%	2,153
Residential	66%	3,408	50%	2,262
Commercial	56%	2,620	50%	2,244
Industrial	48%	2,841	50%	3,052

6.3.1.6 Estimation of IEC 60076-20 Scenario

Analysis of annual energy losses and energy savings in the Philippines from adoption of IEC 60076-20 EI_{B50} level 2 requirements for 60 Hz DTs (specified in Table 5 of IEC 60076-20 Technical Specification) which are equivalent to DOE 2016 MEPS follows the similar approach previously discussed in the baseline section. In this report, three following designs of 50 kVA DTs with different no-load and load losses but meeting the EI_{B50} level 2 requirement for 50 kVA at 99.11% were developed for the analysis:

- **Design A:** a 50 kVA DT with medium levels of no-load and load losses and the total losses is in between Design B and C;
- **Design B:** a 50 kVA DT with low no-load losses and high load losses and the highest total losses compared with other designs;
- **Design C:** a 50 kVA DT with high no-load losses and low load losses and the lowest total losses compared with other designs.

Values of losses, PEI and EI_{B50} of the baseline model and the above three designs are shown in Table 6-5. The load vs efficiency curves of the baseline model and these three designs are are shown in Figure 6-10.

Table 6-5: Loss and Efficiency Values of 50 kVA Distribution Transformer

Distribution Transformer	50 kVA, Single-Phase, 60Hz				
Efficiency Profile	**No-Load Losses (W)**	**Load Losses (W)**	**Total Losses (W)**	**PEI (%)**	**EI_{B50}**
Baseline Model	90	625	715	99.050%	99.08%
Design A	81	631	712	99.095%	99.11%
Design B	23	887	910	99.431%	99.11%
Design C	92	584	676	99.075%	99.11%

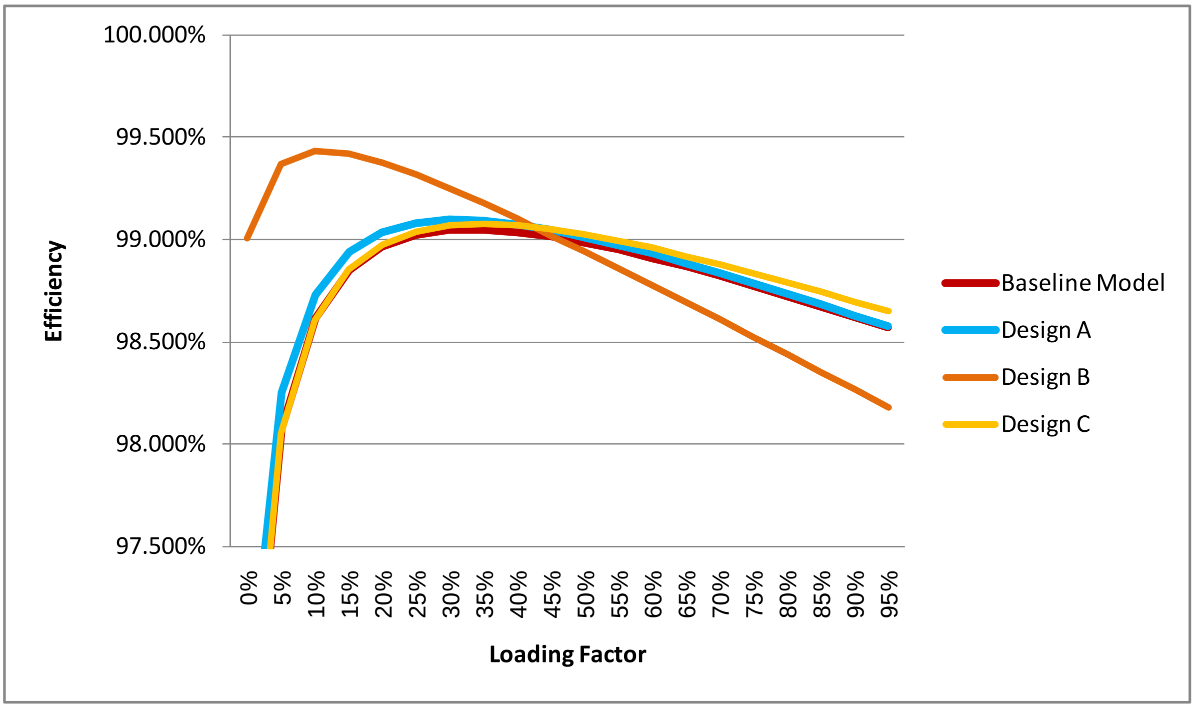


Figure 6-10: Load vs Efficiency Curves of 50 kVA Distribution Transformer

The analysis results on replacing the baseline model with the three designs, as summarized in Table 6-6, show that, under the typical daily load profiles and average annual load factors for different end-use sectors in the Philippines, *Design A and C deliver lower per unit annual energy losses. Although Design B has higher PEI and EI_{B50} than the baseline model, it delivers higher per unit annual energy losses than the baseline model due to its inefficiency at high loading factors.* At a lower average annual load factor of 50%, annual energy losses of the baseline model and the three designs are more comparable but the Design B model is still less efficient compared with the Design A and C models. Shown in Figure 6-11 are per unit annual energy savings from adoption of IEC 60076-20 EI_{B50} level 2 for 50 kVA single-phase 60Hz DTs in the Philippines.

Table 6-6: Analysis of per Unit Annual Energy Losses of Single-Phase 50 kVA 60Hz DT

Daily Load Profile	Average Load Factor (%)	Annual Energy Loss (kWh)			
		Baseline Model	Design A	Design B	Design C
Typical Average Annual Load Factors in the Philippines					
Flat	78%	4,119	4,073	4,927	3,917
Residential	66%	3,408	3,354	3,916	3,251
Commercial	56%	2,620	2,558	2,798	2,514
Industrial	48%	2,841	2,782	3,112	2,721
Average Annual Load Factor @ 50%					
Flat	50%	2,153	2,087	2,135	2,078
Residential	50%	2,262	2,197	2,290	2,180
Commercial	50%	2,244	2,179	2,265	2,163
Industrial	50%	3,052	2,994	3,411	2,918

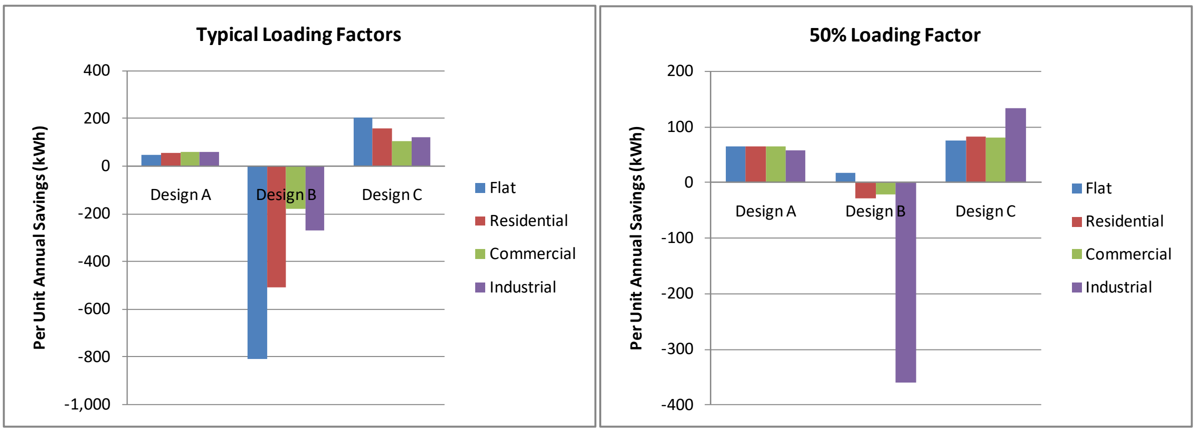


Figure 6-11: Per Unit Annual Energy Savings in kWh from Adoption of IEC 60076-20 in the Philippines

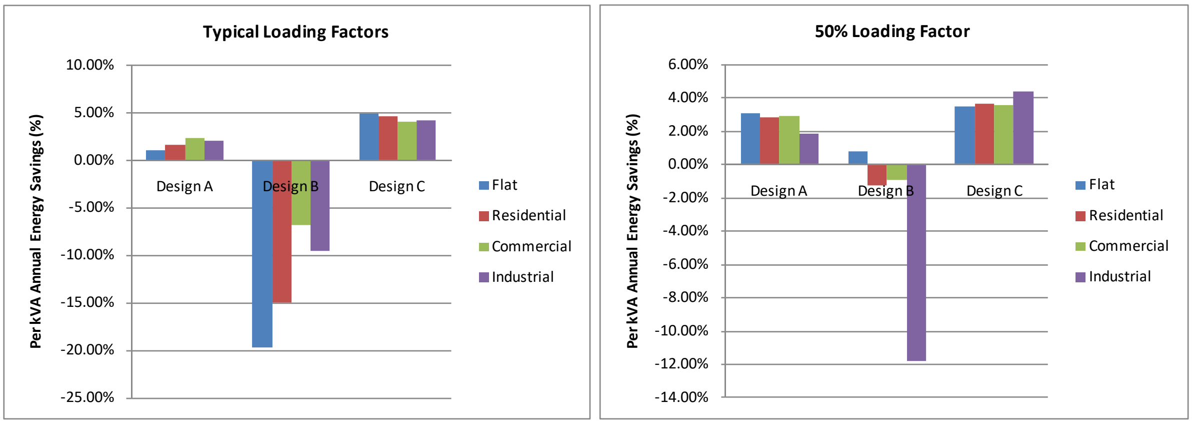


Figure 6-12: Per kVA Annual Energy Savings in % from Adoption of IEC 60076-20 in the Philippines

Shown in Figure 6-13 and Figure 6-14 are graphical illustrations of per unit annual energy losses shown in the above table in comparison with PEI and EI_{B50}. It can be seen that PEI and EI_{B50} do not represent levels of annual energy losses of a DT under different operating conditions.

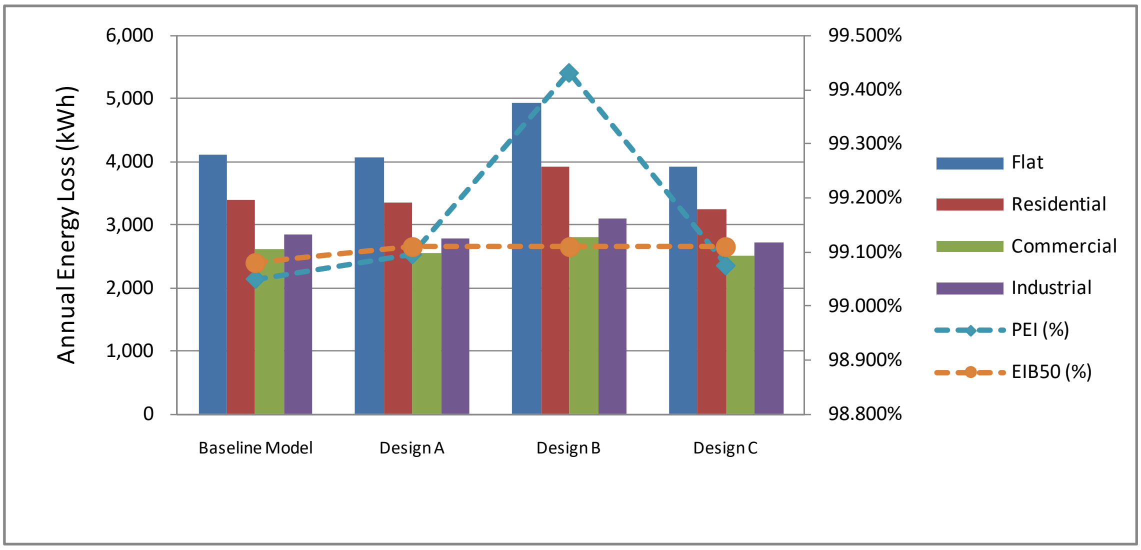


Figure 6-13: 50 kVA Per Unit Annual Energy Losses at Typical Load Factors in the Philippines compared with PEI and EI_{B50}

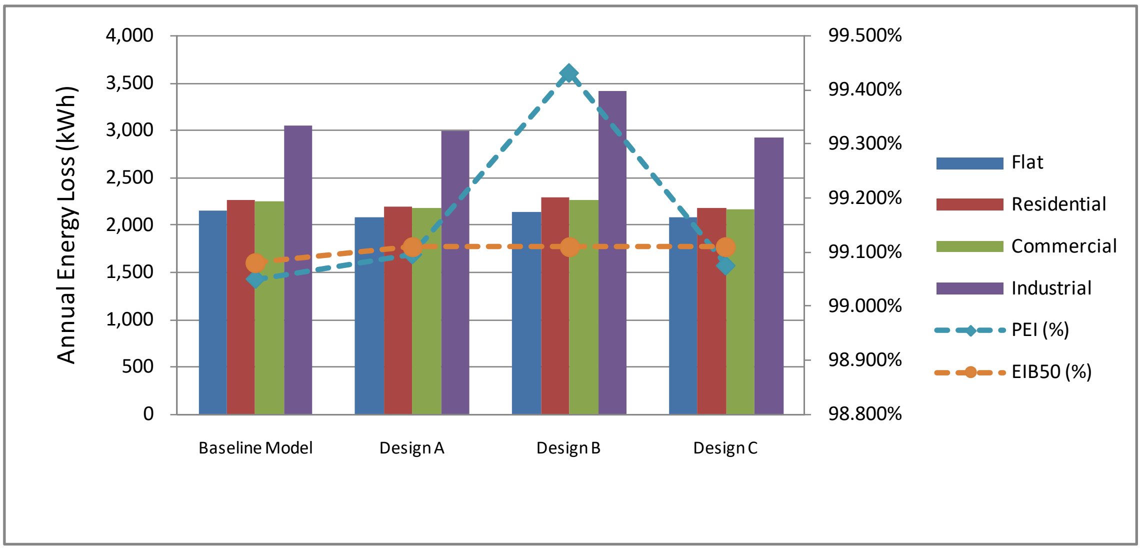


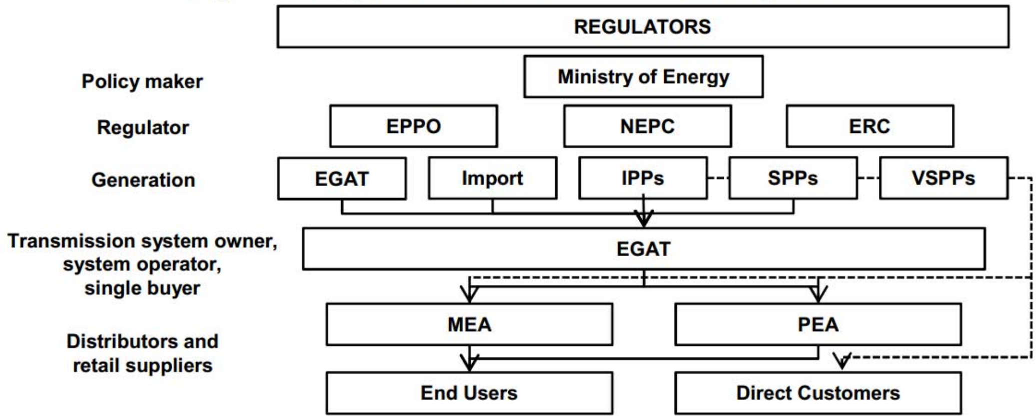
Figure 6-14: 50 kVA Per Unit Annual Energy Losses at 50% Load Factor in the Philippines compared with PEI and EI_{B50}

6.3.2 Thailand

6.3.2.1 Overview of the Power System

Thailand is the second largest economy in Southeast Asia. The power sector of Thailand is regulated by the independent Energy Regulatory Commission, which monitors energy market conditions, reviews tariffs, issues licenses, approves power purchases, and reviews development planning and investment in the electricity industry. Thailand has adopted a single-buyer model in the power subsector under which the Electricity Generating Authority of Thailand (EGAT), the state-owned utility, allows limited private sector participation in electricity generation while maintaining control over system planning, operation, and pricing. EGAT sells electricity to two major state-owned distribution utilities, Metropolitan Electricity Authority (MEA) and Provincial Electricity Authority (PEA). MEA is responsible for providing power services in Bangkok and surrounding areas, while PEA is responsible for providing power services to all other provinces outside the greater Bangkok area and also for implementing rural electrification.

Figure 1: Organization of Thailand's Power System



EGAT = Electricity Generating Authority of Thailand, EPPO = Energy Policy and Planning Office, ERC = Energy Regulatory Commission, IPP = independent power producer, MEA = Metropolitan Electricity Authority, NEPC = National Energy Policy Council, PEA = Provincial Electricity Authority, SPP = small power producer, VSPP = very small power producer.
Source: Energy Regulatory Commission. 2012. *Thailand: Energy Regulation & the Promotion of Energy Conversation*. Bangkok.

Figure 6-15: Structure of Thailand's Power Sector

Annual electricity consumption in Thailand was about 183 TWh in 2016 and consumption by PEA's 19 million customers accounted for about 71% (130 TWh) of the annual consumption, while MEA's consumption by its 3.6 million customers accounted for about 28% (51 TWh). EGAT also directly supplied electricity to large end-users but the total consumption of these large end-users accounted for only about 1% of the annual consumption. Key data on energy sold and distribution networks of MEA and PEA are summarized in the table below.

Table 6-7: Key Data on Energy Sold and Distribution Networks of MEA and PEA, Thailand

Description	MEA (2016)	PEA (2016)
Number of Customers (million)	3.63	18.89
Total Energy Sold (TWh)	51.4	129.67
Total Sub-Station Capacity (MVA)	18,485	N/A
Annual Load Factor (%)	66%	73%
System Loss (%)	3.32%	5.4%

6.3.2.2 Electricity Demand

The industrial sector was the largest end-use sector in 2016 accounting for about 48% of the annual consumption in the same year in Thailand. The business (commercial) and residential sector accounted for approximately the same share of about 25%. The overall system load factor was about 73% in 2016. Within the MEA's service areas, the business (commercial) sector is the largest end-use sector with 40% share in the total electricity sold in 2016, followed by the industrial sector (28%) and the residential sector (25%). As for the PEA's service areas, the industrial sector is the largest end-use sector, accounting for 55% of the total electricity sold in 2016, trailed by the residential sector at 24% and the business sector at 18%.

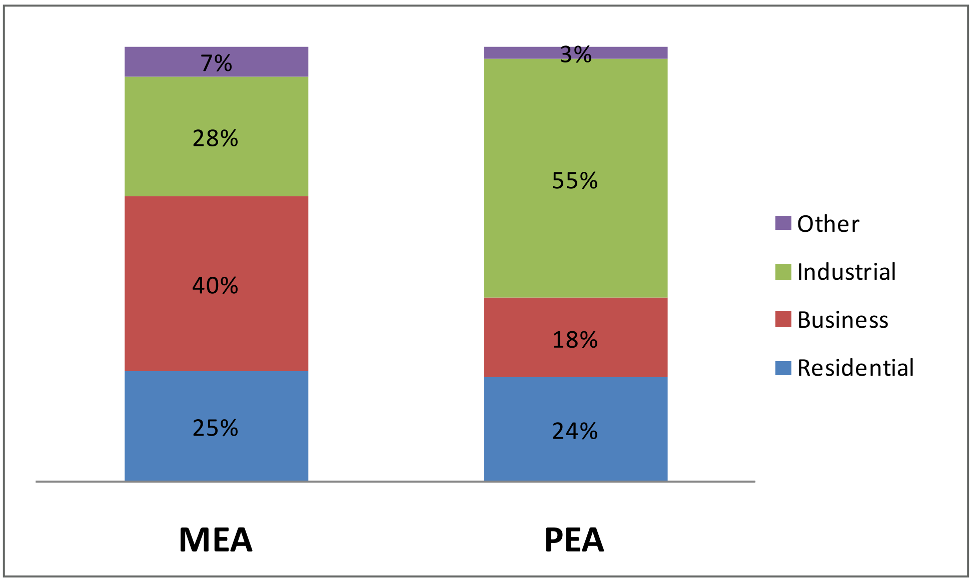


Figure 6-16: Electricity Consumption by Key End-Use Sectors in MEA and PEA's Service Areas, in Thailand

Annual energy demand profiles of MEA's and PEA's networks clearly represent typical annual energy consumption patterns of a tropical economy where electricity consumptions are high during the summer months (March to June). The average annual load factors of MEA's and PEA's distribution networks in 2016 are 66% and 73% respectively.

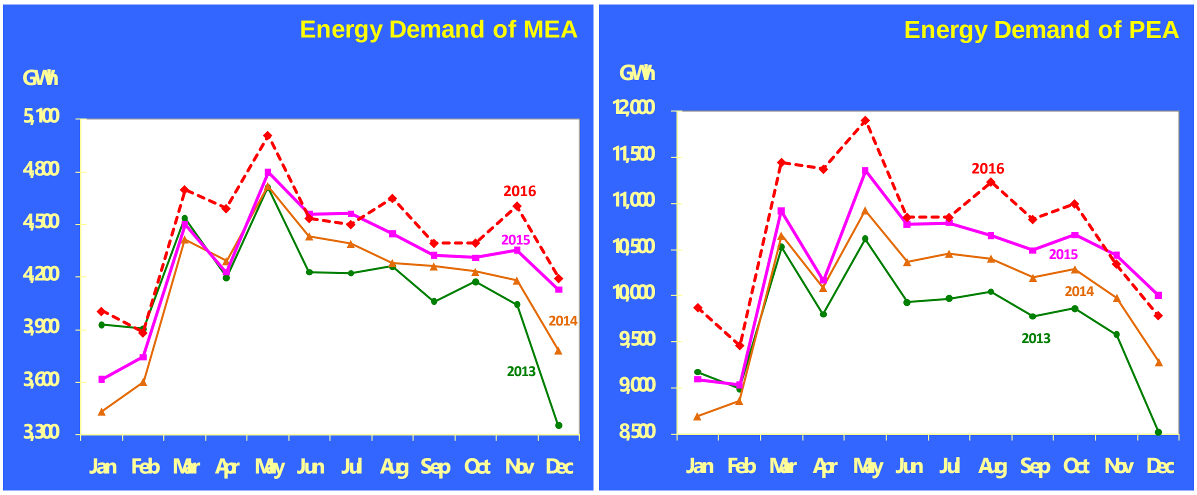


Figure 6-17: Annual Energy Demand Profiles of MEA and PEA

There was no available data on typical daily load profiles for different types of consumers in MEA's and PEA's service areas, however daily consumption profiles of PEA's customers under different tariff classifications during the month of May 2015 are shown in Figure 6-18 to Figure 6-21. The load profiles of PEA's residential customers clearly show an evening peak around 8pm to 9pm. The load profiles of PEA's small commercial customers show two salient peaks, the afternoon peak around 3pm and the evening peak around 7.30pm to 8pm. The load profiles of commercial and public sector office buildings clearly demonstrate the morning and afternoon peaks and working hours, while the load profiles for large commercial and industrial customers show multiple peak demand, representing operating schedule of the facilities.

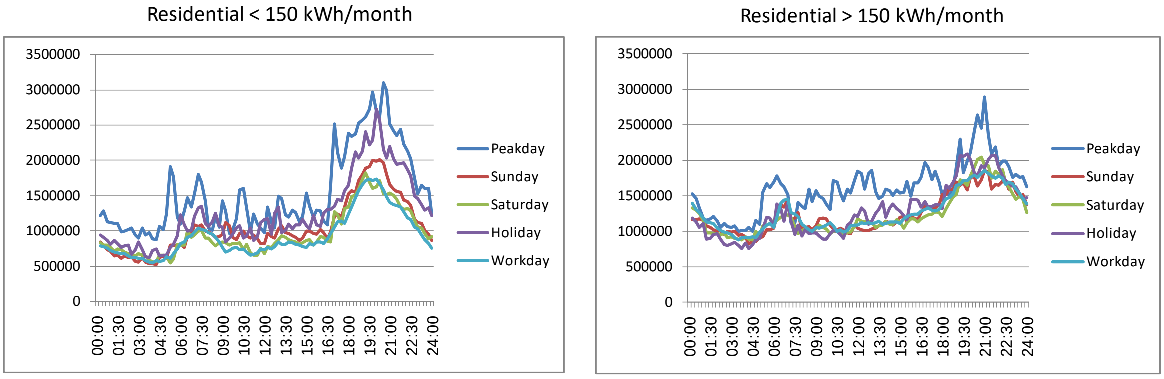


Figure 6-18: Daily Consumption Profiles of PEA's Residential Customers

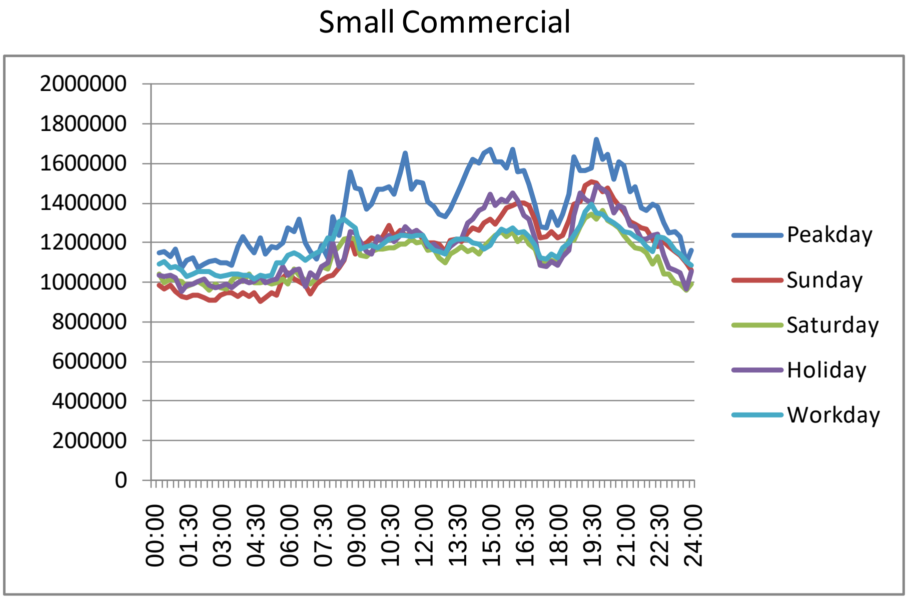


Figure 6-19: Daily Consumption Profiles of PEA's Small Commercial Customers

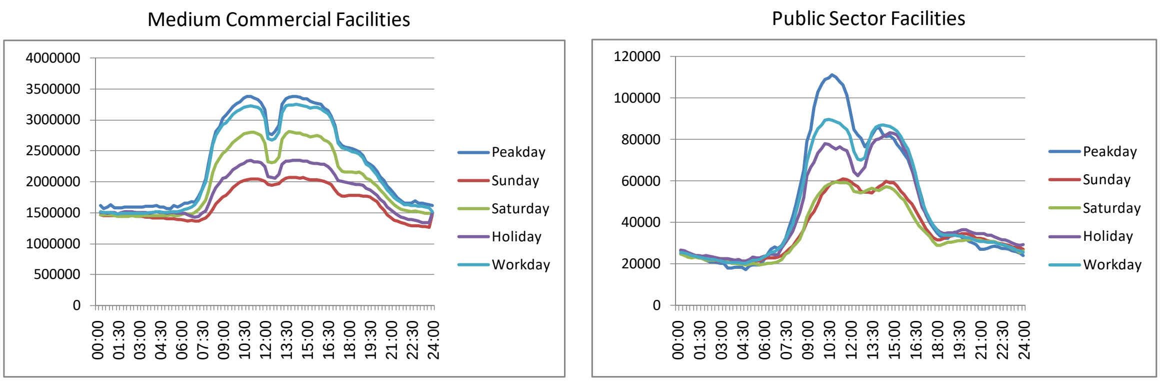


Figure 6-20: Daily Consumption Profiles of PEA's Commercial and Public Sector Facilities

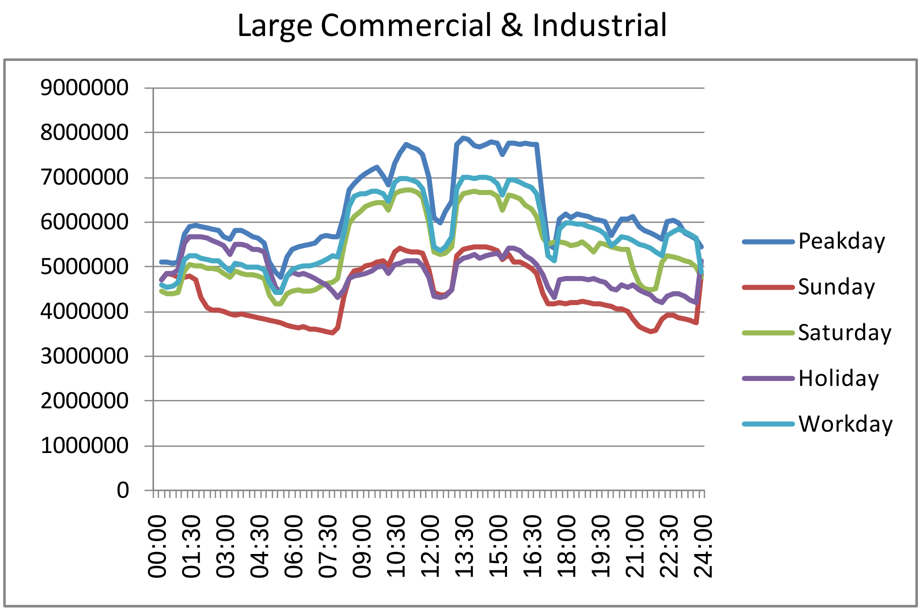


Figure 6-21: Daily Consumption Profiles of PEA's Large Commercial and Industrial Customers

6.3.2.3 Distribution Transformer Stock and Market

Based on data provided by MEA and PEA, there are about 382,000 distribution transformers owned by MEA and PEA in 2016 with the total distribution transformer capacity of about 47,655 MVA. There is no data on number of distribution transformers owned by private sector in Thailand however it is estimated that the total privately-owned distribution transformer capacity was about 48,000 MVA which is almost equivalent to the total distribution transformer capacity of MEA and PEA combined. Overall, the total distribution transformer capacity in Thailand was about 96,000 MVA in 2016. There was no available data on historical and projection of distribution transformer stocks in Thailand. However a recent study on distribution transformers commissioned by PEA estimated that PEA procures about 20,000 units of distribution transformers every year. Based on electricity statistics provided by the Energy Policy and Planning Office (EPPO), electricity consumptions by MEA's and PEA's customers have had an average growth of about 3% and 5% respectively over the past 5 years.

Virtually all utility and privately-owned distribution transformers in Thailand are oil-immersed distribution transformers and the primary input voltages are 24kV for MEA and 22kV and 33kV for PEA. Most of distribution transformers within MEA's network are three-phase distribution transformer. As for PEA, about 48% of all distribution transformers installed are single-phase distribution transformers with kVA rating from 10kVA to 30kVA, however aggregated capacity of these small single-phase transformers accounts for only about 10% of the total distribution transformer capacity of PEA. There is no data on the common kVA rating of distribution transformers in each major end-use sector in MEA's and PEA's service areas, but the most popular kVA ratings in terms of aggregated kVA installed are 500 kVA for MEA and 160 kVA for PEA.

Table 6-8: Distribution Transformer Stock and Market in Thailand

Description	MEA (2016)	PEA (2016)	Private Sector
Number of Distribution Transformer installed (thousand) [1]	42	281	N/A
Total Distribution Transformer Capacity (MVA) [1]	11,426	36,229	48,000

Description	MEA (2016)	PEA (2016)	Private Sector
Typical kVA Rating of Distribution Transformer [2]	150, 225, 300, 500	100, 160, 250	N/A
Annual Procurement(Unit)	N/A	20,000	N/A

Note: [1] The installation figures include only distribution transformers owned by MEA and PEA. Distribution transformers installed by MEA's and PEA's customers are not included.

[2] For kVA rating lower than 3,150 kVA

6.3.2.4 Efficiency Standard for Distribution Transformers

Thailand does not have any energy efficiency standards for distribution transformers, however all procurements by MEA and PEA specify maximum no-load losses and load losses as shown in Table 6-9, Table 6-10 and Table 6-11. MEA's requirements on maximum losses are more stringent than PEA's. It is not mandatory for the private sector to follow the maximum losses requirements specified by MEA and PEA.

Table 6-9: Maximum No-Load and Load Losses for Distribution Transformers, MEA

Rating (kVA)	No Load Loss (24kV)	Load Loss at 75 °C
5	70	160
45	160	360
75	220	580
112.5	255	840
150	300	1,000
225	420	1,530
300	480	1,860
500	670	3,030
750	840	4,370
1,000	1,000	6,400
1,500	1,200	10,000

Table 6-10: Maximum No-Load and Load Losses for Single-Phase Distribution Transformers, PEA

Rating (kVA)	No Load Loss (22kV and 19/33 Y kV)	Load Loss at 75 °C
10	60	145
20	90	300
30	120	430
50	150	670

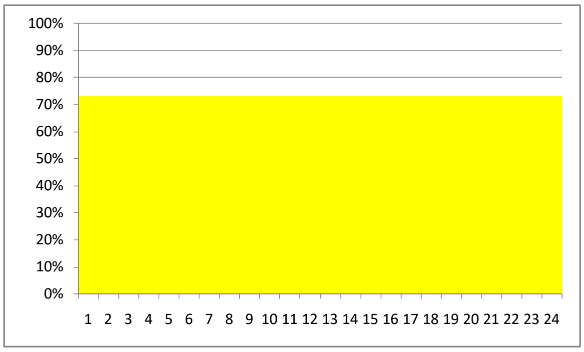
Table 6-11: Maximum No-Load and Load Losses for Three-Phase Distribution Transformers, PEA

Rating (kVA)	No Load Loss (22kV)	No Load Loss (33kV)	Load Loss at 75 °C
50	160	170	950
100	250	260	1,550

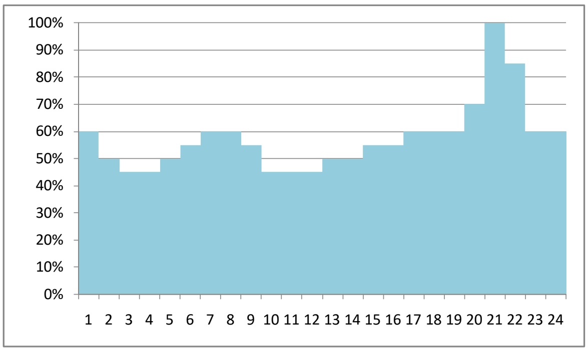
Rating (kVA)	No Load Loss (22kV)	No Load Loss (33kV)	Load Loss at 75 °C
160	360	370	2,100
250	500	520	2,950
315	600	630	3,500
400	720	750	4,150
500	860	900	4,950
630	1,010	1,050	5,850
1,000		1,300	12,150
1,250	1,500	1,530	14,750
1,500	1,820	1,850	17,850
2,000	2,110	2,140	21,600

6.3.2.5 Estimation and Baseline Modeling of Per Unit Annual Energy Losses

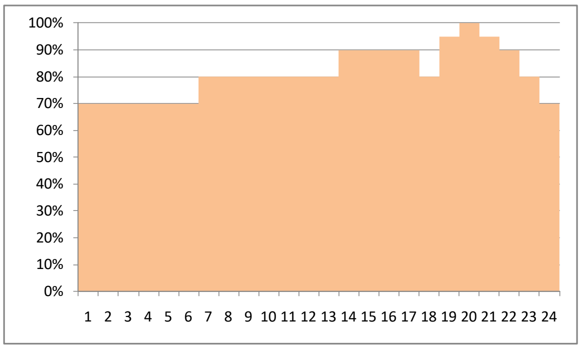
Analysis of baseline energy losses in this report focus on annual energy losses of the most common kVA rating in MEA's and PEA's distribution networks, i.e., 500 kVA for MEA and 160 kVA for PEA. The baseline efficiency levels of these two kVA ratings are based on the procurement requirements on maximum no-load and load losses specified by both utilities. Data on daily load profiles of different end-use sector obtained from PEA was used to construct different daily load profiles, as shown in the figure below, for the analysis of both MEA and PEA. Note that for the analysis of MEA's flat load profile, the maximum load factor of 66% was used to reflect the average annual load factor in the MEA's networks.



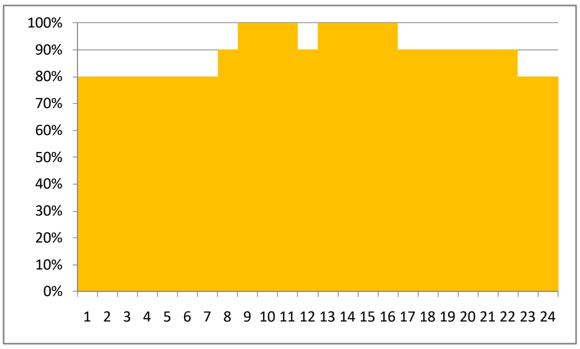
Load Profile: Flat; Maximum Load Factor: 73%



Load Profile: Residential (evening peak); Maximum Load Factor: 58%



Load Profile: Commerical (afternoon & evening peaks); Maximum Load Factor: 81%



Load Profile: Industrial (morning & afternoon peaks); Maximum Load Factor: 89%

Figure 6-22: Different Daily Load Profiles for Thailand Baseline Analysis

The analyses under different daily load profiles and load factors of various end-uses (as shown above) as well as at 50% load factor for MEA's and PEA's DTs were undertaken, and the analysis results are shown in Table 6-12 the tables below Table 6-13. It should be noted that the maximum average load factor for the residential daily load profile in Thailand is 58% unless the distribution transformer is overloaded during the peak demand. Based on the analysis at 50% load factor, variations of baseline annual energy losses due to diversity of load profles in Thailand are described below:

- For MEA's 500 kVA DT – 12,373 kWh (for the flat load profile) to 12,830 kWh (for the residential load profile)
- For PEA's 160 kVA DT – 7,687 kWh (for the industrial load profile) to 7,978 kWh (for the residential load profile).

Table 6-12: Per Unit Baseline Annual Energy Losses of MEA's 500 kVA Distribution Transformer

Daily Load Profile	Average Load Factor (%)	Baseline Annual Energy Loss (kWh)	Average Load Factor (%)	Baseline Annual Energy Loss (kWh)
Flat	66%	17,431	50%	12,373
Residential	58%	15,065	50%	12,830
Commercial	66%	17,512	50%	12,690
Industrial	66%	17,521	50%	12,542

Table 6-13: Per Unit Baseline Annual Energy Losses of PEA's 160 kVA Distribution Transformer

Daily Load Profile	Average Load Factor (%)	Baseline Annual Energy Loss (kWh)	Average Load Factor (%)	Baseline Annual Energy Loss (kWh)
Flat	73%	12,957	50%	7,687
Residential	58%	9,527	50%	7,978
Commercial	73%	13,115	50%	7,881
Industrial	73%	13,070	50%	7,778

6.3.2.6 Estimation of IEC 60076-20 Scenario

6.3.2.6.1 MEA Analysis

MEA has specified quite stringent maximum no-load and load losses for procurement of its distribution transformers comparing with IEC 60076-20 technical specification. As for the most common kVA rating in MEA's networks, 500 kVA three-phase distribution transformer, MEA has specified higher no-load loss than the level 2 requirement in Table 4 of IEC 60076-20 (670W vs 459W) but load loss requirement is lower (3,030W vs 3,900W). PEI of MEA's 500 kVA transformers are slightly lower than IEC 60076-20 (99.430% vs 99.465%) while EI_{B50} is almost equivalent to IEC. In this report, following three designs of 500 kVA DTs with different no-load and load losses were developed for the analysis:

- **Design A:** a 500 kVA DT with level 2 maximum no-load and load losses as specified in Table 4 of IEC 60076-20. It should be noted that any DTs meeting the maximum no-load and load losses in Table 4 will also meet the EI_{B50} requirements specified in Table 6 of of IEC 60076-20;
- **Design B:** a 500 kVA DT with low no-load losses and high load losses and meeting the level 2 EI_{B50} requirement at 99.464% specified in Table 6 of of IEC 60076-20;
- **Design C:** a 500 kVA DT with high no-load losses and low load losses and meeting the level 2 EI_{B50} requirement at 99.464% specified in Table 6 of of IEC 60076-20.

Values of losses, PEI and EI_{B50} of the baseline model and the above three designs are shown in the table below. The load vs efficiency curves of the baseline model and these three designs are are shown in Figure 6-23.

Table 6-14: Loss and Efficiency Values of 500 kVA DT

Distribution Transformer	500 kVA, 50Hz, 24kV				
Efficiency Profile	No-Load Losses (W)	Load Losses (W)	Total Losses (W)	PEI (%)	EI_{B50}
Baseline Model	670	3,030	3,700	99.430	99.459
Design A	459	3,900	4,359	99.465	99.464
Design B	230	4,913	5,143	99.575	99.464
Design C	918	1,887	2,805	99.474	99.464

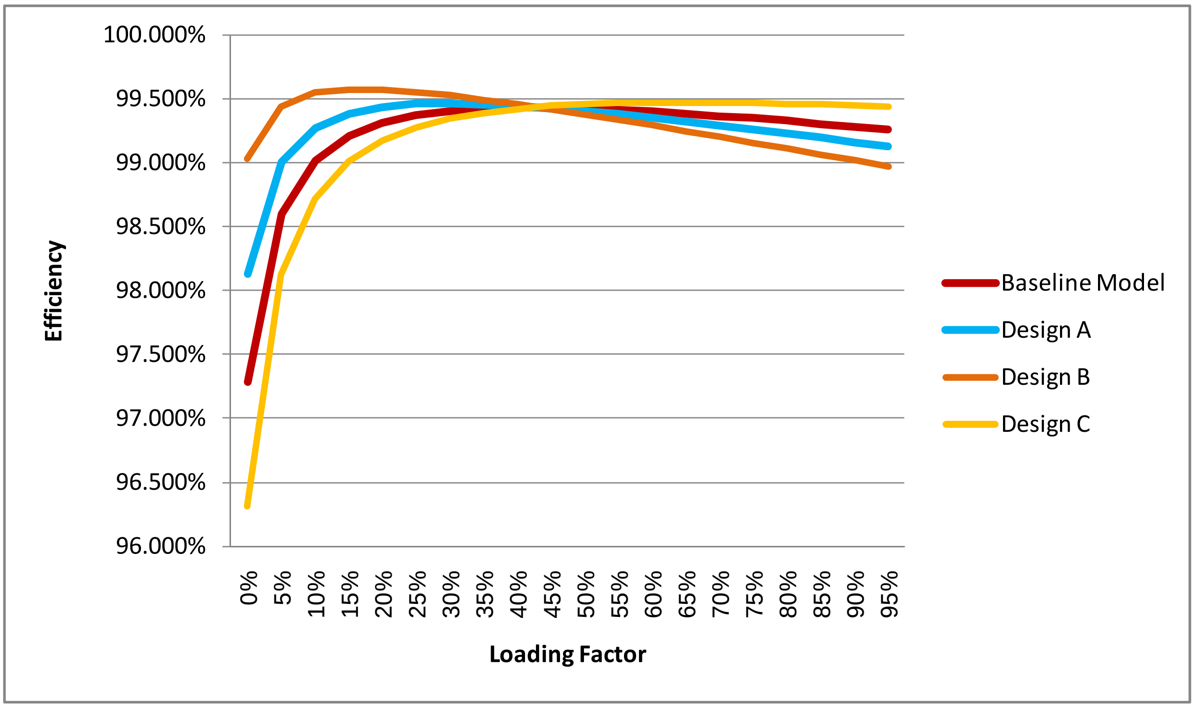


Figure 6-23: Load vs Efficiency Curves of 500 kVA Distribution Transformer

The analysis results summarized in Table 6-15 show that, under the typical daily load profiles and average annual load factor[20] for different end-use sectors in MEA's network, the baseline model with MEA's maximum no-load and load losses delivers lower per unit annual energy losses than the Design A and B models. The Design C model with high no-load losses and low load losses design for EI_{B50}, is more efficient than the baseline model in both load factor scenarios and delivers lower annual energy lossesn than the baseline model. Shown in Figure 6-24 are per unit annual energy savings from adoption of IEC 60076-20 for 500 kVA three-phase 50Hz DTs in MEA's networks.

[20] Average annual loading factor at 66% for the commercial and industrial sector and 58% for residential sector

Table 6-15: Analysis of per Unit Annual Energy Losses of 500 kVA Distribution Transformer

Daily Load Profile	Average Load Factor (%)	Annual Energy Loss (kWh)			
		Baseline Model	Design A	Design B	Design C
Typical Average Annual Load Factor for MEA's Network @ 66%					
Flat	66%	17,431	18,903	20,758	15,241
Residential	58%	15,065	15,857	16,921	13,768
Commercial	66%	17,512	19,006	20,888	15,291
Industrial	66%	17,521	19,019	20,904	15,297
Low Average Annual Load Factor @ 50%					
Flat	50%	12,373	12,392	12,556	12,091
Residential	50%	12,830	12,980	13,297	12,376
Commercial	50%	12,690	12,801	13,071	12,289
Industrial	50%	12,542	12,610	12,830	12,197

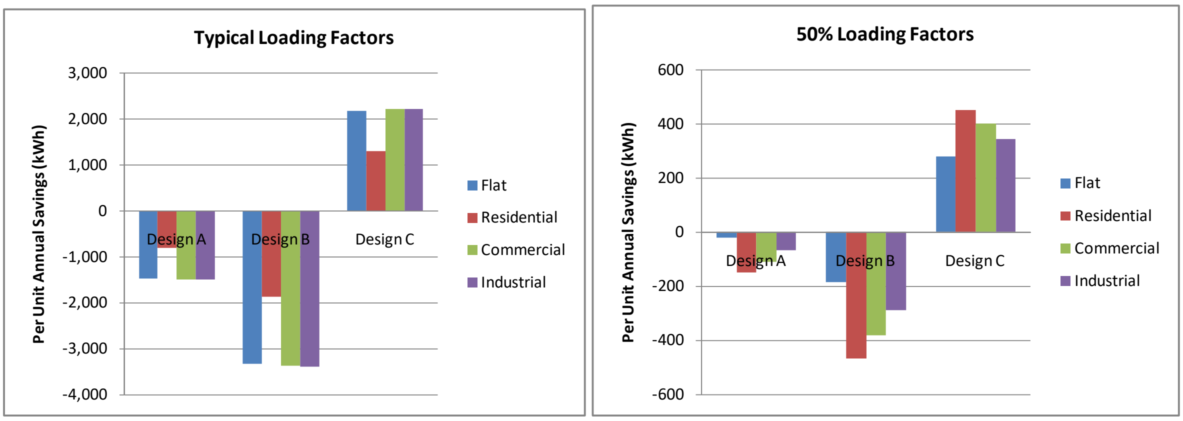


Figure 6-24: Per Unit Annual Energy Savings in kWh from Adoption of IEC 60076-20 in MEA's Networks

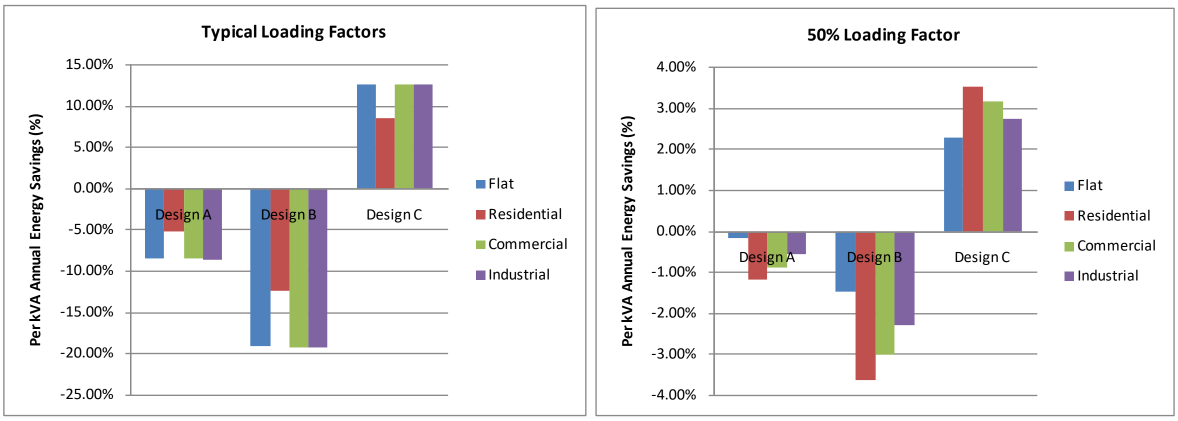


Figure 6-25: Per kVA Annual Energy Savings in % from Adoption of IEC 60076-20 in MEA's Networks

Shown in Figure 6-26 and Figure 6-27 are graphical illustrations of per unit annual energy losses of different designs of 500 kVA DT in comparison with PEI and EI_{B50}. It can be seen for these two figures that PEI and EI_{B50} do not represent annual energy losses of a distribution transformer under different operating conditions.

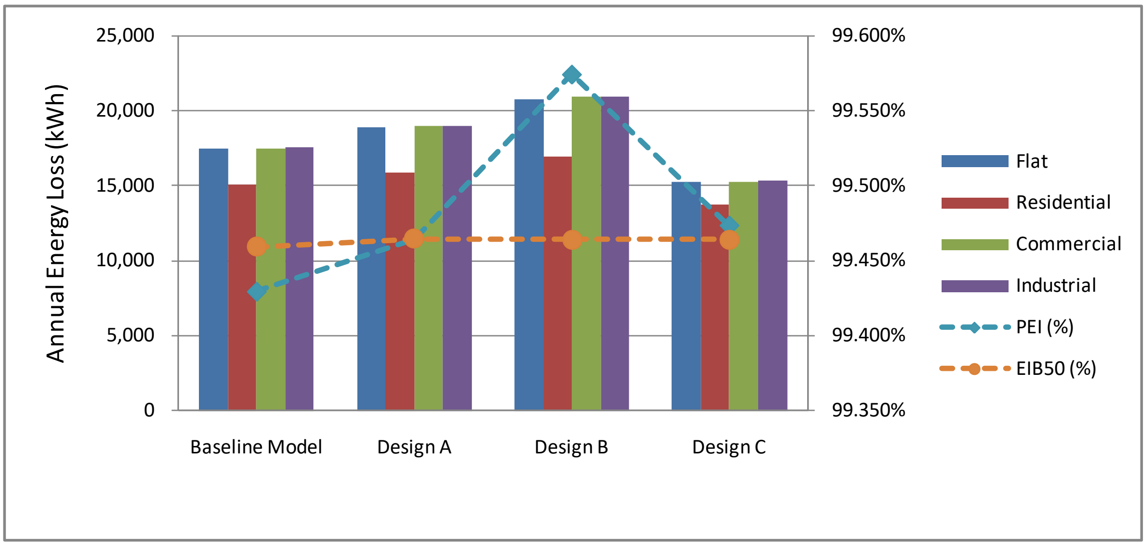


Figure 6-26: 500 kVA Per Unit Annual Energy Losses at Typical Load Factors in MEA's Networks compared with PEI and EI_{B50}

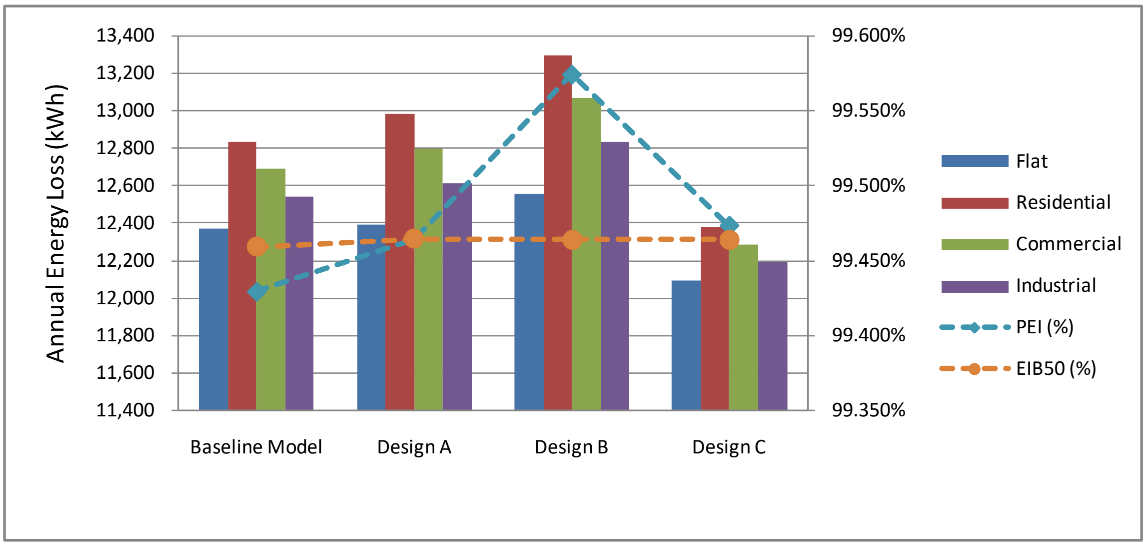


Figure 6-27: 500 kVA Per Unit Annual Energy Losses at 50% Load Factor in MEA's Networks compared with PEI and EI_{B50}

6.3.2.6.2 PEA Analysis

PEA has specified maximum no-load and load losses for procurement of its DTs, however the maximum losses requirements are higher than the IEC 60076-20 level 2 requirements in Table 4. In this report, three following designs of 160 kVA DTs with different no-load and load losses were developed for the analysis:

- **Design A:** a 160 kVA DT with level 2 maximum no-load and load losses as specified in Table 4 of IEC 60076-20. It should be noted that any DTs meeting the maximum no-load and load losses in Table 4 will also meet the EI_{B50} requirements specified in Table 6 of of IEC 60076-20;
- **Design B:** a 160 kVA DT with low no-load losses and high load losses and meeting the level 2 EI_{B50} requirement at 99.271% specified in Table 6 of of IEC 60076-20;

- **Design C:** a 160 kVA DT with high no-load losses and low load losses and meeting the level 2 EI_{B50} requirement at 99.271% specified in Table 6 of of IEC 60076-20.

Values of losses, PEI and EI_{B50} of the baseline model and the above three designs are shown in the below table. The load vs efficiency curves of the baseline model and these three designs are are shown in Figure 6-28.

Table 6-16: Loss and Efficiency Values of 160 kVA Distribution Transformer

Distribution Transformer	160 kVA, 50Hz, 22kV				
Efficiency Profile	No-Load Losses (W)	Load Losses (W)	Total Losses (W)	PEI (%)	EI_{B50}
Baseline Model	360	2,100	2,460	98.913%	98.964%
Design A	189	1,750	1,939	99.280%	99.271%
Design B	95	2,167	2,262	99.434%	99.271%
Design C	378	921	1,299	99.262%	99.271%

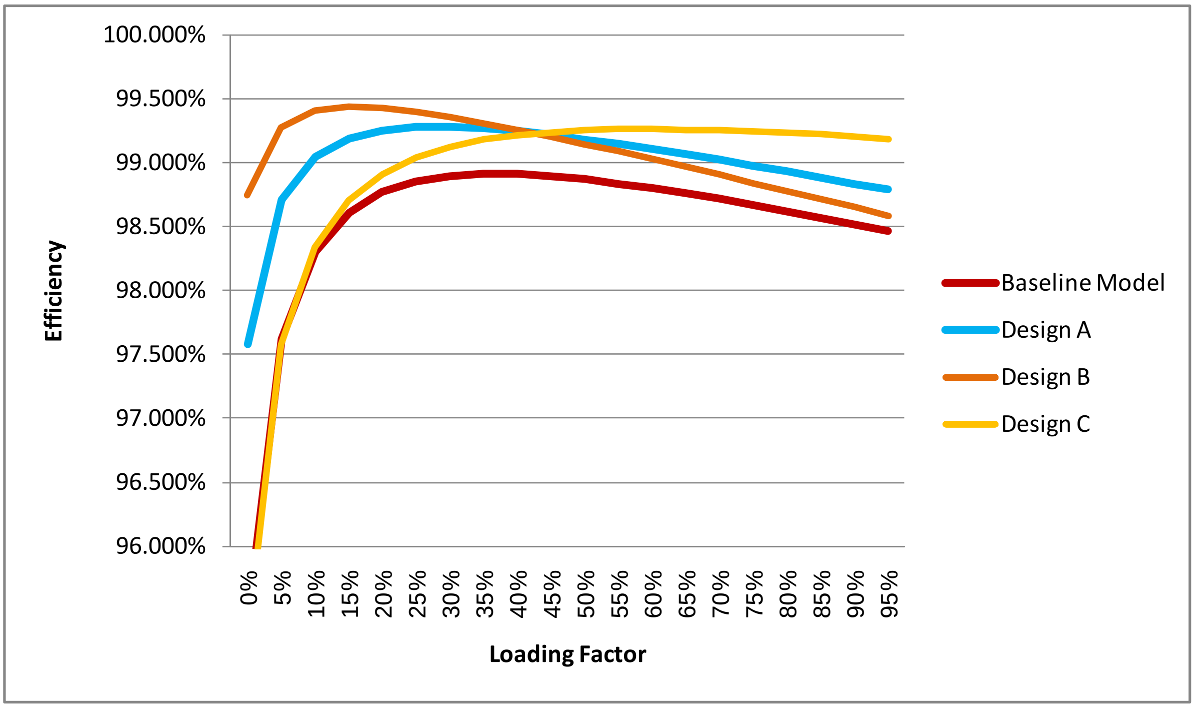


Figure 6-28: Load vs Efficiency Curves of 160 kVA Distribution Transformer

The analysis results summarized in Table 6-17 show that, under the typical daily load profiles and average annual load factor21 for different end-use sectors in PEA's network, PEA's maximum loss requirements for 160 kVA distribution tranformer deliver higher per unit annual energy losses in all scenarios when compared with the three designs that meet IEC 60076-20 requirements. At a lower average annual load factor of 50%, the analysis results show similar patterns as the average annual factors of the PEA's network. Shown in Figure 6-29 are per unit annual energy savings from adoption of IEC 60076-20 for 160 kVA three-phase 50Hz DTs in PEA's networks.

[21] Average annual loading factor at 73% for the commercial and industrial sector and 58% for residential sector

Table 6-17: Analysis of per Unit Annual Energy Losses of 160 kVA Distribution Transformer

Daily Load Profile	Average Load Factor (%)	Annual Energy Loss (kWh)			
		Baseline Model	Design A	Design B	Design C
Typical Average Annual Load Factor for PEA's Network @ 73%					
Flat	73%	12,957	9,825	10,944	7,610
Residential	58%	9,527	6,967	7,404	6,106
Commercial	73%	13,115	9,957	11,107	7,679
Industrial	73%	13,070	9,919	11,060	7,659
Low Average Annual Load Factor @ 50%					
Flat	50%	7,687	5,433	5,505	5,299
Residential	50%	7,978	5,676	5,806	5,427
Commercial	50%	7,881	5,595	5,706	5,384
Industrial	50%	7,778	5,510	5,600	5,339

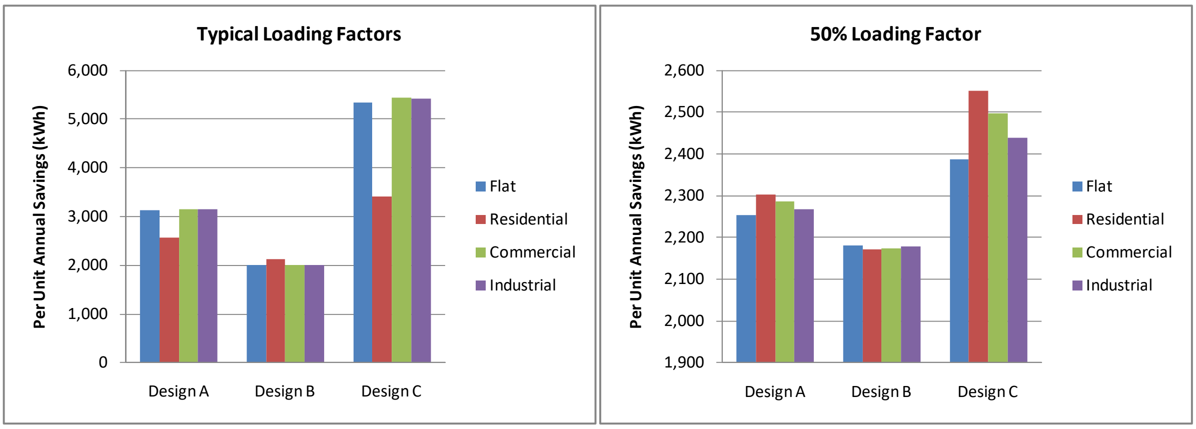


Figure 6-29: Per Unit Annual Energy Savings in kWh from Adoption of IEC 60076-20 in PEA's Networks

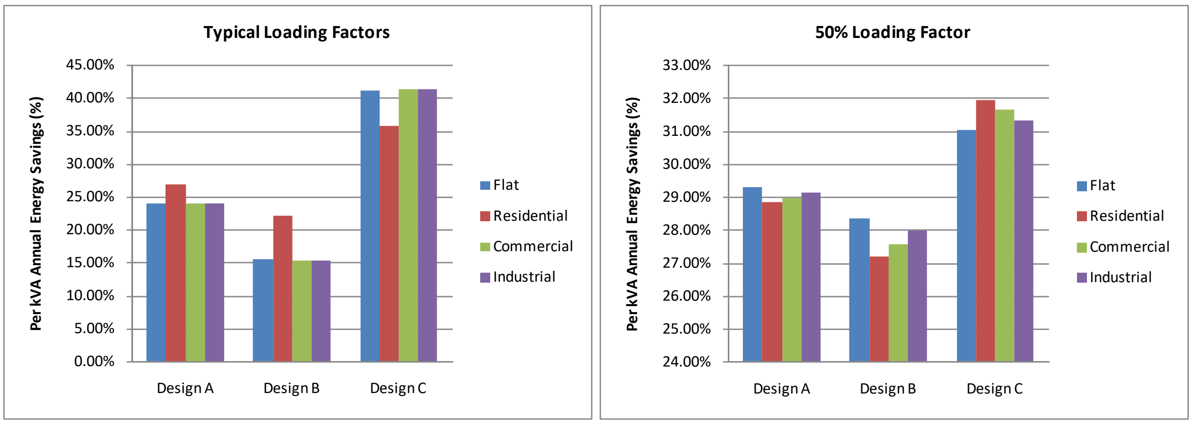


Figure 6-30: Per kVA Annual Energy Savings in % from Adoption of IEC 60076-20 in PEA's Networks

Shown in Figure 6-31 and Figure 6-32 are graphical illustration of per unit annual energy losses for different designs of a 160 kVA distribution transformer under different daily load profiles and average annual load factors. It can be seen for these two figures that PEI and EI_{B50} do not represent annual energy losses of a distribution transformer under different operating conditions.

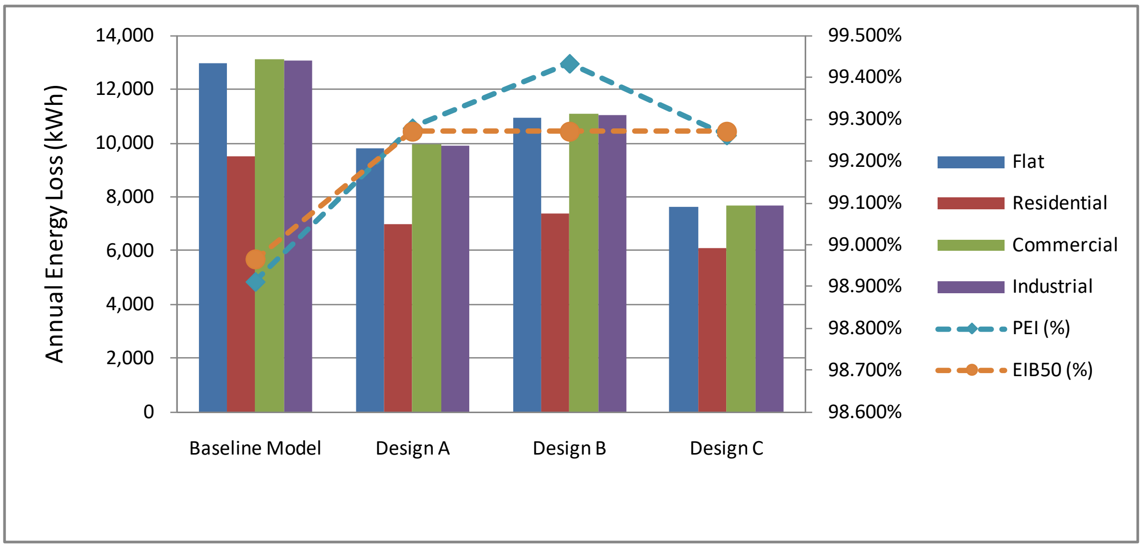


Figure 6-31: 160 kVA Per Unit Annual Energy Losses at Typical Load Factors in PEA's Networks compared with PEI and EI_{B50}

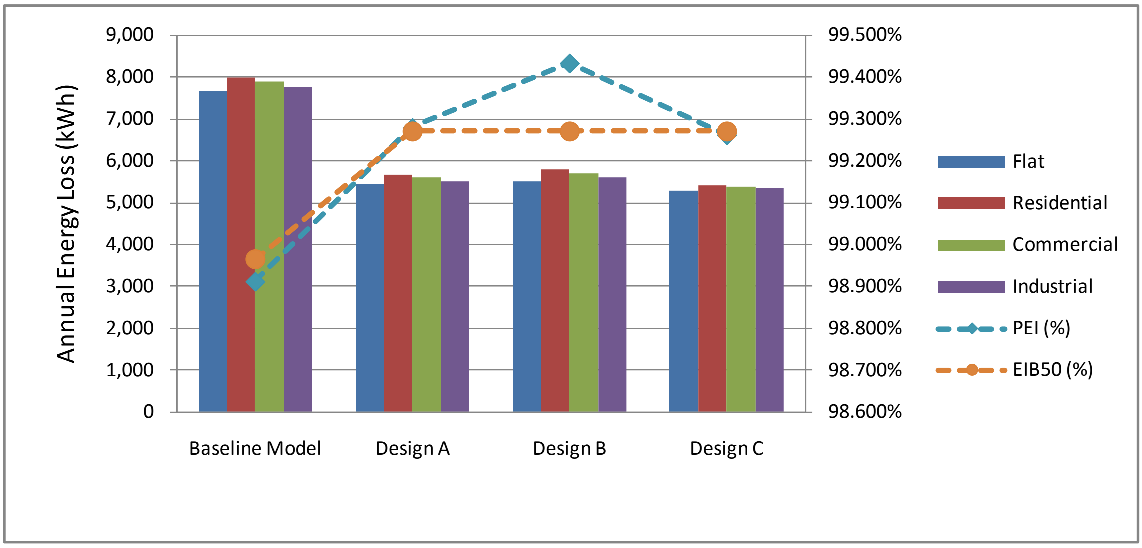


Figure 6-32: 160 kVA Per Unit Annual Energy Losses at 50% Load Factors in PEA's Networks compared with PEI and EI_{B50}

6.3.3 USA

6.3.3.1 Overview of the Power System

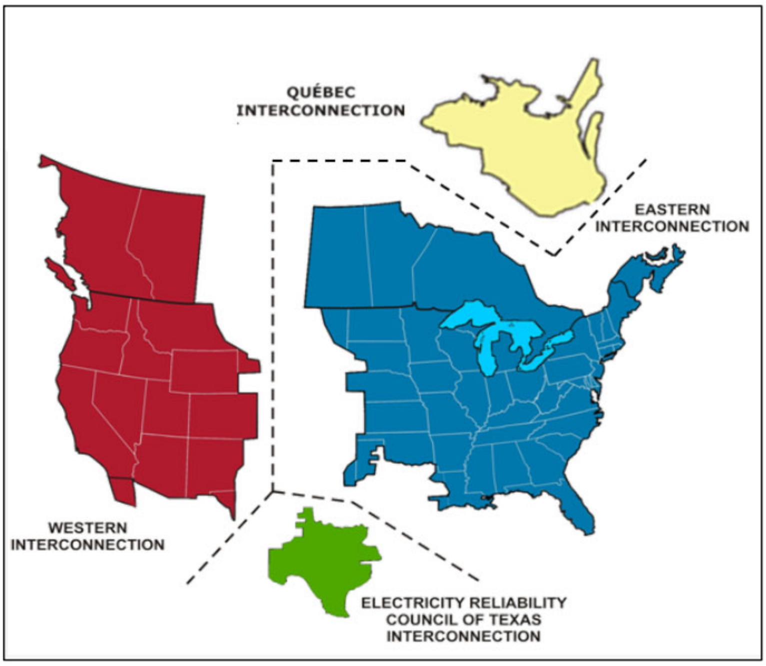
The electricity sector of the United States includes a large array of stakeholders that provide services through electricity generation, transmission, distribution and marketing for industrial, commercial, public and residential customers. It also includes many public institutions that regulate the sector. The Federal Energy Regulatory Commission (FERC) is an independent agency within the U.S. Department of Energy (DOE) that regulates the interstate transmission of electricity (as well as natural gas and oil) within the United States. The North American Electric Reliability Corporation (NERC) is a not-for-profit international regulatory authority whose objective is to ensure the reliability of the bulk power system in North America. In 2006, FERC designated NERC as the government's electrical reliability organization

(ERO), thereby granting NERC the power to oversee and regulate the electrical market according to certain reliability standards. Although NERC is the organization that audits power companies and levies fines for non-compliance, the authority behind NERC's decisions comes from FERC.

Based on the United States Electricity Industry Primer Report published by DOE in July 2015, there are more than 3,200 electric utilities in the US, serving over 145 million customers. There are various types of electric utilities in the US, including:

- **Investor-Owned Utilities (IOUs)** are for-profit companies owned by their shareholders. These utilities may have service territories in one or more States.
- **Public Power Utilities** (also known as "Municipals" or "Munis") are not-for-profit utilities owned by cities and counties. City-owned utilities are referred to as municipal utilities (munis). Universities and military bases can own and operate their own utilities.
- **Cooperatives (Co-Ops)** are not-for-profit entities owned by their members. They must have democratic governance and operate at cost.
- **Federal Power Programs** include the Bonneville Power Administration (BPA), the Tennessee Valley Authority (TVA), the Southeastern Power Administration (SWPA), the Southeastern Power Administration (SEPA), and the Western Area Power Administration (WAPA).
- **Independent Power Producers**, or sometimes called a non-utility generator, are privately owned businesses that own and operate their own generation assets and sell power to other utilities or directly to end users.

North America's power system consists of four distinct power grids, also called interconnections. The Eastern Interconnection includes the eastern two-thirds of the continental United States and Canada from the Great Plains to the Eastern Seaboard. The Western Interconnection includes the western one-third of the continental United States, the Canadian provinces of Alberta and British Columbia, and a portion of Baja California Norte in Mexico. The Texas Interconnection comprises most of the State of Texas, and the Canadian province of Quebec is the fourth North American interconnection. The grid systems in Hawaii and Alaska are not connected to the grids in the lower 48 states.

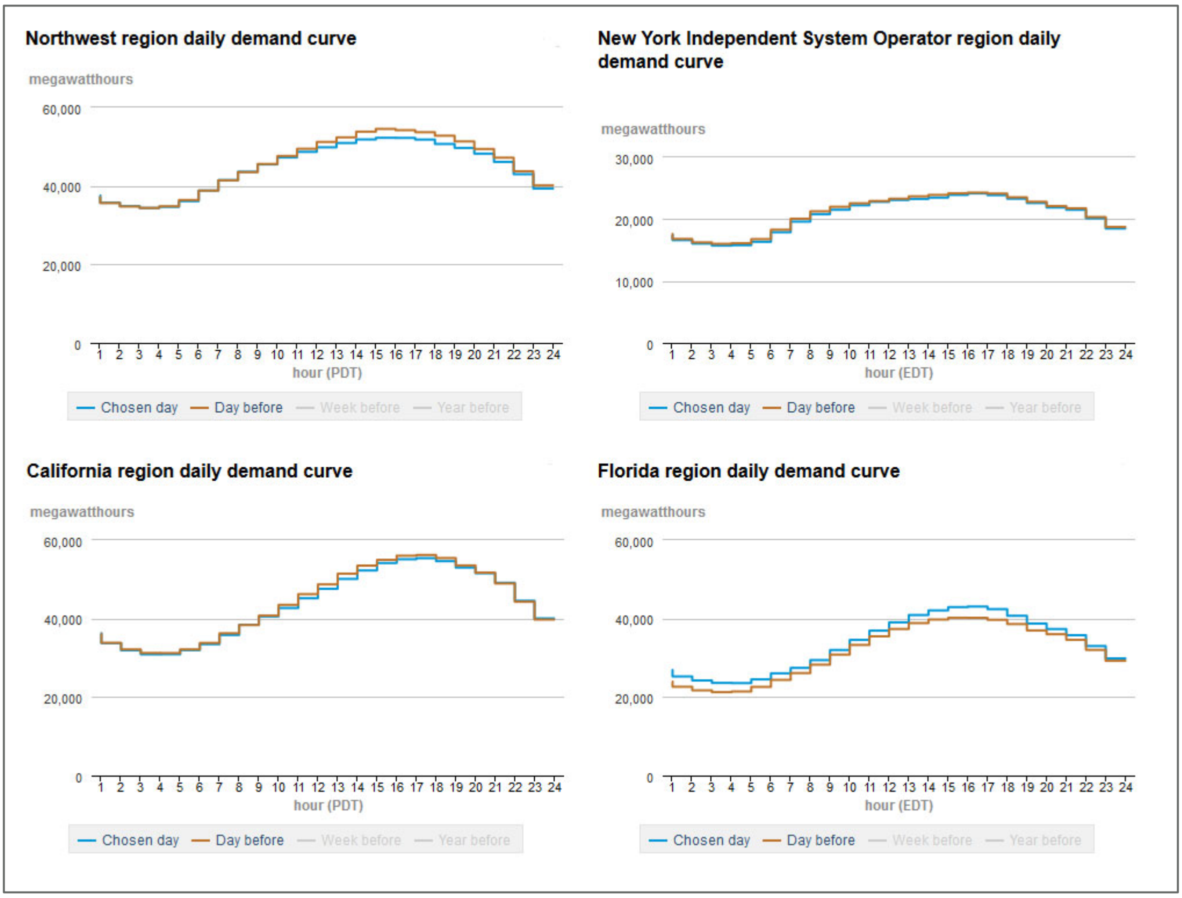


Source: The United States Electricity Industry Primer Report, DOE, July 2015

Figure 6-33: Map of Four North American Power Grid Interconnections

6.3.3.2 Demand Characteristics

Electricity consumption data based on data from the US DOE Energy Information Administration shows that in 2015 the total US consumption of electric energy was 4,144.3 TWh. The residential sector consumed about 34% of the total consumption, followed by the commercial sector at 33% and the industrial sector at 24%. The remaining consumptions were met by other end-uses, such as transportation, etc. The U.S. Energy Information Administration (EIA) estimates that electricity transmission and distribution losses average about 5% of the electricity that is transmitted and distributed annually in the United States[22]. Considering a large geographical coverage and different climatic conditions, daily demand curves in different regions in the US are shown in Figure 6-34.



Source: U.S. Energy Information Administration

Figure 6-34: Daily Demand Curves on June 21, 2017

Based on data compiled by this study, average annual load factors of residential, commercial and industrial end-uses in PG&E's networks in California in 2006 were about 40%, 60% and 70% respectively. Load factors during the peak month were about 5% to 8% higher than the annual load factors. Detailed data on daily load profiles of different end-use sectors within PG&E's service areas is not available, however daily load profiles of PG&E's single-phase distribution transformers supplying residential customers shows two salient peaks, morning (around 6-8am) and evening (around 5-7pm), as shown in Figure 6-35. Daily load profiles of commercial and industrial customers based on loading of three-phase distribution transformers supplying customers in these sectors in the PG&E system are relative flat, as shown in Figure 6-36.

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[22] https://www.eia.gov/tools/faqs/faq.php?id=105&t=3

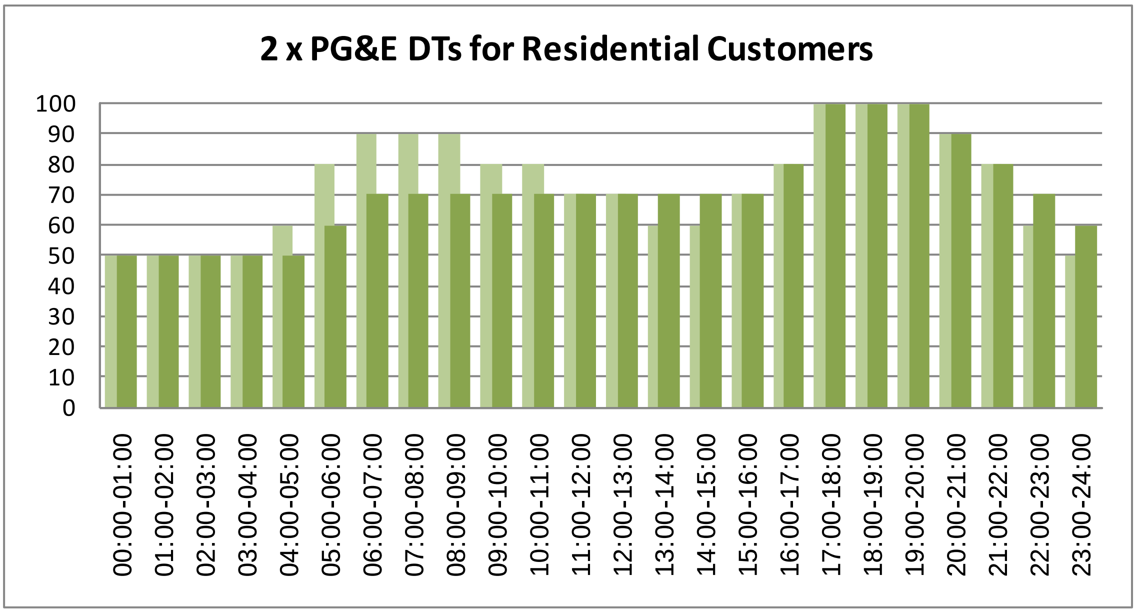


Figure 6-35: Residential Load Profile supplied by PG&E's 1-Phase Distribution Transformers

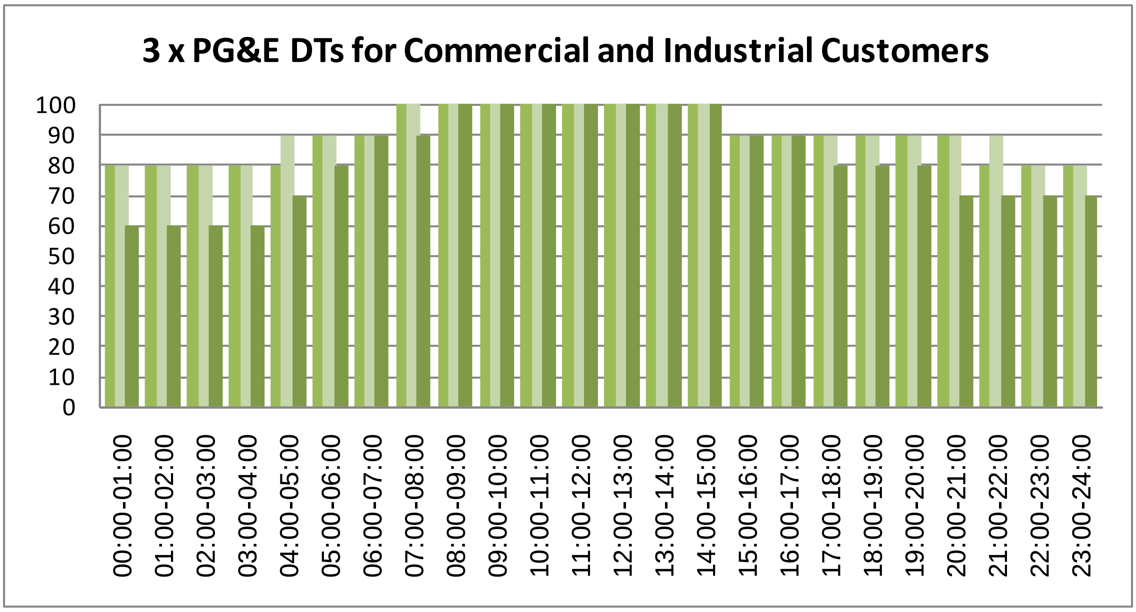


Figure 6-36: Commercial and Industrial Load Profile supplied by PG&E's 3-Phase Distribution Transformers

6.3.3.3 Efficiency Standard for Distribution Transformers

The United States has been working on the improvement of high-efficiency distribution transformers for over 20 years. The US Department of Energy (DOE) has been regulating the energy efficiency level of low voltage dry-type DTs since 2002, when the US Congress adopted the National Electrical Manufacturers Association (NEMA) standards (NEMA TP-1-2002) as mandatory efficiency requirements for low-voltage dry-type distribution transformers. This standard was later extended to liquid-immersed and medium-voltage dry-type distribution transformers in 2010. In 2011, DOE initiated work on reviewing its MEPS on distribution transformers, including all three groups – liquid-immersed, low-voltage dry-type and medium-voltage dry-type transformers. In 2013, DOE completed this process and published the new efficiency requirements in the Code of Federal Regulations at 10 CFR 431.196, and the new requirements for liquid-immersed distribution transformers which have been effective since January 1st, 2016 are summarized in Table 6-18.

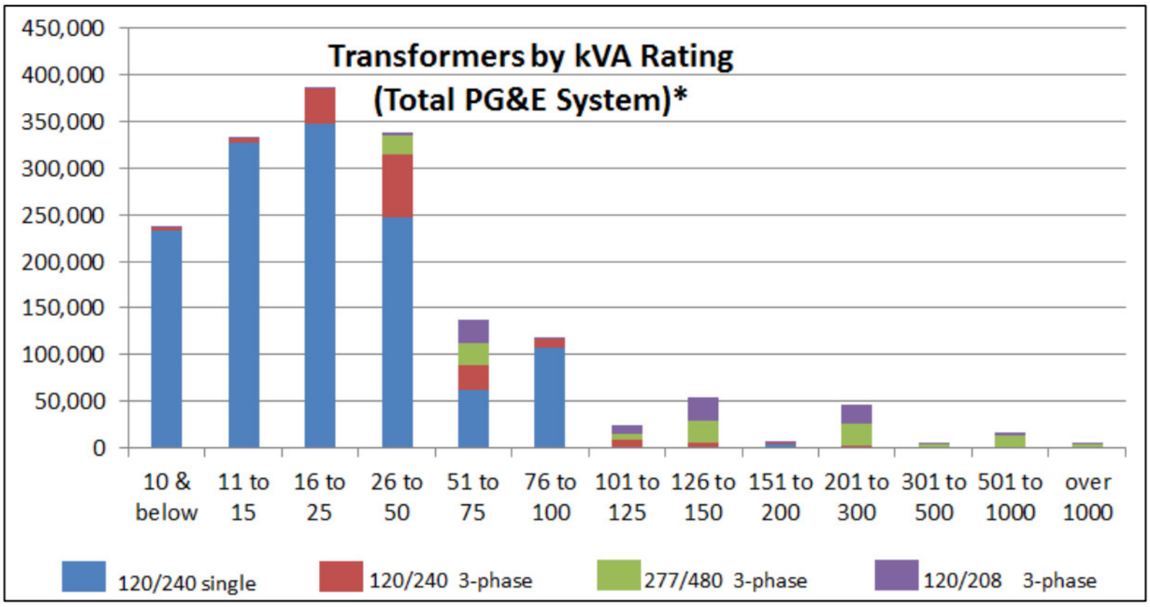
Table 6-18: Minimum Efficiency Values for Liquid-Immersed Distribution Transformers (DOE, 2016)

Single-Phase		Three-Phase	
Rating (kVA)	**Efficiency (%)**	**Rating (kVA)**	**Efficiency (%)**
10	98.70%	**15**	98.65%
15	98.82%	**30**	98.83%
25	98.95%	**45**	98.92%
37.5	99.05%	**75**	99.03%
50	99.11%	**112.5**	99.11%
75	99.19%	**150**	99.16%
100	99.25%	**225**	99.23%
167	99.33%	**300**	99.27%
250	99.39%	**500**	99.35%
333	99.43%	**750**	99.40%
500	99.49%	**1,000**	99.43%
667	99.52%	**1,500**	99.48%
833	99.55%	**2,000**	99.51%
		2,500	99.53%

Any liquid-immersed distribution transformers with kVA ratings not appearing in the table shall have their minimum efficiency level determined by linear interpolation of the kVA and efficiency values immediately above and below that kVA rating. Note that all efficiency values are at 50 percent of name plate rated load, determined according to the DOE Test Method for Measuring the Energy Consumption of Distribution Transformers under Appendix A to Subpart K of 10 CFR part 431, in which the efficiency calculation method is in line with Method B specified in IEC 60076-20.

6.3.3.4 Distribution Transformer Stock and Market

The previous APEC study on Energy Efficiency Potential for Distribution Transformers in the APEC Economies published in 2013 estimated the total distribution transformer stock in the US at 31.6 million units and annual sales at about 780,000 units. More up-to-date data on the distribution transformer stock in the US is not available, however a PG&E report issued in December 2016 provides information on distribution transformers installed in PG&E system, as shown in Figure 6-37. It is estimated that the PG&E system has around 1.7 million distribution transformers installed with an aggregated capacity of around 186,000 MVA. The most popular kVA rating in terms of units installed is between 16 to 25 kVA.



Source: Electric Program Investment Charge (EPIC), PG&E, December 2016

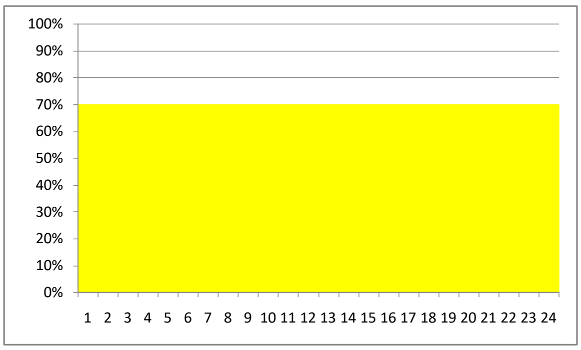
Figure 6-37: Distribution Transformers installed in the PG&E System

6.3.3.5 Baseline and Estimation of Per Unit Annual Energy Losses

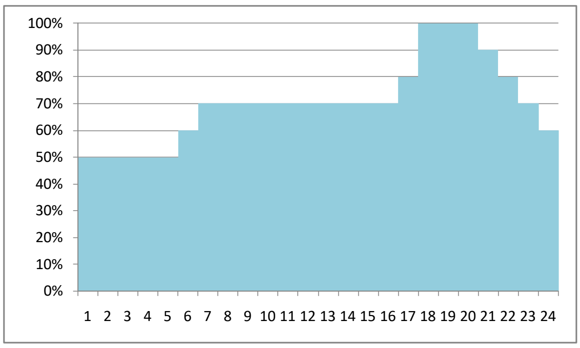
Analysis of baseline energy losses in this report focus on annual energy losses by the most common kVA rating in the PG&E system, i.e., 25 kVA single-phase distribution transformer. Considering that the new MEPS for liquid-immersed distribution transformers has recently been effective since January 1st, 2016, the baseline efficiency levels of distribution transformers in the US in this report are based on the DOE 2010 MEPS which specifies EI_{B50} for 25 kVA single-phase distribution transformer at 98.91%.

The analysis model in this report uses no-load and load losses to estimate annual energy losses in kWh at different daily load profiles and also load factors. Distribution transformer designers have multiple choices to design transformers to meet the same EI_{B50} efficiency level but performing differently at light and heavy loading. No-load and load losses of the baseline 25 kVA model in this report were determined using a typical load-efficiency curve of a distribution transformer per NEMA TP-1, and no-load losses of 70W and load losses of 298W which deliver the efficiency of 98.91% at 50% loading were referenced in the analysis.

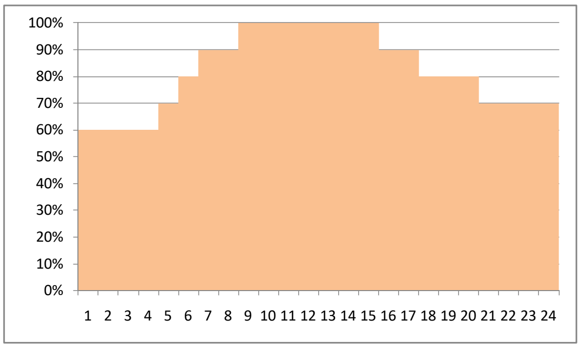
Data on daily load profiles of different end-use sector obtained from PG&E was used to construct different daily load profilesfor the analysis, as shown in Figure 6-38.



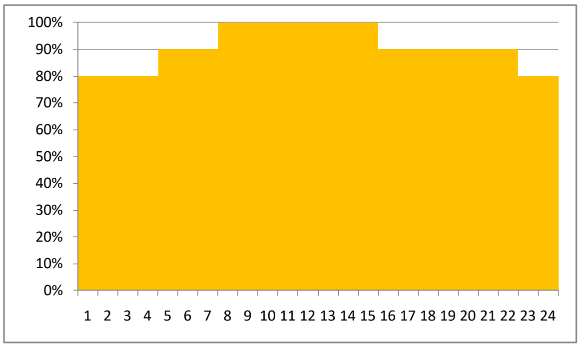
Load Profile: Flat;
Maximum Load Factor: 70%



Load Profile: Residential (evening peak);
Maximum Load Factor: 70%



Load Profile: Commerical (daytime peak);
Maximum Load Factor: 82%



Load Profile: Industrial (morning & afternoon peaks);
Maximum Load Factor: 91%

Figure 6-38: Different Daily Load Profiles for the US Baseline Analysis

The analyses under different daily load profiles of various end-uses as shown in Section 3.4.2 were undertaken. The analysis results for 25 kVA single-phase distribution transformer are shown in the table below Based on the analysis at 50% load factor, variations of baseline annual energy losses due to diversity of load profles in the US range from 1,258 kWh (for the flat load profile) to 1,296 kWh (for the residential load profile).

Table 6-19: Per Unit Baseline Annual Energy Losses of 25 kVA Single-Phase Distribution Transformer

Daily Load Profile	Average Load Factor (%)	Baseline Annual Energy Loss (kWh)	Average Load Factor (%)	Baseline Annual Energy Loss (kWh)
Flat	70%	1,892	50%	1,258
Residential	40%	1,053	50%	1,296
Commercial	60%	1,581	50%	1,289
Industrial	70%	1,899	50%	1,269

6.3.3.6 Estimation of IEC 60076-20 Scenario

Analysis of annual energy losses from adoption of IEC 60076-20 requirements specified in Table 5 which are equivalent to DOE 2016 MEPS follows the similar approach previously discussed in the US baseline section. In this report, three following designs of 25 kVA DTs with different no-load and load losses but meeting the EI_{B50} level 2 requirement for 25 kVA at 98.95%, were developed for the analysis:

- **Design A:** a 25 kVA DT with medium levels of no-load and load losses and the total losses is in between Design B and C;
- **Design B:** a 25 kVA DT with low no-load losses and high load losses and the highest total losses compared with other designs;
- **Design C:** a 25 kVA DT with high no-load losses and low load losses and the lowest total losses compared with other designs.

Values of losses, PEI and EI_{B50} of the baseline model and the above three designs are shown in Table 6-20. The load vs efficiency curves of the baseline model and these three designs are are shown in Figure 6-39.

Table 6-20: Loss and Efficiency Values of 25 kVA Distribution Transformer

Distribution Transformer	25 kVA, Single-Phase, 60Hz				
Efficiency Profile	No-Load Losses (W)	Load Losses (W)	Total Losses (W)	PEI (%)	EI_{B50}
Baseline Model	70	298	368	98.844%	98.91%
Design A	66	293	359	98.886%	98.95%
Design B	18	502	520	99.229%	98.95%
Design C	75	255	330	98.896%	98.95%

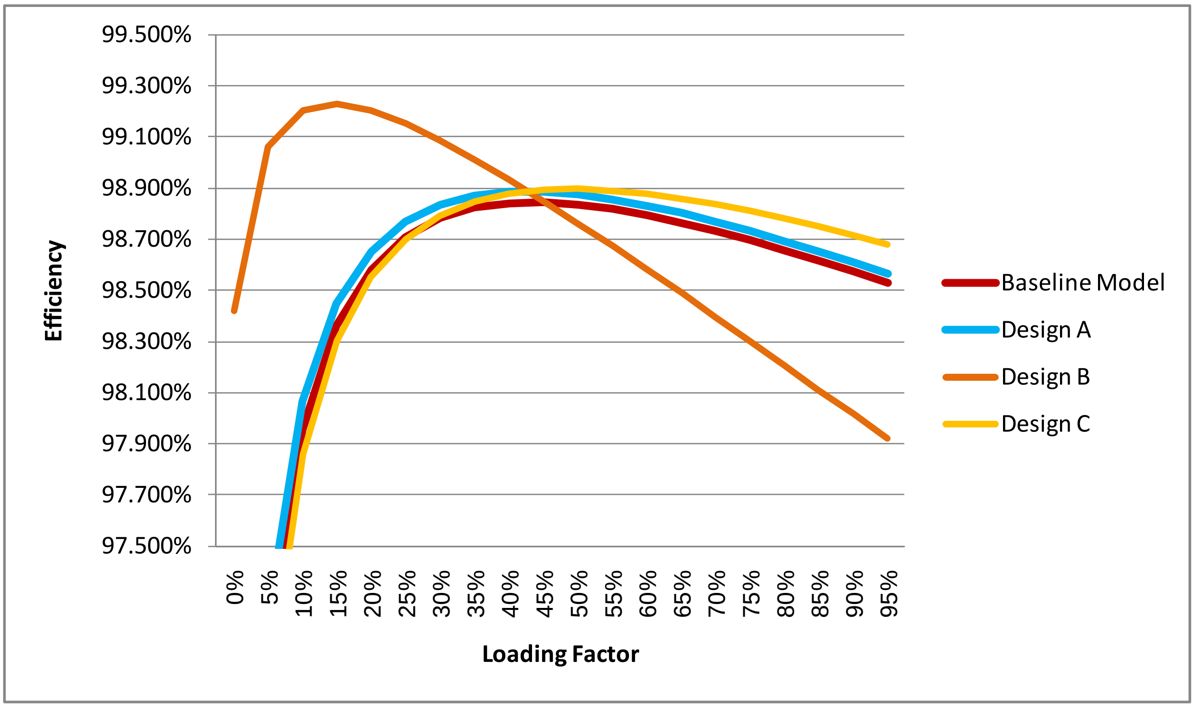


Figure 6-39: Load vs Efficiency Curves of 25 kVA Distribution Transformer

The analysis results on replacing the baseline model with the three designs, as summarized in Table 6-21, show that, *under the typical daily load profiles and average annual load factors for different end-use sectors in the PG&E systems, Design A and C deliver lower per unit annual energy losses. Although Design B has higher PEI and EI_{B50} than the baseline model, it delivers higher per unit annual energy losses than the baseline model, except for the residential sector due to its low load factor of 40%.* At an average annual load factor of 50%, the Design A and C models deliver lower energy savings while the Design B model become more comparable to the baseline model in terms of annual energy losses. Shown in Figure 6-40 are per unit annual energy savings from adoption of IEC 60076-20 EI_{B50} level 2 for 25 kVA single-phase 60Hz DTs in the PG&E's systems.

Table 6-21: Analysis of per Unit Annual Energy Losses of 500 kVA Distribution Transformer

Daily Load Profile	Average Load Factor (%)	Annual Energy Loss (kWh)			
		Baseline (DOE 2010)	EI_{B50} Level 2 (DOE 2016) – Medium Total Losses Design	EI_{B50} Level 2 – Low NL/ High LL (High Total Losses)	EI_{B50} Level 2 – High NL/ Low LL (Low Total Losses)
Typical Average Annual Load Factor for PG&E's System					
Flat	70%	1,892	1,836	2,316	1,749
Residential	40%	1,053	1,011	903	1,030
Commercial	60%	1,581	1,529	1,791	1,482
Industrial	70%	1,899	1,843	2,327	1,755
Low Average Annual Load Factor @ 50%					
Flat	50%	1,258	1,212	1,248	1,206
Residential	50%	1,296	1,249	1,311	1,238
Commercial	50%	1,289	1,242	1,299	1,232
Industrial	50%	1,269	1,223	1,267	1,215

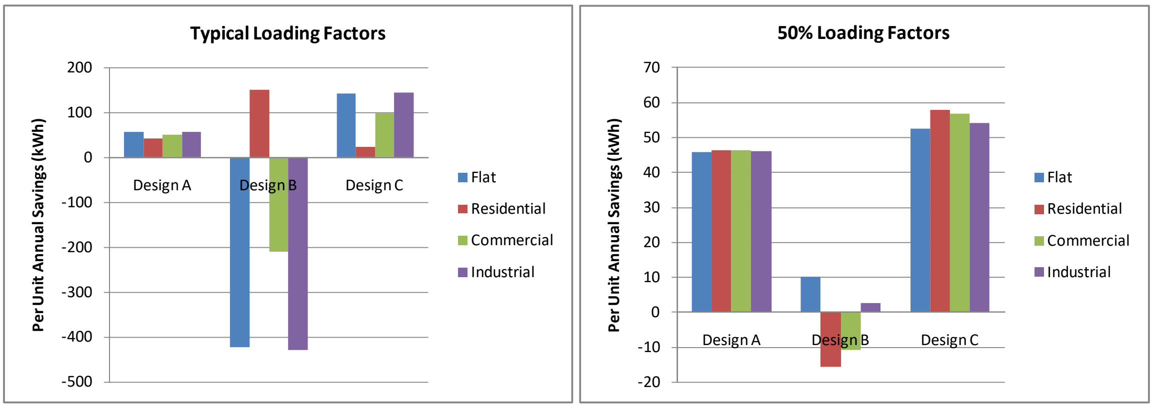


Figure 6-40: Per Unit Annual Energy Savings in kWh from Adoption of IEC 60076-20/DOE 2016 in PG&E's Systems

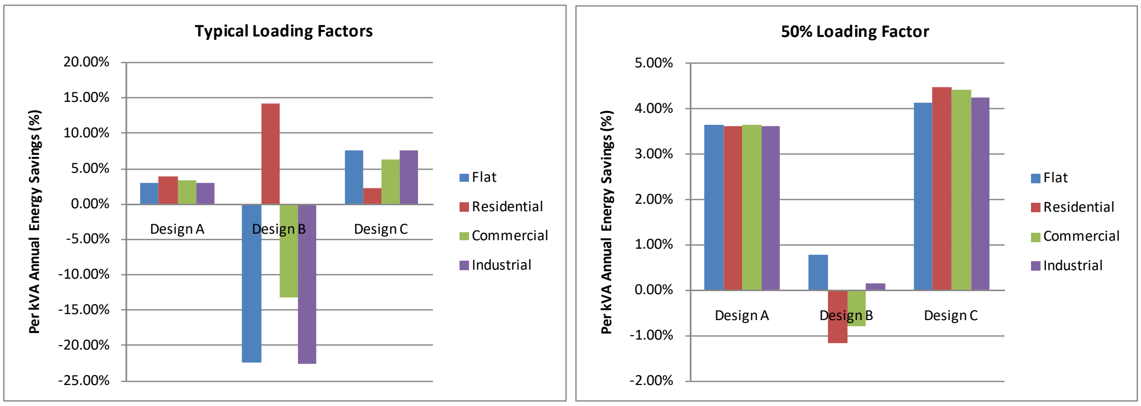


Figure 6-41: Per kVA Annual Energy Savings in % from Adoption of IEC 60076-20/DOE 2016 in PG&E's Systems

Shown in Figure 6-42 and Figure 6-43 are graphical illustration of per unit annual energy losses for different designs of a 25 kVA distribution transformer under different daily load profiles and average annual load factors. It can be seen from **Error! Reference source not found.** that PEI and EI_{B50} do not represent levels of annual energy losses of a distribution transformer under different operating conditions.

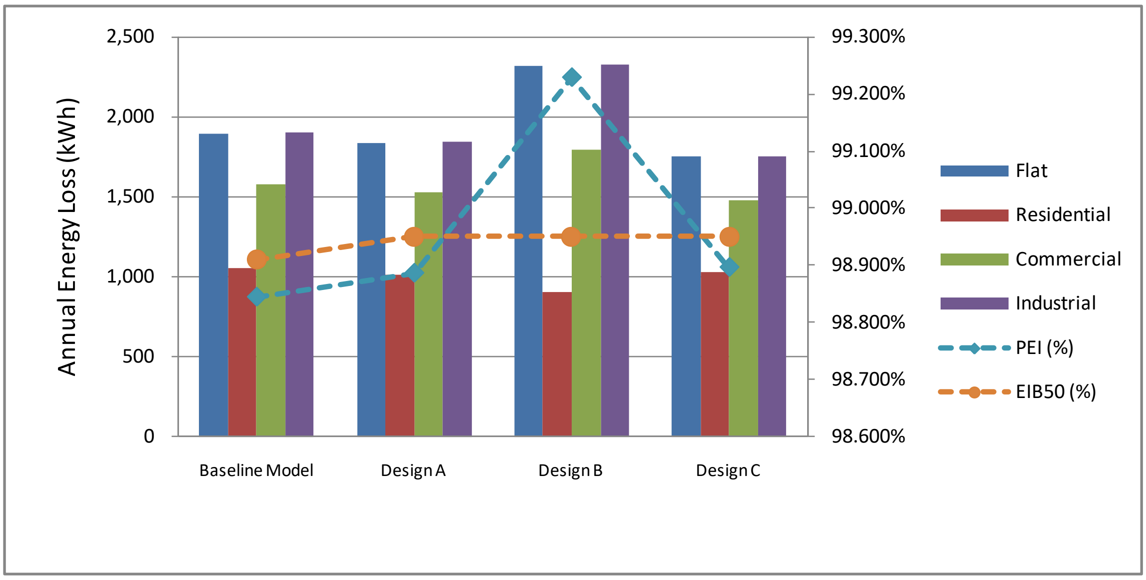


Figure 6-42: Comparison of 25 kVA Per Unit Annual Energy Losses at Typical Load Factors in PG&E's System

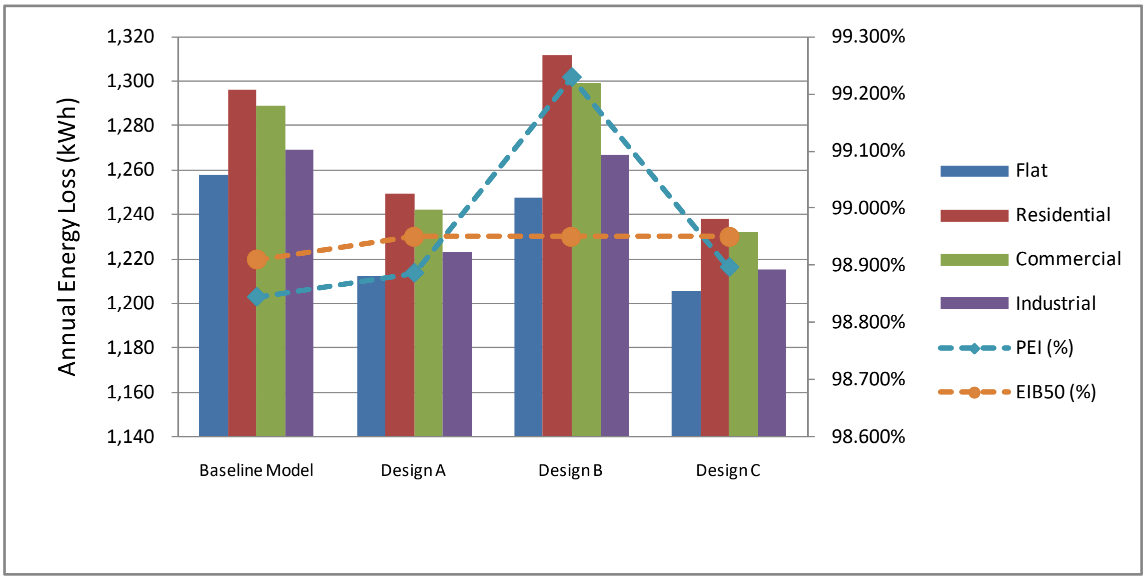


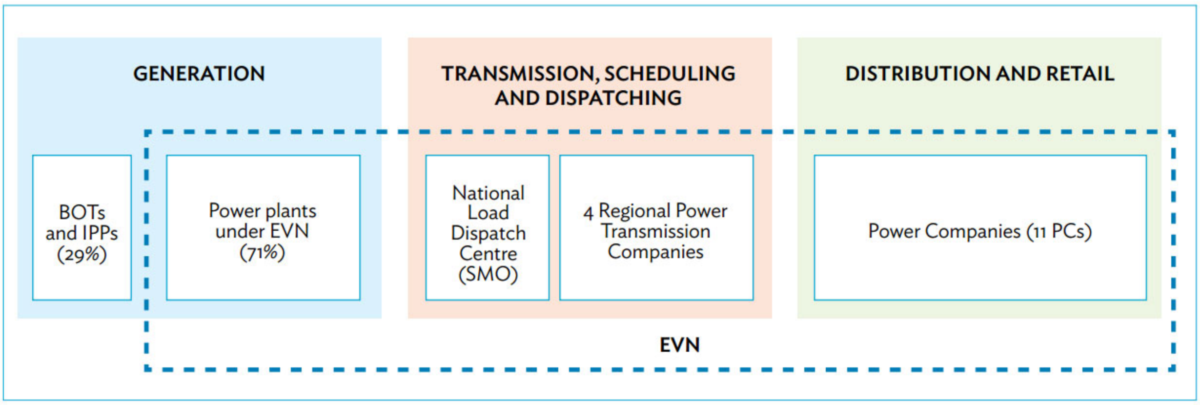
Figure 6-43: Comparison of 25 kVA Per Unit Annual Energy Losses at 50% Load Factor in PG&E's System

6.3.4 Viet Nam

6.3.4.1 Overview of the Power System

Before 1995, the power sector of Viet Nam was government-owned, with the Ministry of Energy managing three regional power companies, each responsible for generation, transmission and distribution within its own territory. The first stage of reform began in 1995 when these regional power companies were merged into a single monopoly power company, Electricity of Viet Nam (EVN, now known as Viet Nam Electricity). EVN was partially restructured in 2003, selecting some generation and distribution assets for partial privatization, a process referred to as equitization.

The power sector reforms in Viet Nam formally commenced in July 2005 when the Electricity Law of 2004 came into force. Under the reform program, the National Power Transmission Corporation (NPT) was established in 2008. The EVN's four transmission companies and three power grid management boards were reorganized to form the NPT, a 100% EVN-owned entity, which was made responsible for managing the power transmission grid. In 2010, the existing 11 regional power distribution companies in Viet Nam were reorganized into five power distribution corporations under EVN[23], responsible for supplying power and for the maintenance of the distribution grid up to 110kV in the five following areas: North, Central, South, Hanoi, and Ho Chi Minh City. In 2012, the estimated T&D losses were about 8.9%.



BOT = build-operate-transfer, EVN = Viet Nam Electricity, IPP = independent power producer, SMO = system and market operator.
Source: Assessment of Power sector reforms in Viet Nam, Country Report, ADB, 2015

Figure 6-44: Structure of the Power Sector in Viet Nam

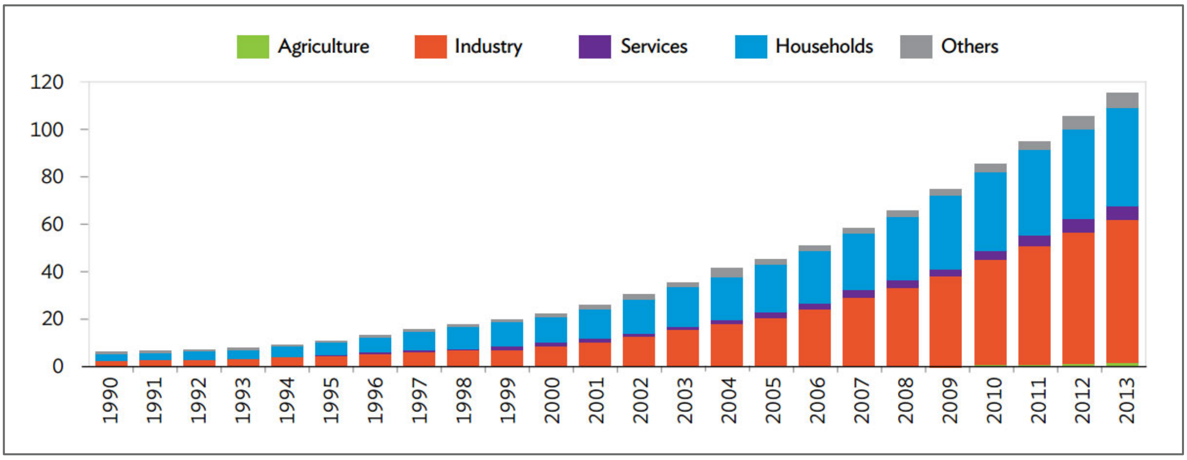
In 2012, the generation side of EVN was reorganized into three power generation companies. Each of these three power generation companies was to operate within a holding company structure but the goal is to fully separate these companies from EVN once the competitive wholesale market commences. Viet Nam has a clear Road Map for power reform that starts with a single buyer for power, proceeds to a competitive wholesale market, then finally towards a competitive retail market. It originally envisioned an initial pilot stage with limited competition amongst selected state-owned generators with a single buyer by 2009, a competitive wholesale market by 2017, and a competitive retail market by 2023. This schedule has encountered some delays and the pilot competitive generation market started only in 2012.

6.3.4.2 Demand Characteristics

The total electricity consumption in Viet Nam was 115 TWh in 2013. The residential sector had been the largest end-use sector consuming almost half of the economy-wide electricity consumption until 2004 when the industrial sector has become the largest consuming sector in Viet Nam. In 2013, the

[23] Northern Power Corporation (EVNNPC), Central Power Corporation (EVNCPC), Southern Power Corporation (EVNSPC), Hanoi Power Corporation (EVNHANOI), the Ho Chi Minh City Power Corporation (EVNHCMC)

industrial sector consumed about 53% of the total consumption, followed by the residential sector at about 36% and the remaining consumptions were met by other end-uses, such as services, agriculture, etc.



Source: Assessment of Power sector reforms in Viet Nam, Country Report, ADB, 2015

Figure 6-45: Electricity Consumption in Viet Nam, 1990 – 2013

In terms of annual electricity by the power distribution corporations under EVN, the Southern Power Corporation (EVNSPC) occupied the largest share of 35% in 2013, followed by the Northern Power Corporation (EVNNPC) at 30%. Ho Chi Minh City appeared to be the largest consuming city in Viet Nam with15% share of the total electricity consumption in 2013, as shown in Figure 6-46.

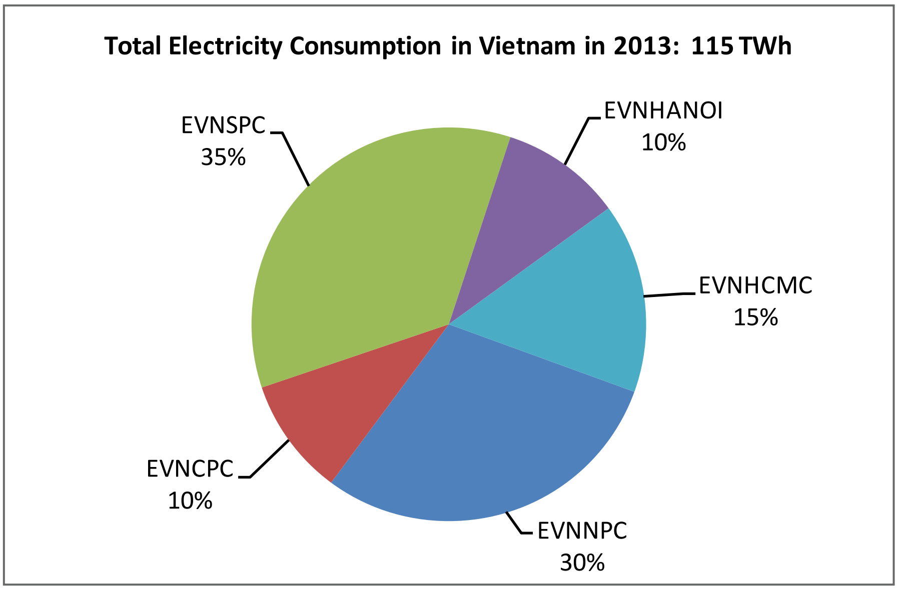
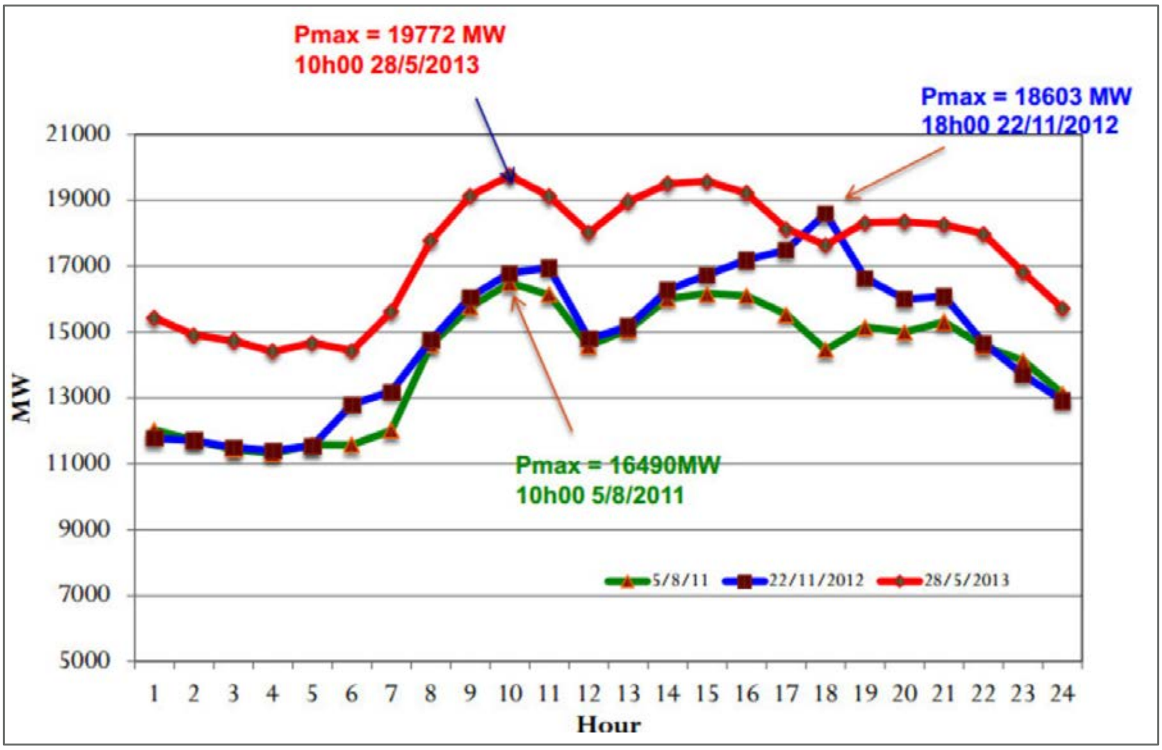


Figure 6-46: Share of Annual Electricity Consumption in Viet Nam in 2013 by EVN Power Corporation

Data on average annual load factors of residential, commercial and industrial end-uses in Viet Nam is not available. However the system daily load profiles of EVN in 2013, as shown in Figure 6-47, show three distinct peaks, morning (around 9-10am), afternoon (around 3pm) and evening (around 7-9pm). Load factor estimated using the 2013 system profile is about 88%.



Source: EVN Smart Grid Plan Presentation, Nguyen Hai Ha, Frankfurt, November 2013

Figure 6-47: EVN System Daily Load Profiles in 2011, 2012 and 2013

6.3.4.3 Distribution Transformer Stock and Market

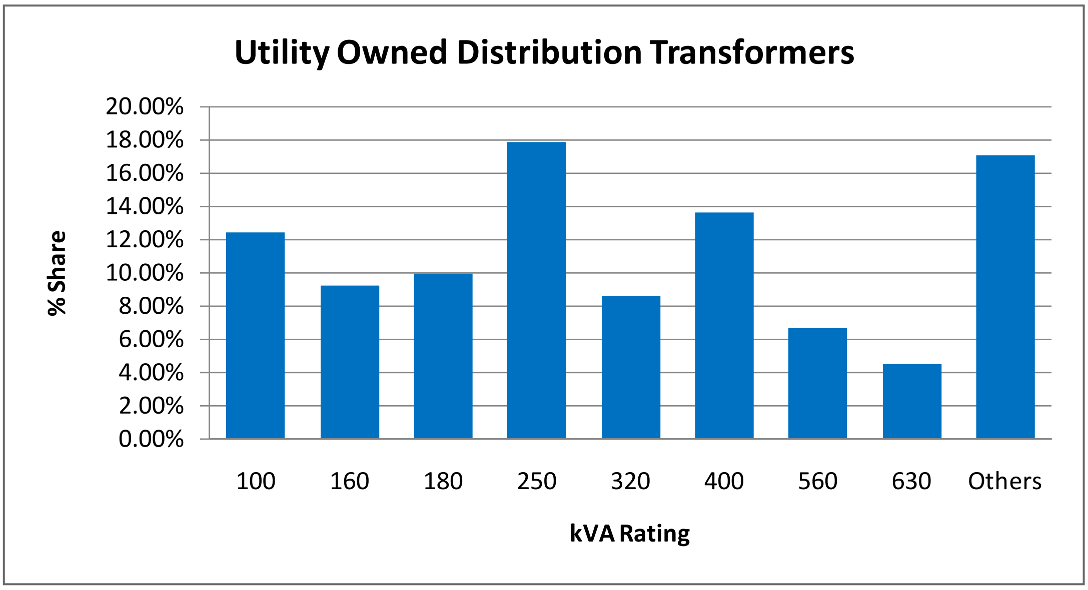
Based on the Market Study for Utility Distribution Transformer - Viet Nam, commissioned by ICA in 2015, utility owned DTs are liquid-immersed DTs. In the past, distribution networks in Viet Nam are quite complex due to diversity of medium voltage lines, including 8 kV, 15 kV, 22 kV, 35 kV and 66 kV. EVN has been working to standardize all medium voltage lines to 22 kV. As a result, EVN has gradually replaced old DTs with new 22 kV DTs since 2008. The ICA study estimated the total DT stock in Viet Nam in 2014 at about 110,000 MVA. Privately owned DTs accounted for a larger share of about 64% or about 70,000 MVA. The utility owned DT stock in 2014 was about 260,000 units with a total installed capacity of 41,015 MVA, as detailed in Table 6-22.

Table 6-22: Utility Owned Distribution Transformer Stock in Viet Nam, 2014

Utility Owned DT Stock (2014)	EVNNPC	EVNCPC	EVNSPC	EVNHANOI	EVNHCMC	Total
Unit Installed	35,997	19,903	174,139	9,345	22,259	**261,643**
	14%	8%	67%	4%	9%	100%
Installed Capacity (MVA)	7,604	3,873	21,182	4,150	4,206	**41,015**
	19%	9%	52%	10%	10%	100%

Source: Market Study for Utility Distribution Transformer - Viet Nam, ICA, 2015

The ICA study also reported that the most popular kVA rating in Viet Nam in terms of units installed is 250 kVA three-phase DTs.



Source: Market Study for Utility Distribution Transformer - Viet Nam, ICA, 2015

Figure 6-48: Profile of Utility Owned Distribution Transformers in Viet Nam, 2014

6.3.4.4 Efficiency Standard for Distribution Transformers

The Vietnamese standards (abbreviated as "TCVN") for DTs generally follow IEC 60076 series. Viet Nam has also promulgated minimum energy performance standards for DTs as specified in TCVN 8525:2015 which superseded the previous edition promulgated in 2010. TCVN 8525:2015 references EI_{B50} as MEPS levels for both liquid-immersed and dry-type DTs with kVA rating up to 4,000 kVA and rated voltage up to 35 kV, however the EI_{B50} values specified for most kVA rating of liquid-immersed DTs, as shown in the table below, are lower than the basic EI_{B50} value (level 1) for liquid-immersed 50Hz DTs specified in IEC 60076-20: Table 6. In other words, the MEPS requirements in Viet Nam are less stringent compared with IEC 60076-20.

Table 6-23: MEPS for Liquid-Immersed Distribution Transformers in Viet Nam (Table 1, TCVN 8525:2015)

kVA Rating	Minimum Energy Performance Standard, MEPS (%)	kVA Rating	Minimum Energy Performance Standard, MEPS (%)
25	98.40	**560**	99.22
31,5/32	98.50	**630**	99.26
50	98.66	**750**	99.28
75	98.77	**800**	99.30
100	98.87	**1,000**	99.32
125	98.92	**1,250**	99.35
160	98.97	**1,500**	99.37
180	99.01	**1,600**	99.39
200	99.06	**2,000**	99.41
250	99.10	**2,500**	99.42
315/320	99.16	**3,000**	99.44
400	99.19	**3,200**	99.46
500	99.21	**3,500**	99.48
		4,000	99.50

Source: TCVN 8525:2015

In addition to TCVN 8525, each EVN power distribution corporation has specified its own maximum no-load and load losses for DTs as summarized in the table below. Although these maximum losses requirements are not harmonized, they can be broadly categorized into three groups, i.e. the maximum losses requirements referenced by: 1) EVNHANOI; 2) EVNNPC and EVNCPC; and 3) EVNSPC and EVNHCMC.

Table 6-24: Maximum Losses Requirements of EVN Power Distribution Corporations

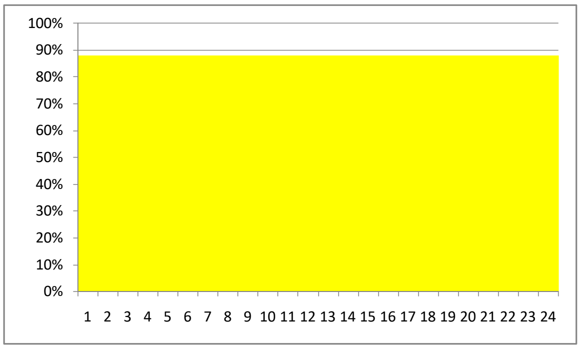
Capacity kVA	No Load loss Po (W)					Load loss Pk @ 75oC (W)				
	HCM	HN	SPC	CPC	NPC* (TCVN)	HCM	HN	SPC	CPC	NPC* (TCVN)
31.5				110					500	
50				190					1000	
75				270					1400	
100			205	330				1258	1750	
160	280		280	510		1940		1940	2350	
180	309	375	315	510	530	2202	1790	2185	2350	2575
250	340	490	340	550	700	2600	2275	2600	3250	3250
320	390	505	390	720	720	3330	2730	3330	3900	3900
400	450	630	433	900	900	4200	3220	3818	4600	4600
560	580	800	580	1000	1140	4810	4310	4810	5500	6160
630	787	910	787	1300	1300	5570	4550	5570	6500	6500
750	855	1010	855	1300	1350	6725	5800	6725	11000	8750
800	880		880	1300		6920		6920	11000	
1000	980	1190	980	1700	1700	8550	8400	8550	12000	12000
1250	1020	1260	1020	1700	1800	10690	9800	10690	12000	14000
1500	1305	1500	1223	2200	2250	13680	10800	12825	16000	16000
1600	1305		1305	2200		13680		13680	16000	
2000	1500	1960	1500	2800	2800	17100	14000	17100	20000	20000
2500	2870	2450	2870	3500	3500	21740	15400	21740	22000	22000
3000		2800	3440	4200	4000		17730	27660	28000	25330
3200			3680	4200				28620	28000	
3500		3150	3920		4500		20060	29580		28670
4000		3500	4400		5000		22400	31500		32000

Source: Market Study for Utility Distribution Transformer - Viet Nam, ICA, 2015

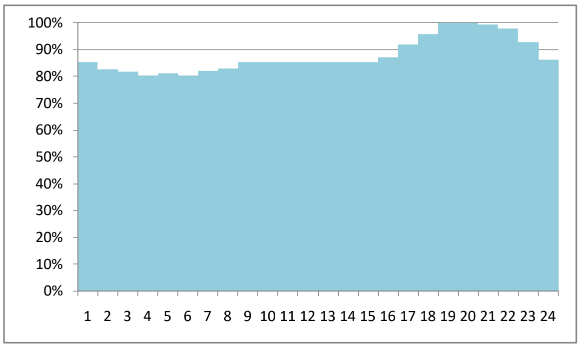
6.3.4.5 Baseline and Estimation of Per Unit Annual Energy Losses

Analysis of baseline energy losses in this report focus on annual energy losses by the most common kVA rating of utility owned DTs, i.e., 250 kVA three-phase DT. Considering that the DT stocks of EVNSPC and EVNHCMC combined accounted for about 76% of the total units installed by uilities, this report chose the maximum no-load and load losses of EVNSPC and EVNHCMC for 250 kVA DT as the baseline efficiency levels for the analysis. The report did not consider the MEPS levels specified by TCVN 8525:2015 as the EI_{B50} requirement of 99.10% for 250 kVA DT is less stringent than the maximum no-load losses of 340W and load losses of 2,600W for 250 kVA DT of EVNSPC and EVNHCMC which deliver the EI_{B50} of 99.26%.

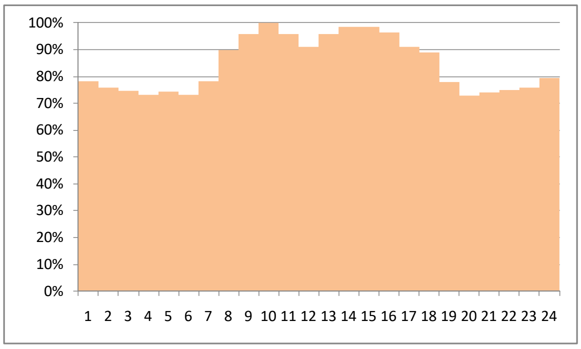
Considering that data on daily load profiles of different end-use sector is not available, different daily load profiles for the analysis were constructed based on the EVN system load profiles as shown in the figure below.



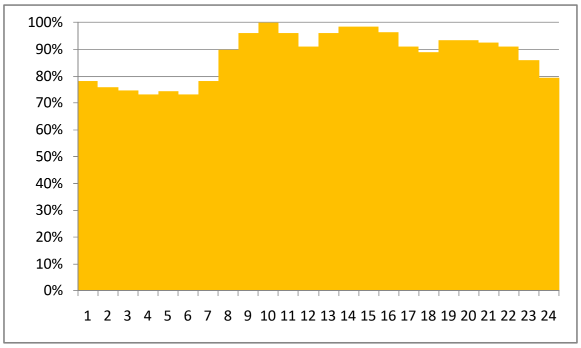
Load Profile: Flat;
Load Factor: 88%



Load Profile: Residential (evening peak);
Load Factor: 84%



Load Profile: Commerical (morning & afternoon peaks);
Load Factor: 88%



Load Profile: Industrial (multiple peaks);
Load Factor: 88%

Figure 6-49: Different Daily Load Profiles for Viet Nam Baseline Analysis

Based on the abovementioned load profiles, the analysis results for a 250 kVA three-phase DT are shown in Table 6-25. For the analysis at 50% load factor, variations of baseline annual energy losses due to diversity of load profles in Viet Nam range from 8,706 kWh (for the residential load profile) to 8,731 kWh (for the flat load profile).

Table 6-25: Per Unit Baseline Annual Energy Losses of 250 kVA Three-Phase Distribution Transformer

Daily Load Profile	Average Load Factor (%)	Baseline Annual Energy Loss (kWh)	Average Load Factor (%)	Baseline Annual Energy Loss (kWh)
Flat	88%	20,616	50%	8,709
Residential	88%	20,606	50%	8,706
Commercial	84%	19,419	50%	8,701
Industrial	88%	20,686	50%	8,731

6.3.4.6 Estimation of IEC 60076-20 Scenario

EVN power distribution corporations have specified different requirements for maximum no-load and load losses. This report selected the maximum no-load and load losses of EVNSPC and EVNHCMC as the baseline values, however these maximum no-load and load losses appear to be less stringent than IEC 60076-20 requirements for level 2 maximum no-load and load losses (Table 4). In this report, three following designs of 250 kVA DTs with different no-load and load losses were developed for the analysis:

- **Design A:** a 250 kVA DT with level 2 maximum no-load and load losses as specified in Table 4 of IEC 60076-20. It should be noted that any DTs meeting the maximum no-load and load losses in Table 4 will also meet the EI_{B50} requirements specified in Table 6 of of IEC 60076-20;
- **Design B:** a 250 kVA DT with low no-load losses and high load losses and meeting the level 2 EI_{B50} requirement at 99.36% specified in Table 6 of of IEC 60076-20;
- **Design C:** a 500 kVA DT with high no-load losses and low load losses and meeting the level 2 EI_{B50} requirement at 99.36% specified in Table 6 of of IEC 60076-20.

Values of losses, PEI and EI_{B50} of the baseline model and the above three designs are shown in Table 6-26. The load vs efficiency curves of the baseline model and these three designs are are shown in Figure 6-50.

Table 6-26: Loss and Efficiency Values of 250 kVA DT

Distribution Transformer	250 kVA, Three-Phase, 50Hz, 22kV				
Efficiency Profile	**No-Load Losses (W)**	**Load Losses (W)**	**Total Losses (W)**	**PEI (%)**	**EI_{B50}**
Baseline Model	340	2,600	2,940	99.247%	99.260%
Design A	270	2,350	2,620	99.362%	99.360%
Design B	135	2,946	3,081	99.494%	99.360%
Design C	540	1,166	1,706	99.365%	99.360%

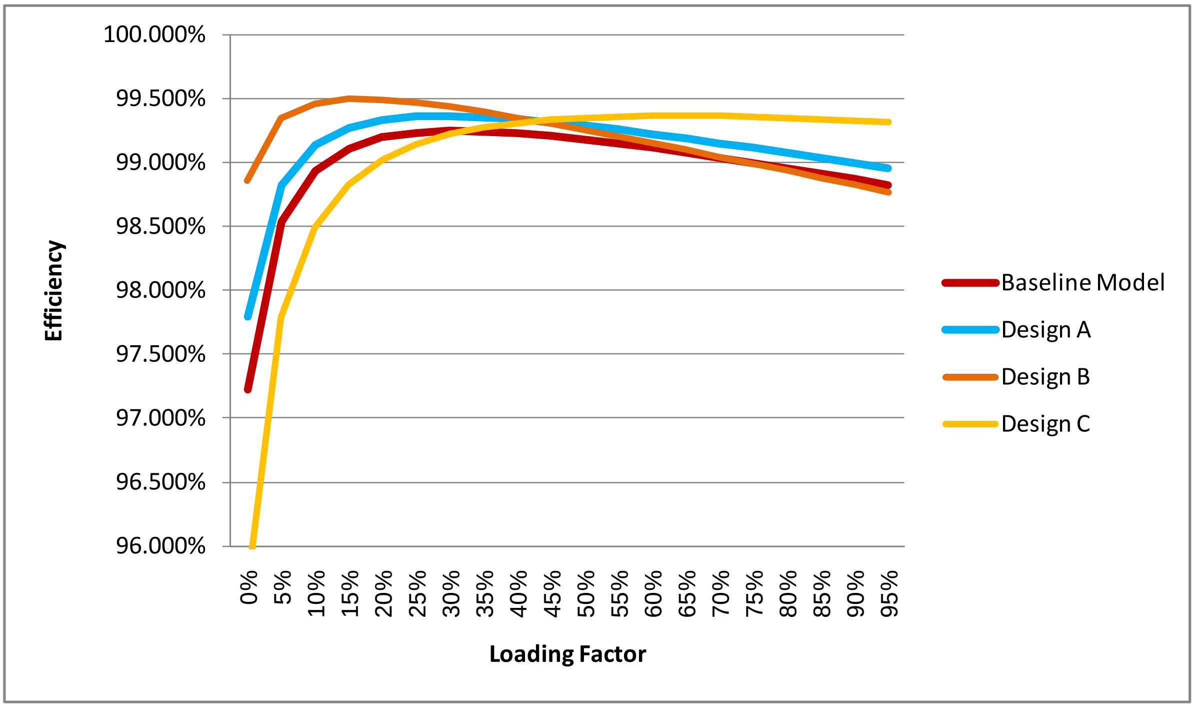


Figure 6-50: Load vs Efficiency Curves of 250 kVA Distribution Transformer

The analysis results summarized in Table 6-27 show that, *under the typical daily load profiles and average annual load factor for different end-use sectors in Viet Nam, Design A and C deliver lower per unit annual energy losses. Although Design B has higher PEI and EI_{B50} than the baseline model, it* *delivers higher per unit annual energy losses than the baseline model due to its inefficiency at high loading factors.* At a lower average annual load factor of 50%, all the three designs are more efficient than the baseline model. Shown in Figure 6-51 are per unit annual energy savings from adoption of IEC 60076-20 for 250 kVA three-phase 50Hz DTs in Viet Nam.

Table 6-27: Analysis of per Unit Annual Energy Losses of 250 kVA Distribution Transformer

Daily Load Profile	Average Load Factor (%)	Annual Energy Loss (kWh)			
		Baseline Model	Design A	Design B	Design C
Typical Average Annual Load Factor @ 88%					
Flat	88%	20,616	18,307	21,166	12,637
Residential	88%	20,606	18,298	21,154	12,632
Commercial	84%	19,419	17,225	19,809	12,100
Industrial	88%	20,686	18,370	21,244	12,668
Low Average Annual Load Factor @ 50%					
Flat	50%	8,709	7,545	7,675	7,299
Residential	50%	8,706	7,542	7,671	7,298
Commercial	50%	8,701	7,538	7,666	7,296
Industrial	50%	8,731	7,565	7,701	7,309

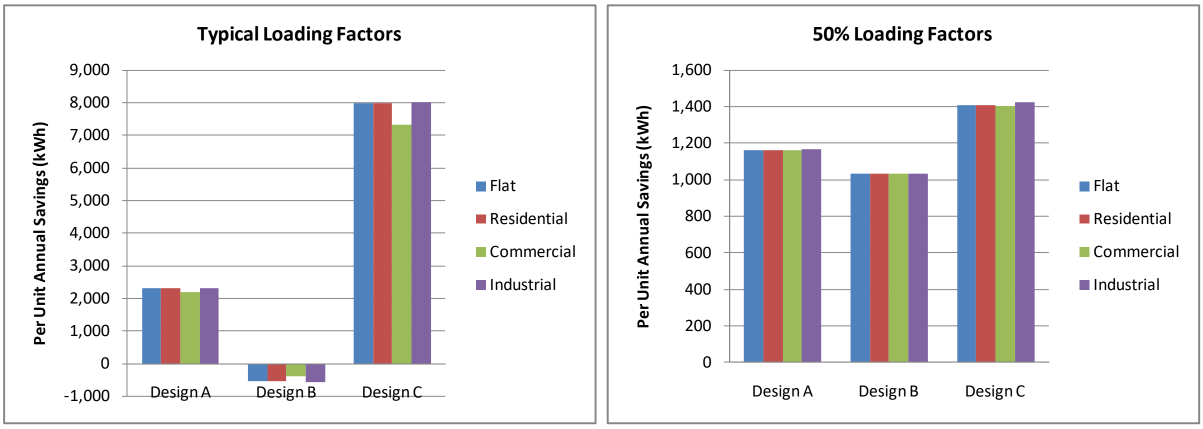


Figure 6-51: Per Unit Annual Energy Savings in kWh from Adoption of IEC 60076-20 in Viet Nam

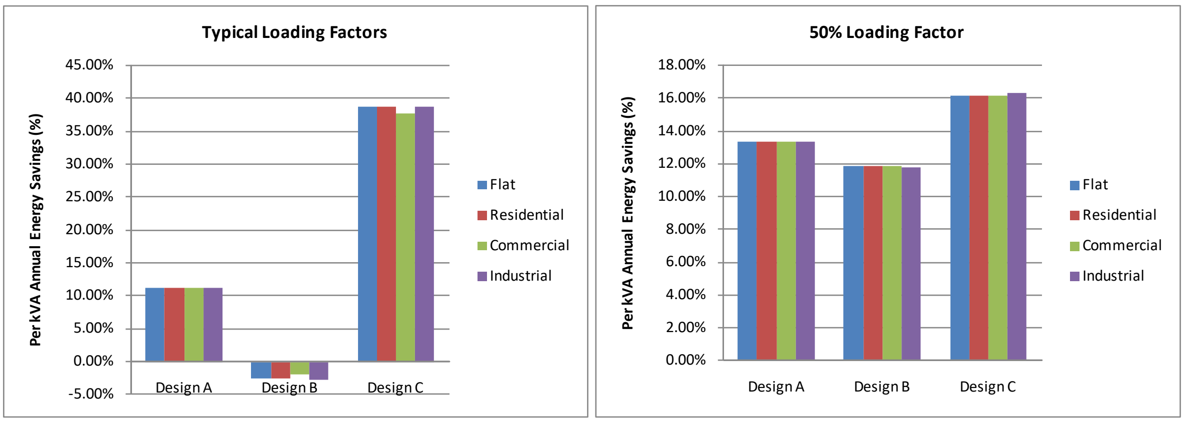


Figure 6-52: Per kVA Annual Energy Savings in % from Adoption of IEC 60076-20 in Viet Nam

Shown in Figure 6-53 and Figure 6-54 are graphical illustrations of per unit annual energy losses of different designs of 250 kVA DT in comparison with PEI and EI_{B50}. It can be seen for these two figures that PEI and EI_{B50} do not represent annual energy losses of a distribution transformer under different operating conditions.

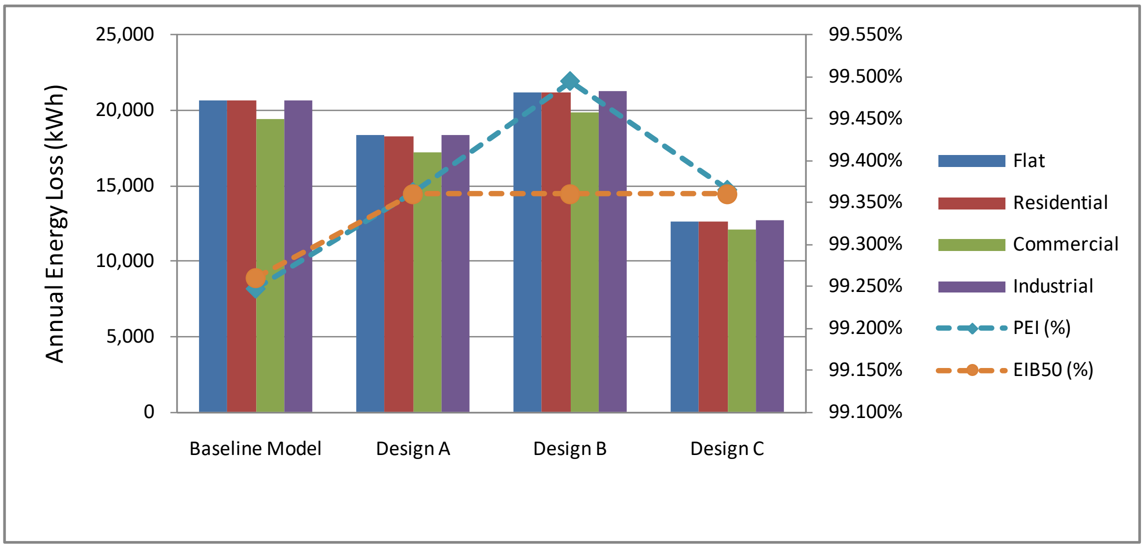


Figure 6-53: 250 kVA per Unit Annual Energy Losses at Typical Load Factors in Viet Nam compared with PEI and EI_{B50}

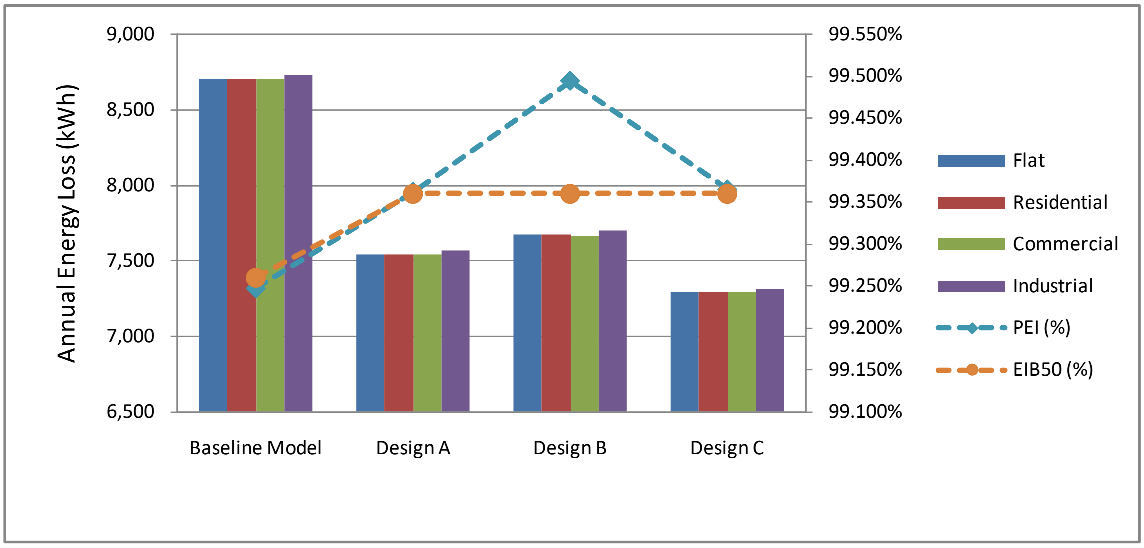


Figure 6-54: 250 kVA Per Unit Annual Energy Losses at 50% Load Factor in Viet Nam compared with PEI and EI_{B50}

6.4 ANNEX D – EMISSION FACTORS IN APEC ECONOMIES

No.	Member Economies	Emission Factor (tCO_2/MWh)	Source
1	Australia		
2	Brunei Darussalam		
3	Canada		
4	Chile	0.614	IGES
5	People's Republic of China	0.876	IGES
6	Hong Kong, China		
7	Indonesia	0.76	IGES
8	Japan		
9	Republic of Korea	0.631	IGES
10	Malaysia	0.668	IGES
11	Mexico	0.528	IGES
12	New Zealand		
13	Papua New Guinea		
14	Peru	0.6	IGES
15	Philippines	0.508	IGES
16	Russia		
17	Singapore	0.486	IGES
18	Chinese Taipei		
19	Thailand	0.547	IGES
20	United States	0.6161	EPA
21	Viet Nam	0.564	IGES

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