National Appliance and Equipment Energy Efficiency Program

Analysis of Potential for Minimum Energy Performance Standards

for

Distribution Transformers

Prepared for the Australian Greenhouse Office

by

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Final Report

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Mark Ellis & Associates is a consultancy service specialising in the design, management and evaluation of sustainable energy policies and programs. MEA brings over 17 years experience in Europe and Australasia to the following areas of expertise:

- energy and greenhouse policy
- greenhouse modelling
- design of energy efficiency strategies
- implementation and management of energy efficiency programs
- energy information and advisory services
- green pricing schemes
- energy sector micro-economic reform
- low energy planning and building design
- environmental impacts of energy generation technologies and fuels

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EXECUTIVE SUMMARY

This report covers distribution transformers with power rating from 10kVA to 2,500kVA and an input voltage of >5kV. Typically, the main transmission systems link the power production centres and the major cities and operate at voltages up to 500kV. Transmission transformers in Australia have capacities of between 2 to 3MVA up to 45MVA and are used to step down voltages to about 66kV.

Below this voltage, the system of wires for transporting electricity is known as the distribution system. Distribution transformers, typically 1 to 5MVA, are used to provide distribution voltages in the range of 11/22/33kV for commercial and domestic customers. Distribution transformers operate at 415V and 240V with ratings of less than 2.5 MVA (down to 10 kVA).

Transformers consist of two primary components; a core made of magnetically permeable material; and conductors, or windings, typically made of a low resistance material such as aluminium or copper.

Copper or aluminium conductors are wound around a magnetic core to transform current from one voltage to another. Liquid insulation material or air ("dry-type") surrounds the transformer core and conductors to cool and electrically insulate the transformer. Dry-type transformers tend to be used in customer premises for safety reasons.

There are losses associated with both the primary elements of a transformer. Core losses occur continuously due to the need to keep the transformer energised and ready to serve demand. Conversely, winding losses depend solely upon transformer load and result from resistance in the windings. Core Losses are constant while winding losses increase exponentially with the electricity load.

Many different distribution transformer designs are available and transformer engineers modify transformer design and vary material depending upon the needs of a particular customer (cost of energy, capacity, etc.).

Advances in transformer design have produced substantial transformer efficiency improvements over the past 20 years. The most significant improvements have been made in core technologies with the use of high-efficiency silicon-steel and amorphous metal. Efficiency gains have also been achieved with windings by using materials with lower resistivity or greater diameters.

Market Profile

The estimated total number of utility-owned distribution transformers is approximately 488,000 with a capacity of at least 79,000 MVA. Assuming that utilities own 85% of transformers in Australia, there is estimated to be 86,000 privately-owned distribution transformers, with a capacity of approximately 14,000 MVA. The majority of these are dry-type.

The total stock of distribution transformers in Australia is therefore assumed to be around 574,000 units, with a capacity of approximately 92,700 MVA.

It appears likely that around 70% of the total stock of private and utility-owned distribution transformers are three phase and 30% are single phase. Similarly, the majority of utility-owned distribution transformers are estimated to be liquid-filled, with only 14% of the total stock (private and utility) comprising dry-type.

Assuming the lifespan of distribution transformers is 30 years, annual sales of transformers for Australian markets are estimated to be around 19,100 units with a capacity of 3,100 MVA.

Industry sources suggest that the value of the Australian distribution transformer market is $150m per annum and that between 75%-85% of capacity is produced in Australia.

In the smaller size ranges, particularly with dry-type units, the proportion of imports is likely to be larger, with the bulk of products sourced from Southern Asia. It should be noted that there is no existing or planned regulation of transformers in the countries where most imported products are sourced. There is evidence to suggest that these imported products operate to generally lower efficiencies than locally manufactured transformers.

Standards

Australian Standard 2374 relates to dry-type and liquid filled distribution transformers. It does not currently establish any guidelines, targets or performance standards for losses or efficiency, nor are there requirements for a unit's rated losses or efficiency to be displayed on a rating plate fixed to each tested transformer.

Mexico is the only country that has introduced MEPS (1999) for distribution transformers, Canada appears likely to follow in January 2001, and America is expected to follow in mid 2003.

In the United States, the National Electrical Manufacturers Association (NEMA) publishes a *Guide for Determining Energy Efficiency for Distribution Transformers (TP-1-1996)*, and a standard test method for the measurement of energy consumption in transformers (TP-2). The Canadian proposed regulations are based on these US NEMA guidelines to provide for harmonization with North America.

Also in the US, the **Energy Star** transformer program provides technical assistance to partners to ensure that transformers are not oversized, and has developed a model to provide a standard methodology for the evaluation of multiple transformer bids. To compliment this tool, the program also labels transformers that conform to its targets.

Recommendations

Minimum Energy Performance Standards are recommended for transformers in Australia for the following reasons:

- total electricity losses in Australia in 1998 attributable to transformers and wires are estimated at 21,806 GWh, representing 12% of the power generated;
- it is assumed that losses from distribution transformers in Australia comprise at least 25% of total losses, representing 5,400GWh or 5.4Mt CO_2-e per year. Losses are estimated to rise to 6,700GWh and emissions are estimated to rise to 6.0Mt CO_2-e by 2015 as electricity demand and consumption increase;
- although most distribution transformers currently built and installed in Australia are likely to meet the minimum energy performance standards proposed in America and Canada, units installed privately (around 15% of the market) are not likely to comply. Furthermore, there is evidence that higher loss transformers may gain greater market share over the next decade or so, in response to pressures for purchasers to minimise first costs.
- MEPS are a very effective tool when there is market failure and the normal market forces do not deliver the best outcomes from a community perspective. The network regulatory regime currently does not seem to contain the economic incentives for the network operators to be concerned about the levels of electricity losses that accumulate from their networks. In the absence of the necessary economic drivers, MEPS is one way of maintaining transformer efficiency levels in the distribution/transmission networks;
- stakeholders report that there is also market failure in the industrial sector of the market, where transformers are privately owned. Here developers, focusing on the initial capital costs and not being concerned about the running costs of the power supply, put in the cheapest transformers available.
- the adoption of minimum energy performance standards in Australia with equivalent loss levels to those standards proposed in both America and Canada, could increase new transformers' efficiency relative to the likely trends.
- additional equivalent savings could be anticipated from voluntary 'best practice' programs aimed at reducing losses attributable to incorrect sizing;

The MEPS levels recommended for Australian are based on those proposed for Canada and used by the US Energy Star program, with adjustments made to take into account the different frequencies used in the power systems in North America (60Hz) and Australia (50Hz). We note however, there are some within the industry that consider that Australian MEPS levels should not be higher than those proposed for Canada and the US. A working group has been established to examine this issue further.

The recommended MEPS levels, including adjustments, are shown in the following tables:

Table E1: Liquid-Filled Distribution Transformers, Proposed Standards

Power rating	Efficiency proposal
[KVA]	% [50 Hz operation]
Single phase units [50% load] [Including SWER Transformers]	
10	98.5
15	98.7
25	98.9
Three phase units [50% load]	
25	98.4
50	98.7
100	98.9
200	99.1
300	99.1
500	99.2
750	99.3
1000	99.4
1500	99.5
2000	99.5
2500	99.5

Table E2: Dry-Type Distribution Transformers, Proposed Standards

Power rating	Efficiency proposal
[KVA]	% [50 Hz operation]
Single phase units [50% load]	
15	97.9
25	98.3
Three phase units [50% load]	
25	97.6
50	98.0
100	98.3
200	98.6
300	98.7
500	98.9
750	99.0
1000	99.0
1500	99.1
2000	99.1
2500	99.2

Since the great majority of transformers are locally manufactured, we also recommend that the implementation of new standards in Australia should have sufficient lead times to allow existing suppliers to adjust, thereby minimising any potential for loss of market share or economic impact.

In view of the substantial savings to be made from installing efficient transformers of the appropriate size, the following recommendations are made for activities:

- adjustment of the network regulatory regime to change economic drivers so that appropriate incentives are offered to network managers to up grade their current stocks of transformers and to only purchase energy efficient units;

- a labelling program for products sold into the private ownership market;
- best practice program to assist correct transformer sizing;
- promotion of advice from energy experts, including utilities;
- promotion of innovative finance packages whereby energy savings pay for capital costs;

Greenhouse Reduction Potential

Detailed modelling of distribution transformer losses has not yet been done for Australia but is planned for 2001. The following comprises a preliminary estimate of the potential savings due to the implementation of MEPS.

Based on available information concerning the stock and performance of Australian distribution transformers, it is estimated that implementation of the proposed MEPS level in 2005 would reduce greenhouse emissions by approximately 32kt CO_2-e per annum. Cumulative annual savings to 2010 and 2015 are estimated to be 185kt CO_2-e and 346kt CO_2-e, respectively.

It is considered likely that, unconstrained by regulation, there will be a trend for an increasing number of higher loss transformers to enter the Australian market. Although it is difficult to quantify the impact of this on greenhouse emissions, under this scenario emissions would increase over the next decade. Indicative estimates suggest that total savings in 2015 would be in the region of 650 kt CO_2-e to 950 kt CO_2-e.

Due to the long-life of distribution transformers, savings are predicted to continue for at least 30 years at approximately the same rate.

Analysis of Potential for Minimum Energy Performance Standards for Distribution Transformers

1. PURPOSE

This report has been commissioned by the Australian Greenhouse Office as part of the National Appliance and Equipment Energy Efficiency Program (NAEEEP). Its purpose is to explore the potential for energy and greenhouse savings through the introduction in Australia of Minimum Energy Performance Standards (MEPS) for distribution transformers.

2. SCOPE

This report covers distribution transformers with power rating from approximately 10kVA to 2,500kVA and an input voltage of >5kV. This includes dry-type and liquid filled, single and three-phase units, owned by electricity utilities or privately.

3. PRODUCT DESCRIPTION

3.1 Background

Distribution transformers convert high-voltage electricity to lower voltage levels acceptable for use in homes and businesses.

Transmission and distribution systems (the electricity network or grid) link electric generators with end users through a network of power lines and associated components. Typically, the main transmission systems link the power production centres and the major cities and operate at voltages up to 500kV. Transmission transformers in Australia have capacities of between 2 to 3MVA up to 45MVA and are used to step down voltages to about 66kV.

Below this voltage, the system of wires for transporting electricity is known as the distribution system. Distribution transformers, typically 1 to 5MVA, are used to provide distribution voltages in the range of 11/22/33kV for commercial and domestic customers. Distribution transformers operate at 415V and 240V with ratings of less than 2.5 MVA (down to 10 kVA).

For some energy intensive commercial and industrial applications, for example mine sites, aluminium smelters and large commercial complexes, electricity is supplied at high voltage by utilities. These customers may own their own transformers located on site, to produce the desired voltages.

3.1.1 Nameplate Rating

Transformers are rated in kilovolt-amps (or kVAs), known as the Nameplate Rating. The nameplate rating designates the maximum capacity, or "load," the transformer is designed to handle. Thus, a 10kVa transformer is operating at "full-load" when the demand on the transformer is 10 kilowatts (kW)* (*Note:The power rating of a transformer in kilowatts is the product of the kVA rating and the power factor [See Kennedy 1998 for further definitions].) At unity power factor

In practice, transformers can operate at very high loads (beyond their nominal rated capacity) for short periods. The ability of transformers to handle high loading levels is particularly important in residential applications, where demand may range from less than 10 percent of rated capacity during much of the day to over 200 percent of rated capacity for short peak periods.

3.1.2 Distribution Transformer Basics

Copper or aluminium conductors are wound around a magnetic core to transform current from one voltage to another. Liquid insulation material or air ("dry-type") surrounds the transformer core and conductors to cool and electrically insulate the transformer.

Since small distribution transformers do not generate much heat, a higher proportion of these tend to be dry-type. Dry types are also less flammable, and are therefore often selected for use when they must be located in confined spaces on a customer's premises.

3.1.3 Transformer Design Characteristics

Transformers consist of two primary components:

- A core made of magnetically permeable material; and
- A conductor, or winding, typically made of a low resistance material such as aluminium or copper.

3.2 Transformer Loss Basics

Core Losses are constant. Winding Losses increase exponentially with the square of the load.

A transformer uses the core's magnetic properties and current in the primary winding (connected to the source of electricity) to induce a current in the secondary winding (connected to the output or load). Alternating current in the primary winding induces a magnetic flux in the core, which in turn induces a voltage in the secondary winding. A voltage step-down results from the exchange of voltage for current, and its magnitude is determined by the ratio of turns in the primary and secondary windings. A transformer with 50 primary turns and five secondary turns would step the voltage down by a factor of 10, for example from 13,500 volts to 1,350 volts.

A given transformer's energy output is lower than the level specified by the nameplate rating due to inefficiencies in both the core and the windings. In general, transformer losses are less than two percent of the total transformer load.

The magnitude of the losses is dependent upon the loading of the transformer. Core losses (also called no load losses) remain constant while winding losses increase with the square of the load. Thus, for a transformer with an average load of 25 percent, the core losses may represent approximately 75 percent of total energy losses. Conversely at 100 percent of rated load, the winding losses may represent more than 80 percent of total energy losses. Thus, core losses make-up a greater share of total losses at lower transformer loads, while the winding losses make-up a greater share of total losses at higher transformer loads.

Many different distribution transformer designs are available, depending on the loading patterns and needs of the end-user. Transformer engineers modify transformer design and vary material depending upon circumstances. Transformer design includes variations of:

(I) the material used for the core;

(ii) the material used for the windings;

(iii) the material that insulates the core and the winding;

(iv) the number of phases of the current that passes through the transformer;

(v) mounting; and

(vi) the rated size.

The following sections describe these factors in more detail. Further detail is provided in a special report by Professor Trevor Blackburn contained in Appendix I.

3.2.1 Core Material

Transformer cores are usually made of either grain-oriented silicon steel or amorphous metal. Silicon steel comes in a variety of grades, each with its own conductive and efficiency characteristics. Amorphous metal, a more costly but highly efficient material, can significantly reduce core losses. Constructing the core of laminated sheets, insulated from each other, also reduces losses, but adds to the cost, weight and volume of the transformer.

The type of core material preferred by a utility is usually dependent on the cost of its core losses and the expected transformer loading levels. Since the marginal cost of energy for electricity utilities is usually rather low, the financial incentive for moving to high efficiency transformer materials may be limited.

3.2.2 Winding Material

Generally, copper and aluminium are used for transformer windings. As with silicon steel, these materials are available in a variety of grades and thicknesses, each with their own efficiency characteristics. The types of windings chosen by the transformer designer are also dependent on the cost of a specific utility's losses and on assumed transformer loading levels.

3.2.3 Insulating Material

The majority of utility distribution transformers are liquid filled. The non-conducting liquid (mineral oil is most commonly used) serves to electrically insulate and cool the transformer. As the core temperature of the transformer rises, the efficiency decreases, so an efficient cooling method improves performance. Typically, transformers perform best at temperatures below 55^{o}C above the ambient temperature.

Liquid-filled transformers transfer heat more efficiently than dry-type transformers and are generally preferred for larger applications. Most liquids used in transformers now are non-flammable.

3.2.4 Phase

Transformers may be designed to step down a single alternating current from one voltage to another, called single-phase transformers, or contain three primary and three secondary windings and therefore provide the output in three-phases. Three-phase transformers induce a more constant magnetic flux and output voltage necessary for motors, heating, ventilating, air-conditioning (HVAC) and other large equipment. Technically, the three-phase transformer is equally efficient to the single-phase transformer.

In the US, over 95% of average annual transformer sales comprise single-phase distribution units, mostly in the 15kVA to 25kVA range. Since the larger transformers tend to be three-phase, these comprise 38% of the total MVA sold each year [USEPAb, 1998].

Table 1: Average Annual Sales of Distribution Transformers in the US [USEPA, 1998]

Type and Nameplate Rating	Units		Capacity	
	Number	%	(MVA)	%
Single-phase (10-167kVA)	910,885	95.0%	26,364	59.5%
Single-phase (250-500kVA)	3,005	0.3%	1,113	2.5%

Three-phase (avg. 150kVA)	32,500	3.4%	13,973	31.5%
Three-phase (avg. 1,000kVA)	12,500	1.3%	2,842	6.4%
Total	**958,973**	**100%**	**44,292**	**100%**

Information supplied by NRCan suggests that sales in Canada follow a similar trend [pers.com. NRCan, 2000].

There is no equivalent information available on the stock of Australian distribution transformers by phase of units. However it is known that Australia has a substantially higher proportion of three phase units than is the case in the US and Canada. In this respect, the Australian transformer stock profile is more similar to that in Europe. Further analysis of the Australian stock is contained in Section 5.

3.2.5 Mounting

Distribution transformers are either mounted on an overhead pole or on a concrete pad at ground level. There is some evidence to suggest that pole mounted transformers dissipate heat more easily that pad mounted units and may therefore be more fully loaded [Kennedy 1998].

3.2.6 Correct sizing.

Properly sizing a transformer for a given application has a significant impact on the overall transformer efficiency and energy loss level. Oversized transformers are lightly loaded, and consequently lose more energy from excess core losses than optimally sized transformers. Conversely, undersized transformers operate at higher load levels and experience high load losses.

3.3 Energy Losses from New Distribution Transformers

Over the 30-year life of a transformer, a new 50kVA single-phase utility transformer will produce approximately 70MWh in energy losses. An average 1,500kVA liquid-filled three-phase transformer will produce approximately 1.4GWh in losses over its lifetime (see Table 2). [Ellis, 2000]

Table 2: Typical Lifetime Losses from Distribution Transformers

Unit	Lifetime Losses MWh
Av 50kVA unit	80
Av 1500kVA unit	1408

Studies in the US have shown that new, efficient transformer designs could reduce these energy losses and associated air emissions by 10 percent to more than 40 percent, depending on materials used and the loading pattern of the transformer [USEPA 1998b].

Advances in transformer design have produced substantial transformer efficiency improvements over the past 20 years. The most significant improvements have been made in core technologies with the use of high-efficiency silicon-steel and amorphous metal. Due to the large numbers of transformers in service and the constant nature of energy losses, only small increases in efficiency are needed to produce significant economic and environmental gains.

3.4 The Sources of Transformer Efficiency

Transformer energy losses can be reduced by improving the efficiency of the core or windings. The relative importance of core and winding losses depends on the loading on the transformer and the cost of each type of loss to the utility.

3.4.1 Core Loss Reductions

Since the majority of transformer losses at low load levels are due to core inefficiencies, much of the research on reducing transformer losses has concentrated on building more efficient cores. Core losses result from cyclic changes in the magnetic state of iron, and "eddy-current" losses caused by the flow of small currents in the iron. Core losses can be reduced by improving the magnetic permeability of the core material or by using a core material that offers less magnetic resistance.

Considerable progress in reducing core losses has been made over the past twenty years, primarily through material improvements. In the early 1970's, manufacturers introduced more efficient silicon-steels. The four main grades of silicon-steel used in transformers are M2, M3, M4, and M6 (decreasing in efficiency). Differences are due mainly to the chemical composition and the rolling techniques used in manufacture of the core. The increased domestic availability of higher grades of silicon-steel (M2 and M3) and new manufacturing processes has led to the improved efficiency of silicon-steel distribution transformers.

Amorphous metal, a highly efficient material used in transformer cores, possesses good magnetic properties, low inherent magnetic resistance losses, and high resistivity. Due to its ability to be constructed into very thin sheets, “eddy-current” losses are significantly reduced. Amorphous metals have been found to reduce core losses by as much as 70 percent. However, the cost of transformers with more efficient cores increases due to the following factors:

- increasing core efficiency requires the use of more core material;
- the larger core size associated with the energy-efficient transformer necessitates the use of additional winding material, generally resulting in lower winding efficiencies and other costs;
- in addition, the thin lamination of amorphous metal tends to make the core material more difficult to handle; and
- certain types of efficient transformers may encounter specific problems, such as the difficulties associated with larger and heavier transformer design.

3.4.2 Winding Loss Reductions

Winding losses, or load-losses, arise from the conducting material's inherent resistance to the flow of electrical current. Winding losses increase with the square of the transformer load. Efficiency gains can be achieved by using materials with lower resistivity or greater diameters. For example, distribution transformer coils made with low resistivity conductors, such as copper, can have considerably lower load losses than those made with other materials. However, low resistivity conductors often cost more than other conducting materials.

3.4.3 The Importance of Sizing

Overall transformer efficiency depends critically on the percent of time that the transformer is heavily or lightly loaded, the load factor. (*Note:* Load factor is defined as the ratio of average load to peak load.)

Transformers need to be sized to cope with expected peak loads, rather than average loads, and therefore where there is a large disparity between these two, the load factor will be small.

For example, distribution transformers serving primarily residential loads regularly carry average loads that are only 15 percent to 20 percent of the transformer's rated capacity but also must be designed to support peak morning and evening loads. Because of the wide gap between peak and non-peak loads, and the relatively limited amount of time that the transformer is peak-loaded, average transformer loading tends to be fairly low. In this case, total losses may be mainly attributed to core losses.

Larger distribution transformers, used more often in transforming power for commercial or industrial customers, tend to be loaded at higher average levels over the course of the year. Transformers that serve businesses operating from 9:00 am to 5:00 pm, for example, typically experience a consistent and relatively higher load throughout the day. In this circumstance, it is likely that load losses will make the major contribution to total losses.

The following table is provided to illustrate the relative contribution of No Load and Load Losses at different load factors.

Table 3: Illustration of Transformer Losses Varying with Load Factors [USEPA 1998]

Load Factor	No Load Loss kWh/year	Load Loss kWh/year	Total Loss kWh/year
10%	508	27	535
20%	508	109	617
30%	508	246	754
40%	508	437	945
50%	508	683	1,191
60%	508	984	1,492
70%	508	1,339	1,847
80%	508	1,749	2,257
90%	508	2,214	2,722

Correctly sizing a transformer is therefore critical to the quantity and source of losses, and optimising transformer design for efficiency remains a complex task.

To complicate matters, the marginal cost of energy varies dramatically throughout the day, altering the cost of energy losses and the cost-benefit of installing more efficient transformers from the utility perspective.

In addition, transformer loading patterns tend to change over time. Homeowners may accumulate more appliances and equipment (or new houses built in the area), or businesses may expand and consequently increase the load on the transformer. Generally, utilities estimate load growth when sizing and purchasing transformers. In the US it has been calculated that, on average, utilities size single-phase transformers so that transformer peak load at installation is approximately 88 percent of its capacity, and 157 percent of capacity at the end of its service life.

In an effort to improve transformer sizing practices, the U.S. Environmental Protection Agency (EPA), as part of the ENERGY STAR Transformer Program, has developed technical tools to enable utilities to enter utility-specific loading information in order to optimise transformer size and total owning cost (TOC), while providing reliability and energy-efficiency.

4. IDENTIFICATION OF STAKEHOLDERS

There is a range of organisations which have an interest in transformers and their efficiency, including electricity industry trade associations, transmission and distribution (T&D) utilities and their regulators, private owners and consumers.

The electricity supply network in Australia, as opposed to generation or retail, is considered a natural monopoly. Whether the electricity industry is fully deregulated, eg the UK, or only subject to limited competition, eg Canada and the US, the T&D sector is always treated as a monopoly. T&D infrastructure investments are generally paid for by all electricity customers and are not subjected to competitive pressure. As a result, T&D charges are subject to economic control, determined by a number of regulatory authorities. The overall aim of these regulations is to ensure that reliable electricity supply is achieved at least cost to society.

Although the type of regulation employed varies between jurisdictions, they all tend to place some responsibility on the utilities to increase efficiency over time, rather than scrutinising individual investments. However, there is no certainty that this would cause any particular focus on reducing losses, and therefore cutting the operational costs associated with transformers. In fact, the impact of this may be to minimise capital expenditure, to the detriment of investment in increased energy efficiency in the case of transformers.

Therefore, if investment in cost effective improvements to the efficiency of the stock of transformers is not currently taking place, this would be evidence that the present regulatory regime is not delivery the desired outcome. This issue is discussed in later sections.

The range of organisations with an interest in transformers and their efficiency include:

4.1 Electricity Supply Association of Australia (ESAA)

The ESAA publishes data on the electricity industry in Australia including the nominal rating of installed transformers. For the first time in 1998, data was collected on the number of transformers installed in Australia.

In conjunction with AEEMA, the ESAA has developed a technical specification for polemounting distribution transformers [ESAA 1998]. The specification is designed to assist in providing a standard range of polemounting transformers for use in the Australian electricity industry. It includes rationalised ratings, loss capitalisation factors (see Table below), mounting arrangements and fittings where possible. The specification provides some information on how to evaluate the economic cost of losses, and provides a template of information required from tenderers which includes data on losses under loaded and no-load conditions.

Table 4: ESSA Financial Values for Losses in Polemounted Transformers

Transformer Rating	No Load Loss/kW	Load Loss/kW
Up to and including 63kVA	$6,300	$700
100kVA and above	$6,300	$1,800

4.2 Australian Electrical and Electronic Manufacturers Association (AEEMA)

AEEMA is the peak industry association representing local and international companies involved in the design, development and production of electrical and electronic products and systems in Australia. Through its Power & Distribution Transformer Division, AEEMA represents Australia's power and distribution transformers industry on policy, technical and commercial matters with the goal of maximising business opportunities for members. Its objectives are to:

- promote the development of a competitive transformer industry in Australia and internationally
- provide information on developments within the ESI and liaise with the ESAA and individual energy utilities
- coordinate industry input on standards issues
- provide industry views on policy issues

The major activities of the transformer group are the:

- development of common specification for pole top transformers
- input into the Commonwealth Government on trade and policy
- issues including duty matters
- liaising with the ESAA/ESI on industry issues

4.3. Manufacturers

Industry sources suggest that there are approximately 23 manufacturers of distribution transformers, most of which are low volume producers at the lower end of the market. It is likely that the larger companies will be members of AEEMA, who should be able to assist with identifying appropriate companies and contact people. The following are the largest manufacturers/distributors:

- ABB Transmission and Distribution Ltd
- Alstom Australia Ltd
- AW Tyree Transformers Pty Ltd
- Schneider Electric
- Wilson Transformer Company Pty Ltd

4.4 Electricity Utilities

It is believed that the majority of distribution transformers in Australia are purchased and operated Transmission and Distribution Companies (see Appendix A for a list of T&D companies). Many of these utilities have design teams for substations and transformers.

4.5 Regulators

The ACCC is the regulator for the National Electricity Market (NEM), and regulates according to the National Electricity Code. Each jurisdiction has its own regulator with respect to aspects of the distribution system as follows:

- Australian Consumer and Competition Commission (ACCC)
- Independent Pricing and Regulatory Tribunal (IPART), NSW
- Office of Regulator General (ORG), VIC
- Queensland Competition Authority (QCA), QLD
- South Australian Independent Industry Regulator (SAIIR), SA
- Office of the Tasmanian Electricity Regulator (OTTER), TAS
- Office of Energy (OOE), WA
- Independent Pricing and Regulatory Commission, ACT

4.6 Private Owners and Consumers

The following organisations represent many of the larger independent owners of distribution transformers, and consumers.

- Australian Consumers Association
- Energy Action Group
- Energy Users Group of Australia

5. MARKET PROFILE

5.1 Ownership

There are two predominant types of distribution transformer ownership: transmission and distribution utilities, and large private businesses (typically industrial companies).

5.1.1 Utility Owned

This is the largest sector of the market in Australia, probably accounting for between 85%-90% of sales. The quality and extent of data held on the stock of transformers appears to vary considerably for each utility. Since some transformers in current operation are up to 40 years old, and many utilities have experienced changes in their franchise during this period, it is unlikely that utilities have maintained consistent records over this period. Industry sources suggest that a considerable amount of information has traditionally been held by experienced utility personnel, however due to retirements and restructuring, some of this body of knowledge has now disappeared.

Many utilities appear to have limited knowledge on the performance and loading of individual distribution transformers. Some however, have undertaken monitoring exercises of sections of the network, typically where supply constraints are imminent. Many transformers are fitted with a peak load meter which enables monitoring of maximum loads experienced by an individual transformer. Typically these are read manually, although technology is available for remote monitoring.

Transformer purchases by utilities in Australia has traditionally placed considerable emphasis on quality, performance, longevity, low maintenance and low losses. Loss capitalisation has been extensively used by both utilities and Australian manufacturers as means to optimise designs, with the support of the Electricity Supply Association of Australia (ESAA). With the creation of distribution businesses to own and operate the network, and the introduction of private ownership, competition for capital has increased, and accountability for losses changed.

In the UK, there is evidence that deregulation and privatisation has caused increased pressure to reduce capital expenditure and focus on the lowest 'first cost' options [EC 1999, and Appendix F]. Industry sources in Australia suggest that a similar trend is becoming prevalent here, and that this is affecting the purchasing decisions with respect to transformers. A number of utilities report that they have recently purchased transformers from overseas which have lower capital costs, higher losses and will probably not last as long as some other options. However, they argue that in the current regulatory regime, this is the action of a responsible asset manager.

5.1.2 Privately Owned

It is estimated that privately-owned transformers account for between 10% and 15% of the market in Australia. There are a number of sub-markets within the private ownership market, including large industrial owner-operators and developers. The characteristics of these participants are discussed in Appendix F, extracted from [EC 1999].

Private-owners tend to install the cheaper products, and many transformer manufacturers produce products specifically for this market, which are in the region of 5%-10% cheaper and have approximately 10% higher losses than those which have been supplied for the utility market.

5.2 Installed Transformers

5.2.1 Utility Owned

In 1998, there were approximately 490,000 electricity utility owned transformers in use in Australia. This figure excludes generator transformers and those privately owned.

This represented a total nominal capacity of 199,000 MVA. The nominal installed capacity increased by 5.4% between 1994 and 1998, ie. a growth rate of 1.3% per annum. This is consistent with data published in 1995 for NSW which indicated that there were then 164,112 utility owned transformers in the state, with a total capacity of 78,916 MVA [DOE 1996].

Transformers identified in Table 12 include transmission transformers, typically with capacities larger than 2,500 kVA. However, on the basis of this data, these comprise less than 2% of the stock, with the remainder being used for distribution.

The estimated total number of utility-owned distribution transformers is approximately 488,000, with a capacity of at least 79,000 MVA.

Table 5: Transformers installed by Electricity Utilities, 1998, excluding generator transformers [ESAA 1999]

Transformer Rating	Number of transformers installed	Nominal MVA capacity	Average Capacity/Unit (kVA)	Phase (estimated breakdown)
500kv	9	10,990	1,221,000	Single
330kv	122	25,604	200,000	Three
275kv	69	11,773	170,000	Three
220kv	25	12,779	511,000	Three
132kv	576	30,834	53,500	Three
110kv	150	6,813	45,400	Three
88kv	4	75	18,800	Three
66kv	1,586	21,470	13,500	Three
44kv	9	18	2,000	Three
33kv	2,641	16,984	6,400	Three
22kv	187,664	18,775	100	Predominantly Three
< or = to 11kv	226,292	40,196	178	Predominantly Three

SWER*	71,009	2,821	40	Single
TOTAL	**490,156**	**199,131**	**406**	

Notes:

* SWER = single wire earth return (all voltages)

Columns providing information on the Phase and Average Capacity/Unit have been added by the authors as a guide and were not included in the original ESAA data.

Although it has only been possible to gain an approximate estimate of the phase of each category of distribution transformer, it is evident that the majority is three-phase. It appears likely that around 70% of the total stock of private and utility-owned distribution transformers are three-phase and 30% are single-phase. Similarly, the majority of utility-owned distribution transformers are estimated to be liquid-filled, with only 14% of the total stock (private and utility) comprising dry-type.

Further details supplied by the industry would enable a better understanding of the contribution of this group to total losses and greenhouse emissions.

5.2.2 Privately Owned

Information on privately owned transformers has been unobtainable, however discussions with the industry and overseas experience indicate that this sector comprise between 10% and 15% of the market. Assuming that utilities own 85% of transformers, there is estimated to be 86,000 privately-owned distribution transformers, with a capacity of approximately 14,000 MVA. The majority of these are dry-type.

5.3.3 Total Stock

The total stock of distribution transformers in Australia is therefore assumed to be around 574,000 units, with a capacity of at least 92,700 MVA.

5.2 Annual Sales

The average life-expectancy of transformers is approximately 30 years, although there is considerable variation depending upon degree to which individual units have been loaded over their working life. Further reasons for replacement include lightening strikes, corrosion and load increases. New loads, expanding and upgraded networks also provide a market for transformer sales.

Assuming the lifespan of distribution transformers is 30 years, annual sales of transformers for Australian markets are estimated to be at least 19,100 with a capacity of 3,100 MVA (assuming the new units are the same average capacity as those replaced. Industry sources suggest that the value of the Australian distribution transformer market is $150m per annum.

This estimate of turnover is consistent with data from the US which has recorded annual sales of 1.3 million transformers from a stock of 40 million [USEPAa, 1998].

5.3 Refurbishment

There are a number of companies which undertake transformer refurbishment, including: ABB, Alstom, Schneider, AMP Control & NPS. Refurbishment typically comprises inspection of windings, changing of oil, insertion of new gaskets, and repainting.

Although no data is available on the numbers of units refurbished each year, industry sources suggest that it is a significant market, which may be growing as utilities try to drive their assets harder. Some utilities report that where transformers are reaching their capacity, they are replaced by larger units, but the original is refurbished used elsewhere in the network, or kept in storage until wanted.

There appears to be little economic scope for increasing the efficiency of units during the refurbishment process.

5.4 Trends

Electricity demand in Australia has grown consistently in previous years and this trend is forecasted to continue for at least the next ten years, although there is some variation between regions [NEMMCO 2000]. In order to meet demand, a range of large interconnection (transmission) projects and smaller distribution network augmentation and enhancement projects are planned. These, together with the replacement of some of the existing transformer stock for reasons outlined previously, will create a steady market for transformers in Australia.

On the other hand, there is evidence that network businesses are facing pressure to drive their existing assets harder, leading to the acceptance of higher loads on some existing transformers and refurbishment. A recent report on the Victorian distribution system noted that the trend is for increasing load factors in the network with a corresponding growth in losses (ORG, 2000).

In terms of efficiency and greenhouse emissions, we consider it likely that transformers will be purchased increasingly on a 'first cost' basis. This would almost certainly result in the purchase of transformers with higher losses compared to those that have been installed by utilities over the previous few years.

6. INDUSTRY LINKS

The majority of transmission and distribution transformers are manufactured in Australia. Discussions with members of the industry suggest that between 75%-85% of capacity is produced in Australia and this is supported by analysis of import data.

Overseas manufacturers include Toshiba (Japan) and Ealim (Austria). Australian manufacturers with strong overseas links include ABB, Alstom, Schneider and Wilson.

6.1 Imports

Information obtained from Australian Bureau of Statistics on transformer imports in 1999 has been sorted to differentiate between transmission, distribution and smaller transformers (typically used in electrical and electronic equipment). Transformer types suited for utility and private use have also be categorised. The following information has been extracted through this process, which although not exact, does provide a guide to the pattern of imported products.

It is estimated that 700 distribution transformers were imported during 1999, with a value of approximately $17m. This accounts for more than 10% of total estimated annual sales on a $ basis. Although the majority of all sales are for utility use and are liquid-filled, the majority of imports were for dry-type transformers for private use. This is consistent with information suggesting that private purchases look for the lowest cost product, which is often supplied from overseas. It also reflects the long-standing relationship between Australian suppliers and the utilities.

Table 6 below provides a breakdown by type of transformer and likely application.

Table 6: Estimated Breakdown of Distribution Transformer Imports

	Private Purchases	Utility Purchases	Totals
Liquid-Filled	145	33	**178**
Dry-Type	427	96	**523**
Totals	**572**	**129**	**701**
	81%	**18%**	**100%**

6.1.1 Liquid-Filled Distribution Transformers

Table 7 shows the applications for imported liquid-filled distribution transformers, demonstrating that private purchases were more than four times larger than utility purchases. Table 8 shows the country of origin for imported products. As can be seen, products were sourced from 14 countries, with the majority of products coming from France, Sweden, Canada, New Zealand and Switzerland.

Table 7: Application of Liquid-Filled Imported Transformers [from ABS 2000]

Private	145
Utility	33

Table 8: Significant Liquid Filled Distribution Transformer Imports by Country of Origin [from ABS 2000]

Country	Unit Imports, 1999
Canada	20
China	1
France	59
India	1
Indonesia	7
New Zealand	14
Papua New Guinea	2
Singapore	1
Sweden	58
Switzerland	10
Taiwan	2
Turkey	1
United Kingdom	1
United States of America	1

6.1.2 Dry-Type Distribution Transformers

Table 9 shows the applications for imported dry-type distribution transformers, demonstrating that private purchases were more than four times larger than utility purchases. Table 10 shows the country of origin for imported products. As can be seen, products were sourced from 21 countries, with the majority of products coming from Germany.

Table 9: Application of Dry-Filled Imported Transformers [from ABS 2000]

Private	427
Utility	96

Table 10: Significant Dry-Type Distribution Transformer Imports by Country of Origin [from ABS 2000]

Country	Unit Imports, 1999
Austria	2
Belgium-Luxembourg	13
Country Unknown	2
Germany	296
Hungary	1
Finland	1
France	7
Italy	2
Japan	43
Malaysia	3
Netherlands	16
New Zealand	5
Norway	1
Papua New Guinea	1
South Africa	51

Sweden	41
Switzerland	18
Thailand	2
Turkey	12
United Kingdom	5
United States of America	1

It should be noted that there is no existing or planned regulation of transformers in the countries where most imported products are sourced. There is no evidence to suggest that these imported products operate to higher efficiencies than locally manufactured transformers.

Since the great majority of transformers are locally manufactured, the implementation of new standards in Australia should have sufficient lead times to allow existing suppliers to adjust, thereby minimising any potential for loss of market share or economic impact.

7. STANDARD DEVELOPMENT

7.1 Australia

AS 2374, including parts 1 to 3, 5, 6, 7 and 8 (Draft), is the key standard relating to losses in dry-type and liquid filled distribution transformers. Appendix B contains more detailed information on all standards which deal with transformers.

Resistance testing procedures and the calculation of losses is covered in AS 2374.1 for three-phase transformers above 5 kVA and single-phase transformers above 1kVA. With regards to issues related to efficiency and load losses, this standard is identical to IEC 60076. (*Note*: The International Electrotechnical Commission (IEC) is the world organisation that prepares and publishes international standards for all electrical, electronic and related technologies. The IEC's mission is to promote, through its members, international cooperation on all questions of electrotechnical standardisation and related matters, such as the assessment of conformity to standards, in the fields of electricity, electronics and related technologies. The IEC charter embraces all electrotechnologies including electronics, magnetics and electromagnetics, electroacoustics, telecommunication, and energy production and distribution, as well as associated general disciplines such as terminology and symbols, measurement and performance, dependability, design and development, safety and the environment.)

Testing is undertaken after the transformer has been at rest for at least 3 hrs at ambient temperature, and temperatures are required to be measured during testing. Calculation of no-load losses are to include correction for temperature and to sine wave basis. Calculation of load losses are to include correction for temperature and for phase angle error.

Further guidelines on the methodology for these calculations are provided in AS 2374.8, currently in draft form.

AS 2374 does not currently establish any guidelines, targets or performance standards for losses or efficiency. Requirements for information to be displayed on a rating plate fixed to each tested transformer do not include a value for losses or efficiency.

7.2 Summary of Overseas Standards

7.2.1 Canada

It is likely that Canada will be the second country to introduce efficiency standards for the performance of distribution transformers, proposed to be introduced in January 2001.

Using information supplied by the industry, NRCan has estimated annual energy savings due to the introduction of regulation in Canada to be 132 GWh (dry-type) and 0.98 GWh (liquid filled). The proposed regulations cover liquid filled and dry-type transformers and are based on the US NEMA guidelines, TP-1 to provide for harmonization with North America. The only difference is that the Canadian standard proposes efficiency levels for liquid-filled transformers rated at 1000 kVA and 1500 kVA which are slightly higher than their American counterparts. Minimum % efficiency values, taken to two decimal places, are stipulated for each size of transformer.

It is proposed that the NEMA Standards Publication No. TP-2-1998 is used as the test procedure for the measurement of transformer efficiency. Another option under consideration is to use, CSA-C802.1

and CSA-C802.2, which set minimum efficiency standards and test procedures, as the test procedure [NCAN 1999].

Preliminary analysis suggests that the test procedures in TP-2 are equivalent to those in IEC 60076, with respect to the measurement of resistance and calculation of losses.

It is also proposed that regulated transformers will have to carry a verification mark indicating that the energy performance of the product has been verified. Reporting requirements are to remain unchanged, with the exception that % efficiency is to be reported rather than maximum losses.

See Appendix C for further details.

7.2.2 United States

Distribution transformers are estimated to lose approximately 61TWh of electricity per year, resulting in annual greenhouse emissions of 45Mt CO_2. Utilities purchase over 1 million new units each year, and it is estimated that if the average efficiency of utility transformers was improved by one-tenth of one percent, greenhouse emissions reductions of 1.8Mt CO_2 would be achieved over a 30 year period. As a result, the US has currently has a number of voluntary initiatives design to increase the efficiency of distribution transformers (USEPA, 1998b).

In the **Energy Star** transformer program, participating utilities agree to perform an analysis of total transformer owning costs, using a standard methodology, and buy transformers that meet Energy Star guidelines when it is cost-effective to do so. The program provides technical assistance to partners to ensure that transformers are not oversized, and has developed a Distribution Transformer Cost Evaluation Model (DTCEM) to provide a standard methodology for the evaluation of multiple transformer bids. To compliment this tool, the program also labels transformers which conform to its targets (USEPAa, 1998).

The **National Electrical Manufacturers Association (NEMA)** publishes a *Guide for Determining Energy Efficiency for Distribution Transformers (TP-1-1996)*, and a standard test method for the measurement of energy consumption in transformers (TP-2)

The **US Department of Energy (DOE)** Federal Energy Management Program encourages government procurement of energy efficient distribution transformers

The DOE is currently proceeding with industry-wide consultation and the development of test procedures prior to the adoption of efficiency standards for transformers by approximately mid 2003. No firm implementation commitment has been made as yet, however test standards under consideration include the ANSI/IEEE standards (C57.12.90-1993 and C57.12.91-1995) or the NEMA standard (TP-2 1998).

The **Consortium for Energy Efficiency** (CEE) has initiated a program aimed at the 6 million distribution transformers (dry-type) on the customer side of the meter [CEE website], and is part of a consortium with NEMA, USEPA and others to increase information and awareness of the potential for efficient transformers [deLaski et al, 1998].

See Appendix D for further details.

7.2.3 Mexico

The Mexican standard, NOM-002-SEDE-1999, which covers energy efficiency and safety for distribution transformers, was made mandatory in 1999. This sets both the minimum efficiency levels for distribution transformers and the maximum allowed losses, although these are less stringent than those provided in TP-2, proposed for Canada and the US.

NOM-002-sede-1999 also prescribes the test methodologies for calculation of losses (NMX-J-169-ANCE). It also makes allowances for manufacturers whose annual total production is less than 9,000 kVA, who may appeal for a transitionary period before meeting these requirements.

See Appendix E for further details.

7.2.4 Europe

For distribution transformers purchased in the European Union, three levels of standards are applicable:

- world-wide standards (ISO, IEC)
- European standards and regulations (EN, HD)
- national standards (e.g. BSI, NF, DIN, NEN, UNE, OTEL).

European Harmonisation Documents are initiated if there is a need for a European standard. The draft HD is a compilation of the different national standards on the subject. The HD is finalised by eliminating as many national differences as possible.

Among the many international standards for distribution transformers, two main European Harmonisation Documents specify energy efficiency levels:

- HD428: Three-phase oil-immersed distribution transformers 50Hz, from 50 to 2,500kVA with highest voltage for equipment not exceeding 36kV
- HD538: Three-phase dry-type distribution transformers 50Hz, from 100 to 2,500kVA, with highest voltage for equipment not exceeding 36 kV.

A separate HD is under consideration for pole-mounted trans-formers.

Distribution transformers built to HD428 and HD538 have a limited number of preferred values for rated power (50, 100, 160, 250, 400, 630, 1,000, 1,600 and 2,500kVA). Intermediate values are also allowed. The two key figures for energy efficiency, the load losses and the no-load losses, are specified for each rated power.

HD428.1 and HD538.1 provide the limits for load losses and no-load losses for some important types of oil-filled and dry-type distribution transformers, for the preferred rated power range of the transformers. For oil-filled distribution transformers, the HD allows a choice of energy efficiency levels, A, B and C.

Loss values for transformers are usually, declared as maximum values with a specified tolerance. If higher losses are found at the factory acceptance test, the transformer may be rejected or a financial compensation for exceeding the loss limit may be agreed between client and manufacturer. In the same way, a bonus may be awarded to the manufacturer, mainly for large transformers, for a transformer with losses lower than the limits agreed.

HD428 therefore allows customers to choose between three levels of no-load losses and three levels of load losses. In principle, there are 9 possible combinations, ranging from the lowest efficiency, (B-A') to the highest, (C-C'), which may be regarded as providing a high practical standard of energy efficiency for a distribution transformer.

The freedom for choosing different levels of energy efficiency is increased by the fact that transformer buyers can comply with HD428/538 through the use of a capitalisation formula, rather than the tabulated losses shown in the standard. In this, they are free to insert their own capitalisation values, to which no restrictions are imposed. This process of loss capitalisation is described in Section 10.6.

HD428.1 (part 1: general requirements and requirements for transformers with highest voltage for equipment not exceeding 24 kV) as well as other HD sections also contain phrases such as *"in the case of established practice in the market (...) the transformers can be requested and, by consequence, offered, with losses differing from the tabled losses"*, which indicates some freedom to national or local deviations.

See Appendix F for further details.

7.2.4 Chinese Taipei

Since 1992, an eco-label program called "GreenMark" has been run by the Environmental Protection Administration (EPA) and currently covers over 50 products. For conforming products, the GreenMark logo label may be used on product packaging, brochures or on the products themselves itself. It is intended that distribution transformers will be covered by this program although the energy performance criteria have not yet been determined.

See Appendix G for further details.

8. APPROPRIATE MEPS LEVELS FOR AUSTRALIA

8.1 Rationale for MEPS

The current Australian Standards for distribution transformers do not set minimum loss or efficiency levels, and do not require that information on either of these be provided for the purpose of meeting the existing standard.

Overseas, a number of approaches have been used, or are proposed, to reduce the significant losses attributable to distribution transformers. The scale of these losses are a function of (a) inefficiencies due to the design and materials used in transformers, and (b) the size of transformer selected for a given application. In the US, the voluntary Energy Star program has been designed to improve the sizing of transformers, while in Canada, the US and Mexico, the trend is towards the use of mandatory regulation to improve transformer efficiencies.

In each instance where standards are being imposed or proposed, existing pressures have been shown not to result in economically efficient outcomes. For example, analysis undertaken in the US for a number of efficient transformers demonstrated that improving transformer efficiency standards was cheaper than purchasing electricity. In this case, the levelised cost of savings was between US$0.006-0.03/kWh, while typical costs for new generation was US$0.02-0.03 [USEPA 1998]. In Europe, the estimated savings potential due to the use of energy efficient distribution transformers is 2% of generated power, equivalent to 22 TWh/year [EC 1999].

In Australia and all overseas countries analysed, the bulk of distribution transformers are purchased and operated by the Transmission and Distribution (T&D) utilities. In Australia, although the generation and retail sectors are open to competitive pressures, T&D utilities are considered natural monopolies and, as such, are financially regulated by the ACCC and State-based regulators. In the United States and Canada, where deregulation is limited, and the deregulated UK energy market, the T&D sector also remains a regulated monopoly. In all these cases, the regulators oversee the process whereby allowable costs incurred by T&D companies are passed through to consumers, with the general aim of ensuring that reliable electricity supply is provided at least cost to society.

There is a high degree of similarity between the economic regulation of T&D employed in different countries, and all tend to include drivers for increased efficiencies. However, there is evidence that cost effective investment in transformer efficiency is not occurring in countries such as Canada, the US and parts of Europe, and that the existing regulatory regimes are not providing sufficient motivation to ensure investment in efficiency.

The major causes for this appear to include the competition for capital and the treatment of losses in the network. In many cases, the cost of losses are passed through to the customers and there is no financial gain for the network operator in reducing these costs. As a result no return can be gained from investment in more efficient transformers.

In recognition of these market failures, some countries are proposing further specific regulation to improve transformer efficiencies. Regulators in Australia have already begun to highlight a similar issue emerging in the deregulated Australian electricity market. A recent report on distribution system losses in Victoria concluded:

"We note that the regulatory regime in Victoria does not at present provide for incentive measures to drive the Distribution Businesses to optimise distribution system losses. We also note that this situation would appear to be in contrast to the policy on the transmission system."

"A further point is that at present retailers (suppliers) and customers pay for the losses incurred." [ORG, 2000]

A similar report in NSW quoted the submission from EnergyAustralia, as follows:

*"DNSPs can be expected to make investment decisions on the basis of maximising the value to their shareholder. Such decisions all impact in some way upon the losses in their networks. However, under the present regulatory regime the cost of losses is external to the investment analysis and there is **no** incentive to include them. There is no financial benefit to a network in reducing losses.*

In an illustration originally cited by Leith Elder of Great Southern Energy, DNSPs are faced with everyday decisions on transformer purchase. Traditionally, the cost of losses has been evaluated over *the life of the asset using an energy value related to the Bulk Supply Tariff. The quotations for supply of transformers would be adjusted as follows:*

Supplier A – Purchase price $20,000, capitalised losses $20,000, total $40,000

Supplier B – Purchase price $18,000, capitalised losses $30,000, total $48,000

In the present regulatory environment, a rational DNSP would choose offer B, even though it increases total costs to customers. There is no incentive for the DNSP to take into account the cost of energy losses in the purchase decision.

If the cost of losses is to be taken into account in investment decision making, as it must if economic (as opposed to merely financial) investment is to take place, an explicit direction is required to DNSPs to internalise this cost. With an appropriate value for the cost of losses incorporated in investment analysis, the Regulator should then have confidence that investment will take place to optimise (not minimise, as there is inevitably a cost tradeoff) capital investment." [IPART, 1999]

On the evidence of the preliminary examination to date and with the information which has so far been forthcoming from the industry, it would appear that a case for improving transformer efficiencies through further regulation exists in Australia.

Since the great majority of distribution transformers are manufactured locally, it is recommended that any new regulations provide sufficient lead times to enable existing suppliers to alter designs and manufacturing processes. This will enable manufacturers to maintain market share and minimise the economic impact.

Another important factor with regard to MEPS and greenhouse reductions, is the relatively long lifetime of distribution transformers. An inefficient transformer is likely to be operational for 30 years or more, with little opportunity to replace it before it reaches the end of its life. Missing the opportunity of selecting an inefficient transformer now, therefore represents a significant lost opportunity to reduce future greenhouse emissions.

8.2 Recommendations

8.2.1 Performance Standard

The design, manufactures and materials for distribution transformers are similar worldwide. It is therefore recommended that the proposed standards for the US and Canada, provides the basis for a transformer MEPS in Australia. (*Note:* The standards proposed for the US and Canada are equal in all respects except for the liquid-filled 1000 and 1500 kVA categories. The Australian proposals are based on the Canadian proposals.)

It should be noted that the electricity system in North America operates at a frequency of 60 Hertz, while in Australia the system frequency is 50 Hz. Since the no-load (magnetisation) losses scale as the square of frequency this difference will mean that that the no-load losses in North America will be between 30% to 40% higher than in Australia. This suggests that to meet an equivalent standard to that proposed for Nth America for Australia requires lower levels for no-load losses and consequently higher efficiency levels.

A report commissioned from Professor Trevor Blackburn, and included in Appendix I, discusses the ramifications of the different frequencies on transformer performance. The report also translates the values proposed in Canada (60 Hz system) to equivalent efficiency values for transformers operating at 50 Hz. These are the proposed performance values for Australia and are reproduced in Tables 11 & 12 below:

Table 11: Proposed Performance Standard for Liquid Filled Transformers

Power rating	Efficiency proposal
[KVA]	% [50 Hz operation]
Single phase units	**[50% load] [Including SWER Transformers]**
10	98.5
15	98.7

25	98.9
Three phase units	**[50% load]**
25	98.4
50	98.7
100	98.9
200	99.1
300	99.1
500	99.2
750	99.3
1000	99.4
1500	99.5
2000	99.5
2500	99.5

Table 12: Proposed Performance Standard for Dry-type Transformers [Medium Voltage applications]

Power rating	Efficiency proposal
[KVA]	% [50 Hz operation]
Single phase units	**[50% load] ***
15	97.9
25	98.3
Three phase units	**[50% load]**
25	97.6
50	98.0
100	98.3
200	98.6
300	98.7
500	98.9
750	99.0
1000	99.0
1500	99.1
2000	99.1
2500	99.2

Note:

* In the US and Canadian, the Standards prescribe efficiencies for low voltage, dry-type transformers to be measured at 35% loads. Recent data on privately-owned dry-type transformers in the US indicate that average loads may be considerably lower, in the region of 16% [Korn, et al, 2000]. It is suggested that the standard testing conditions should be adjusted to reflect a more realistic loading, in order that losses are minimised. At this stage not sufficient is known about the loading of dry-type transformers, however it is recommended that further investigation is undertaken and if necessary the loading requirement under the proposed standard for these types of transformers is reduced to a more appropriate figure.

It should be noted that in 2003 the standard single phase electricity supply in Australia will switch from 240 volts to 230 volts. The impact of this change on transformers is discussed further in Appendix J, and the above minimum efficiency values are recommended for new transformers designed to meet the new supply voltage levels.

8.2.2 Test Methodology

The current test methodology in IEC 60076, and reproduced in AS 2374 would appear to provide an appropriate test methodology. Since TP-2 is largely equivalent it may be useful as a reference document, however there seems little reason not to use the existing standard.

There is concern that the presence of harmonics in electricity supply will mean that transformers in operation may be more inefficient than when under test conditions. This is particularly likely for privately owned transformers located within consumer's premises, where power quality is less regulated. This issue is canvassed in detail in Appendix J, by Professor Blackburn.

It is unlikely that the proposed transformer standards can address issues of power quality, however it should be noted that losses can increase substantially with increase harmonic content. Professor Blackburn suggests that the onus should be placed on the consumer to comply with power quality standards, as utilities are required to under AS 2279.

Professor Blackburn also discusses issues relating to testing procedures and equipment for transformers, including on-line monitoring of transformer losses.

8.3 Other Programs to Strengthen Demand for Energy Efficient Equipment

Additional action may be needed by governments to ensure that the transformer enhancement process, including in relation to units being refurbished, is embraced nationally by manufacturers, utilities and other owners. Further consultation with the industry should be undertaken to understand what type of programs are appropriate, however potential programs could include the following:

8.3.1 Information

As stated previously, the correct sizing of transformers can help to reduce losses significantly. Because of the wide range of variables involved in sizing transformers, MEPS is not an efficient means of tackling this issue. In the US the voluntary Energy Star program has been used with apparent success to assist utilities in improving the sizing of distribution transformers and in assessing bids. Similar programs have been canvassed in Europe (see Appendix F.8).

Consideration should therefore be given to similar programs under the best practice program which can compliment the introduction of MEPS and improve the way that transformers are sized. This might include technical tools such as evaluation software in order to optimise transformer size on a total cost (TOC) and efficiency basis. Although loss capitalisation is well understood by utilities, many private purchasers are not familiar with this process and may benefit from the provision of tools to assist them to evaluate the cost of losses.

In addition, transformer labelling programs could be considered, particularly for the privately-owned market (see Appendix F.8). The most basic of labelling requirements should be the mandatory provision of information on losses on the rating plate of all transformers, according to a standard format agreed by industry and government. Not only would this provide information to owners (although some may have obtained this information during the purchasing process), but it would facilitate the future evaluation of the performance of the stock, without requiring that the original specifications are located. This would be useful for all transformers.

Further types of labelling could be considered, including:

- Voluntary labelling programs such as Energy Star labelling;
- Mandatory labelling programs which might be a single efficiency label, or a ranking label such as used for domestic refrigeration products.

Due to the difference in product types used in North America, the Energy Star system could not be directly transferred to Australia, however an equivalent system could be established in Australia following further research into the range of products available in the marketplace.

In our opinion, the greatest impact of a labelling program would be on the private ownership market, and most products for this market are currently differentiated by manufacturers. Therefore we consider that a labelling program specifically for this market is feasible. However, since this is such a competitive market, there is probably only a minimal variation in the performance of these products – the greater variation is manifest in the comparison between these products and those designed for the utility market. As a result, we do not consider than a single label program, such as energy star, will address this market effectively.

A more effective approach would be to have a label which showed how a particular transformer performs in relation to a benchmark. For example, this could be the best performing product in each category in the marketplace. Alternatively, the labels could express the efficiency of each transformer, eg. by allocating stars to ranges of efficiency for each transformer category.

In our opinion, such a scheme applied only to the privately owned market would be more effective if it was mandatory. However, we recommend that further examination of the issues involved, and particularly the degree to which labelling can be designed to show product differentiation, is undertaken before the final decision to implement a labelling program is taken.

8.3.2 Expert Advice

A further option, which may be particularly appropriate for private owners of transformers, is the provision of expert advice on transformer design and sizing issues. Programs could include the promotion of advisory services to end-users, and financial assistance to increase the uptake of these services.

Utilities would be in an ideal position to provide such services to customers, in view of the increasing focus on the development of energy services, and the expertise that utilities have in the design and management of transformers. However, any potential income from such an activity is unlikely to overcome the current lack of incentive for network operators to minimise losses, under the current regulatory regimes in Australia (discussed in further detail in 8.3.3 below).

We note that there may some benefit for Electricity Retailers to reduce losses, particularly where they are subject to greenhouse emission reduction targets, as is the case in NSW. However, the difficulties in evaluating the impact of advisory services, and the uncertainties involved means that in practice this is unlikely to provide a sufficiently strong incentive to stimulate the development of new services.

8.3.3 Regulatory Change

A key issue for the promotion of more efficient transformers is the current regulatory regime, particularly as it impacts on electricity network operators. State-based regulators determine issues relation to prices and access for their distribution network and at present perform a similar function for the transmission network, albeit that in the eastern States the later is heavily influenced by the general principles contained in the National Electricity Code (NEC). From the beginning of 2003, the transmission network will run according to the NEC, under the oversight of the Australian Consumer and Competition Commission (ACCC).

Regulation of the monopoly elements of the electricity system is both necessary and complex, with the aim of sustaining a viable industry while at the same time providing reliable energy services to the community at least cost. There are number of approaches taken by network regulators in Australia at the present time, each of which deliver different incentives to those under their jurisdiction. Assessments of the impact of current regulation on utility investment in efficient transformers are included in [ORG, 2000] and [IPART, 1999], both of which conclude that the current regime is likely to act as a deterrent.

Although the issue of designing effective regulation is too involved and complicated for this report, nevertheless it would be a serious omission not to point out that altering the regulatory regime with respect to network operators is likely to be amongst the most cost effective means of reducing future transformer losses in Australia. As a result, we recommend that the respective regulators are thoroughly involved in the process of consultation to develop initiatives in this area, with the aim of achieving an incentive for utilities to invest in efficient assets, such as transformers.

8.3.4 Finance Packages

In some cases, energy efficient options may require additional capital costs, albeit that these are offset by lower running costs. A tried and tested means of overcoming capital costs barriers is through innovative finance packages such as third party financing arrangements and shared savings agreements. Such facilities enable the capital costs of energy efficient improvements to be met by a financial institution and repaid using part of the savings resulting from lower energy bills. It may be appropriate to make these services available to transformer purchasers, particularly smaller private owners, as part of a promotion for energy efficient transformers. Additional incentives could be provided to encourage efficient purchasers, for example by government guarantees or through low interest rates charged on the capital loan.

9. Greenhouse Implications

9.1 Total Greenhouse Emissions

Not enough information is currently available to make an accurate estimate of total greenhouse emissions resulting from distribution transformers in Australia, however preliminary estimates are possible.

The difference between total electricity generated and consumed in Australia, 1998, was 21,800GWh. This represents both losses due to transformers and from wires.

Table 13: T&D Losses in the Australian Electricity System, 1998

Total Generation (GWh)	179,096
Total Consumption (GWh)	157,290
Losses (GWh)	21,806 (12.2%)

Although there is little information on the quantity of losses attributable to transformers in Australia, a study of the UK and European electricity systems estimated that losses in distribution transformers account for approximately 2% of electricity consumption, or just over 30% of transmission and distribution losses. See Table 14.

Table 14: Estimated Losses in UK and European Electricity Network [EU 1999]

Area	Losses
Energy Consumption (EU15)	2,253 TWh (100%)
Energy Losses	6.5%
Total Transmission Losses	1.7%
Total Distribution Losses	4.8%
Distribution Transformer Losses	2%

In the US, similar estimates have shown that transformer losses may be responsible for a higher proportion, up to 40% of total transmission and distribution losses.

Table 15: Non-Generating Public Utility Losses [BPA 1986]

Area	Losses
Distribution Transformers	36.5%
Substation Transformers	2.2%

Transmission System	10.5%
Secondary System	8.1%
Feeders	34.9%
Unaccounted	7.8%

Comparison between networks is difficult, due to differences in technologies employed, voltages, distances and a range of other factors. The US network uses a far larger proportion of single phase transformers than is the case in Australia, which is more similar to the UK network in this respect. However, the distances involved in the UK system are considerably shorter than here so losses associated with the transmission and distribution lines would be expected to be a greater share of total losses.

Following consultation with the industry, we have assumed that distribution transformers in Australian electricity system account for around 25% of T&D losses, equivalent to 5,400 GWh or approximately 5.4 Mt CO_2-e in 1998.

9.2 Greenhouse Reduction Potential

To date it has not been feasible to undertake detailed greenhouse modelling on the potential for greenhouse savings in distribution transformers in Australia, however with the support of the industry and its representative organisations this is planned for 2001. The following comprises a preliminary estimate of the potential savings due to the implementation of MEPS.

Electricity consumption is predicted to grow steadily, at least for the period to 2015 (NEMMCO 2000), and the capacity of transformers has grown at a 1.3% per annum through the 1990's (ESAA 1999). As a result we have estimated that, without constraint, losses are also likely to grow at an average of 1.3% per annum. At the same time, the greenhouse intensity of electricity is predicted to diminish, due to more efficient generation practices and the use of gas fired power stations (although this reduction is small and gradual). Taking into account these factors, the business as usual scenario shows greenhouse emissions rising to 6 Mt CO_2-e by 2015.

Table 16: Business as Usual Greenhouse Emissions

Year	CO2-e (KT)
1998	5,467.1
1999	5,506.9
2000	5,547.1
2001	5,576.3
2002	5,605.7
2003	5,635.2
2004	5,664.9
2005	5,694.7
2006	5,724.7
2007	5,754.8
2008	5,785.1
2009	5,815.6
2010	5,846.2
2011	5,891.8
2012	5,937.8
2013	5,984.1

2014	6,030.7
2015	6,077.8

In 2003, Australia will adopt the standard single phase voltage of 230 volts (AS 60038-2000), in line with proposals by the IEC. This will cause a slight decrease transformer efficiency, although the extent of these will depend upon the means by which electricity supply utilities achieve the change from 240 volts to 230 volts. To this extent, the estimate of future greenhouse emissions from distribution transformers are likely to be conservative. The issues are discussed in Appendix J by Professor Blackburn.

Discussions with the industry suggest that the large majority of distribution transformers currently purchased by utilities would comply, or very nearly comply, with the proposed MEPS levels. The area where most benefit would arise is in the private ownership market where the least efficient products are typically located. This also tends to be the largest market for dry-type transformers. Dry-type transformers provide the greatest potential in terms of improved energy performance.

Based on available information concerning the stock and performance of Australian distribution transformers, it is estimated that implementation of the proposed MEPS level in 2005 would reduce greenhouse emissions by approximately 30kt CO_2-e per annum. Cumulative annual savings to 2010 and 2015 are estimated to be 175kt CO_2-e and 330kt CO_2-e, respectively.

As discussed previously, it is considered likely that, unconstrained by regulation, there will be a trend for an increasing number of higher loss transformers to enter the Australian market. Although it is difficult to quantify the impact of this on greenhouse emissions, under this scenario emissions would increase over the next decade.

To provide a guide we have considered two cases:

- where energy consumption as a result of new transformer purchases each year consume 10% more electricity than 'low loss' equivalents available now, and
- where energy consumption of new transformers consume 20% more electricity than their equivalents.

In the first case, additional emissions in 2015 would total approximately 290kt CO_2-e. In the second case, additional emissions would total approximately 580kt CO_2-e.

Therefore the total impact of MEPS under these scenarios would be a reduction of 330kt CO_2-e plus these additional impacts, as summarised in the following table.

Table 17: Greenhouse Impacts resulting from the Implementation of MEPS

	Total Emissions from Distribution Transformers, 2015 (Mt CO_2-e)	Potential Saving due to MEPS (kt CO_2-e)
Business as Usual	6.0	330
Scenario: 10% growth in consumption by new purchases	6.3	620
Scenario: 20% growth in consumption by new purchases	6.6	910

Due to the long-life of distribution transformers, and therefore the comparatively slow turnover of stock, savings are predicted to continue for at least 30 years at approximately the same rate. This will be the case unless additional measures are implemented designed to stimulate the early retirement of inefficient stock.

It should be noted that these estimates do not include any impact on the correct sizing of transformers from the introduction of the proposed MEPS levels. As stated in previous sections, the correct sizing of transformers can make a significant difference in the quantity of losses achieved, as well as the economics of operating transformers. This issue cannot be efficiently addressed through a MEPS program, however, it is worth considering whether some additional type of advisory program would be effective. For example, in the US, elements of the Energy Star Program are designed to improve the sizing capabilities of transformers.

10. ECONOMIC IMPLICATIONS

Since Australian manufacturers can currently supply a wide range of high efficiency transformers, limitations of access is not a barrier. As far as we are able to ascertain, increasing the efficiency standards for new transformers will not advantage any one Australian supplier over another.

There is a capital cost premium for efficiency in transformers, reflecting increased material costs, and in some cases, handling costs. For example, the approximate difference between the "low loss" transformers currently on the market, and the "industrial" range is in the region of 5-10%. However, this is offset by the financial benefits of reduced losses incurred over the lifetime of the transformer. Payback periods for efficient transformers vary considerably and critically depend upon the value placed on future electricity losses.

Without regulation, the increasing pressure on purchasers to reduce capital costs is likely to result in a growth of imported, higher loss, transformers. This will have ramifications for Australian manufacturers and broader economic impacts.

11. IMPLEMENTATION

11.1 MEPS Timetable

It is understood that NAEEEC proposes to recommend to ANZMEC the following target timeframe for the introduction of MEPS, giving industry an appropriate period of notice to undertake any necessary modifications to production procedures. This proposed timeframe may be modified to take into account specific circumstances that may arise not foreseen at this time.

1.	**Development Stage**	**Timetable**
	Following the publication of this desk-top review of the energy impacts of mandatory and / or voluntary measures, the following steps will occur • an industry expert will work to refine the initial MEPS proposals. • Cost/benefit analysis of potential legislative options. • Industry and stakeholder consultation on potential legislative proposals. • Development of Australian and New Zealand Standards for inclusion in regulations. • Ministerial approval required before introduction of any new regulations.	Commenced from July 2000 and completed by July 2002
2.	**Notification Stage** Period of notification will depend on the level of manufacture undertaken in Australia. Longer periods would apply if Australian industry required to undertake substantial development or re-tooling	The Australian standard will be published by July 2002 containing the MEPS levels and the MEPS will come into effect from July 2005
3.	**Duration Stage** This is the 'stability period' in which no changes to regulations are made (ie MEPS levels unchanged).	Commenced from July 2005 and scheduled for reconsideration by July 2010

11.2 Strategy for public consultation

We understand that stakeholder participation in the process will be mainly through having representation on the project steering committee that NAEEC has established, together with involvement in the normal consultation process undertaken during the Regulatory Impact Statement process.

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USEPA, 1998b.	*Transforming Dollars Into Sense. The economic and environmental benefits of high-efficiency distribution transformers*. Prepared by ICF Incorporated for the US. Environmental Protection Agency, Atmospheric Pollution Prevention Division. Washington DC.

APPENDIX A: MAILING LIST OF INTERESTED PARTIES

A.1 Organisations

A1.1 Electricity Supply Association of Australia Limited (ESAA)

Patrick McMullan, Technical Director, Level 11, 74 Castlereagh Street, Sydney NSW 2000

PO Box A2492, Sydney South, NSW 1235

Tel: 61-2-9233-7222

Facsimile: 61-2-9233-7244

http://www.esaa.com.au/

A.1.2 Australasian Railway Association

PO Box 266, Collins Street West, Melbourne, Victoria 8007

Telephone: (03) 9614 5162

Facsimile: (03) 9614 5514

www.ara.net.au

A.1.3 Australian Greenhouse Office

John Gorton Building, GPO Box 621, Canberra ACT 2601

Telephone: 02 6274 1888 *(International:* +61 2 6274 1888)

Facsimile: 02 6274 1795 *(International:* +61 2 6274 1795)

www.greenhouse.gov.au

A.1.4 Australian Industry Group

Nation Manager Trade Policy, GPO Box 817, Canberra ACT 2601.

A.2 Manufacturers

A.2.1 Australian Electrical & Electronic Manufacturers' Association Ltd (AEEMA)

Executive Director, Brian Douglas, GPO Box 1966, Canberra City, ACT, 2601

Phone: +61 (2) 6247 4655

Fax: +61 (2) 6247 9840

Email: bdouglas@aeema.asn.au

A.3 Individual Manufacturers

A.3.1 Alstom Australia Ltd.

35 Evans Road, Rocklea, QLD 4106

Telephone: 61 7 3274 7750

Facsimile: 61 7 3277 0258

http://www.alstom.com.au/Business/Transformers/

A.3.2 Nu-Lec Group

35-37 South Street, Lytton, Queensland, 4178 Australia.

Tel: +617 3249 5444

Fax: +617 3249 5888

http://www.nulec.com.au/contact.html

A.3.3 ABB Transmission and Distribution Limited

Business Development Manager, P.O. Box 315, Liverpool, NSW 2170

Ph: 9821 0147

Fax: 9600 7050

A.3.4 Schneider Pty Ltd

2 Solent Circuit, Norwest Business Park, Baulkham Hills NSW 2153

Ph: (02) 9851 2800

Fax: (02) 9629 8325

http://www.schneider.com.au/

A.3.5 Wilson Transformer Co. Pty. Ltd

P.O. Box 5, Glen Waverley VIC 3150

Ph: (03) 39560 0411

Fax: (03) 9560 0599

http://www.wtc.com.au

A.3.6 AW Tyree Transformers Pty Ltd

A.3.7 Sola Australia Ltd

A.4 Regulators

The Transformer industry is currently unregulated. However if it were regulated it would seem natural for this regulation to be done by the same departments that regulate the supply industry. These include:

A.4.1 NSW Ministry of Energy and Utilities

PO Box 536, St Leonards, NSW 2065

Telephone: 02 9901-8888

A.4.2 Office of the Chief Electrical Inspector

Chairman, Electrical Approvals. 3/4 Riverside Quay, Southbank VIC 3006. PO Box 262, Collins Street West V 8007

Telephone: (03) 9203-9741

A.4.3 Office of Chief Electrical Inspector

PO Box 262, Collins Street West, VIC 8007

Telephone: 03 9203 9741

Facsimile: 03 9686 2197

A.4.4 Department of Mines and Energy

Electrical Safety Branch, 61 Mary Street, Brisbane QLD 4000. PO Box 194, Brisbane QLD 4001

Telephone: 07 3237 0239

Facsimile: 07 3237 0229

A.4.5 Department of Mines and Energy

Energy Division, Level 19, 30 Wakefield, Adelaide SA 5000

Telephone: 08 8226 5500

Facsimile: 08 8226 5523

A.4.6 Power and Water Authority

Chief Electrical Inspector. 4th Floor JAPE Building, 18-20 Cavenagh Street, Darwin NT 0800.

GPO Box 1921, Darwin NT 0801

Telephone: 08 8924 711

Facsimile: 08 8927 212

A.4.7 Office of Energy

Technical and Safety Division. 20 Southport Street, Leederville WA 6007

Telephone: 08 9422 5200

Facsimile: 08 9422 5244

A.4.8 Hydro-Electric Commission

Chief Electrical Inspector, 4 Elizabeth Street, Hobart TAS 7000.

GPO Box 355D, Hobart TAS 7001

Telephone: 03 623 05855

Facsimile: 03 622 33279

A.4.9 Department of Urban Services

GPO Box 158, Canberra ACT 2601

Telephone: 02 6207 5111

Facsimile: 02 6207 6229

A.5 Testing Interests

In the past Electricity Suppliers (one of the main customers of transformers) have run many of the testing interests for power transformers. However with the deregulation of the supply industry many of these testing interests have been set up as separate entities or their services outsourced.

A.5.1 CSIRO Energy Technology

Mr Harro Drexler, Commercial Manager, PO Box 136, North Ryde NSW 1670

Phone: +61 2 9490 8666

Fax: +61 2 9490 8909

Email: H.Drexler@det.csiro.au

A.5.2 Australian Electrical Testing Centre

University of South Australia, The Levels Campus Buildings U, V, Warrendi Road, Mawson Lakes, South Australia, 5095

Telephone 61 8 8302 3357

Fax 61 8 8302 3383

Email: **aetc@unisa.edu.au**

A.5.3 QAS Homebush

1 The Crescent, Homebush, NSW 2150, Sydney, Australia

Customer Service Toll Free: 1300 360 314

Phone: (612) 97464900

Fax: (612) 9746 8460

Email: customerservice@qas.com.au

http://www.qas.com.au/

A.5.4 NATA

7 Leeds Street, Rhodes, NSW 2138

Ph: +61 2 9736 8222

Fax: +61 9743 5311

http://www.nata.asn.au/

A.6 Consumers

A.6.1 Australian Consumers Association

57 Carrington Road, Marrickville, NSW 2204

Phone 02 9577 3333

Fax 02 9577 3377

http://www.choice.com.au/

A.6.2 AUSTA Energy

John Tabrett, Acting CEO, GPO Box 636, Brisbane, Queensland, Australia 4001

Telephone: (07) 3228 2606

Email: jtabrett@austaenergy.com.au

http://www.austaelectric.com.au/

A.6.3 Delta Electricity Corporate Office

Level 12, Darling Park, 201 Sussex Street, SYDNEY NSW 200. PO Box Q863 QVB NSW 1230 Telephone (02) 9285 2700

Facsimile (02) 9285 2777

http://www.de.com.au/

A.6.4 Eastern Energy Ltd Corporation Pty Ltd

2 Phillip St, BROADMEADOWS 3047.

Tel: 03 9302-4359

Fax: (03) 9229 6112

EEinfo@tua.com.au
http://www.easternenergy.com.au/

A.6.5 ElectraNet SA

A.6.6 Ergon Energy

Brisbane Ground Floor, 61 Mary Street, Brisbane QLD 4000. PO Box 107 Albert Street, Brisbane QLD 4002

Tel: 07 3228 8222

Fax: 07 3228 8118

E-mail: customerservice@ergon.com.au

http://www.ergon.com.au/

A.6.7 GPU Powernet

PO Box 2888, Rowville, VIC 3178

Ph: 03 9764 7404

Email: powernet@gpupowernet.com.au

A.6.8 Hazelwood Corporate

Level 9, 313 Latrobe St, Melbourne Vic 3000

Tel: 03 5135 5000

Fax: 03 9642 8018 *(country code 61)*

Email: hazpower@hazpower.com

http://www.hazelwood-power.com.au/

A.6.9 Integral Energy

PO Box 6366, Blacktown, NSW 2148

Ph: 131 002

Fax: (02) 9853 6000

Email: integral@integral.com.au

http://www.integral.com.au/

A.6.10 Hydro Electric Corporation

4 Elizabeth Street Hobart, Tasmania, 7001

Ph: (03) 6237 3400

webmaster@hydro.com.au

http://www.hydro.com.au/

A.6.11 Loy Yang Power Management Pty Ltd

Bartons Lane, Traralgon, Victoria 3844. PO Box 1799 Traralgon Victoria 3844.

Telephone: +61 3 5173 2917

Facsimile: +61 3 5173 2038

Email: corp_rel@loyyangpower.com.au

http://www.loyyangpower.com.au/

A.6.12 Macquarie Generation

34 Griffiths Road, LAMBTON NSW 2299. PO Box 3416, HAMILTON Delivery Centre NSW 2303

Telephone: +61 2 4968 7499

Facsimile: +61 2 4968 7433

A.6.13 Power & Water Authority

A.6.14 Powerlink

A.6.15 Transend

A.6.16 TransÉnergie Australia

Level 11, 77 Eagle Street, GPO Box 7077, Riverside Centre, Brisbane, Qld 4001

Phone: Tony Cook (07) 3211 8614

Phone: Mike Farr (07) 3211 8613

Fax: (07) 3211 8619

http://www.transenergie.com.au

A.6.17 TransGrid

Steve Jones, Manager, Technology Development

Elizabeth St (cnr Parks St), PO Box A1000, Sydney South NSW 2000

Ph: (02) 9284-3000 201

Email: info@tg.nsw.gov.au

http://www.tg.nsw.gov.au/

A.6.18 Western Power Corporation

GPO Box L921, Perth WA 6842

Telephone +61 8 9 326 4911

Facsimile +61 8 9 326 4595

http://www.wpcorp.com.au/

A.7 Distribution

ACTEW Corporation

ACTEW Energy

Advance Energy

AGL Electricity

Aurora Energy

Australian Inland Energy

Capricornia Electricity Corporation

CitiPower

Eastern Energy

ENERGEX

Energy Australia

ETSA Utilities

Far North Queensland Electricity Corporation

Great Southern Energy

Hydro Electric Corporation

Integral Energy

Mackay Electricity Corporation

North Queensland Electricity Corporation

Northern Territory Power Transmission Pty Ltd

NorthPower

Powercor Australia

South West Power

United Energy

Wide Bay-Burnett Electricity Corporation

APPENDIX B: DETAILS OF AUSTRALIA STANDARDS

B1. Relevant Australian Standards

The following standards relate directly or indirectly to transformers:

AS 1137.3-1981 Insulators - Porcelain and glass indoor and outdoor station post insulators (for voltages greater than 1000 V a.c.): Covers materials, characteristics, fixing arrangements, and type, batch and routine tests, for insulators and insulator units designed to provide rigid support for busbars, parts of isolators, parts of air-break switches and other conductors in stations and for similar applications, but does not apply to insulators for supporting overhead transmission line conductors nor to bushing insulators. An appendix deals with selection and application of post insulators.

AS 1194.1-1984 Winding wires - Enamelled round copper winding wires: Specifies dimensions and material requirements for conductor and enamel covering and prescribes tests to establish compliance. Provides for coverings of PVA, PUR, PEI and PE-A1.

AS 1194.2-1983 Winding wires - Enamelled rectangular copper winding wires: Specifies material requirements and dimensions for conductor and enamel covering and prescribes tests to establish compliance. Provides for coverings of PVA, PEI and PE-A1.

AS 1194.3-1984 Winding wires - Enamelled round aluminium winding wires: This Standard specifies dimensions and material requirements for conductor and enamel covering and prescribes tests to establish compliance. Provides for coverings of PVA and PEI.

AS 1194.4-1985 Winding wires - Enamelled rectangular aluminium winding wires: Specifies requirements for conductor and enamel covering and prescribes tests to establish compliance. Provides covering of PVA, PEI and PE-AI.

AS/NZS 1194.5:1996 Winding wires - Test methods: Specifies test methods for round and rectangular, copper and aluminium winding wires in Standards AS/NZS 1194 Parts 1 to 4, where relevant.

AS 1265-1990 Bushings for alternating voltages above 1000 V: Specifies bushings supplied separately for use in the construction of indoor and outdoor electrical equipment, transformers and electrical installations that are connected to a.c. systems having a rated voltage above 1000 V. The bushings are capacitance graded or non-capacitance graded. It is technically identical with and has been reproduced from IEC 137. Modifications have been included to suit Australian conditions.

AS 1767-1975 Insulating oil for transformers and switchgear (incorporating Amdt 1): Applies to unused oil delivered in tank wagons or in drums, intended for the immersion filling of transformers, switchgear and certain other electrical equipment in which oil is required as an insulant or for heat transfer. It specifies composition, appearance, characteristics, and method of sampling of the oil, and methods of testing for sludge and acidity after oxidation, flashpoint, viscosity, pour point, electric strength, acidity, corrosive sulphur, water content, density, loss tangent and resistivity.

AS 1824.1-1995 Insulation co-ordination - Definitions, principles and rules: Specifies the procedure for the selection of the standard withstand voltages for the phase-to-earth, phase-to-phase and longitudinal insulation of the equipment and the installation of three-phase a.c. systems having a highest voltage for equipment above 1 kV. It also lists the standardized values from which the standard withstand voltages shall be selected. This Standard is technically equivalent to and has been reproduced from IEC 71-1:1993.

AS 1824.2-1985 Insulation coordination (phase-to-earth and phase-to-phase, above 1 kV) - Application guide: Provides guidance in the application of AS 1824.1. It includes sections on voltage stresses in service, insulation withstand and protective devices, coordination between stresses, and withstand levels in various voltage ranges. Appendices cover surge transference through transformers, validity of tests described in AS 1824.1, examples of application and clearances in air to ensure a specified impulse withstand voltage in installations.

AS 1931.1-1996 High-voltage test techniques - General definitions and test requirements: Applies to tests with direct, alternating and impulse voltage and with impulse currents on equipment having its highest voltage above 1 kV. This Standard is identical with and has been reproduced from IEC 60-1:1989 and its Corrigendum:1992.

AS 1931.2-1996 High-voltage test techniques - Measuring systems: Applies to complete measuring systems and to their components for the measurement of high-voltages and currents during tests with direct voltage, alternating voltage, lightning and switching impulse voltages and for tests with impulse currents. This Standard is identical with and has been reproduced from IEC 60-2:1994.

AS 2374.1-1997 Power transformers - General: Specifies the technical requirements for single and three-phase power transformers, including auto transformers, but excludes single-phase transformers rated at less than 1 kVA, three-phase transformers rated at less than 5 kVA, and certain special transformers such as instrument, starting, testing and welding transformers, transformers for static converters and those mounted on rolling stock. Based on IEC 60076-1:1993. Includes Australian variations such as commonly used power ratings and preferred methods of cooling, connections in general use, and details regarding connection designation.

AS 2374.2-1997 Power transformers - Temperature rise: Specifies temperature-rise limits and methods of test for measuring temperature rise. Based on but not equivalent to, and has been reproduced from IEC 60076-2:1993. Includes Australian variations.

AS 2374.3.0-1982 Power transformers - Insulation levels and dielectric tests - General requirements: Specifies the insulation levels and dielectric tests for power transformers as defined in AS 2374.1. Based on IEC 60076-3.

AS 2374.3.1-1992 Power transformers - Insulation levels and dielectric tests - External clearances in air: Sets out minimum clearances in air between live parts of bushings on oil-immersed power transformers and objects at earth potential. The text has been reproduced from IEC 60076-3-1:1987 and the tabulated minimum clearances have been modified.

AS 2374.5-1982 Power transformers - Ability to withstand short-circuit: Specifies the design of power transformers as defined in AS 2374.1, and the requirements necessary both in regard to their ability to withstand short-circuit and the means of demonstrating that ability. Based on IEC 60076-5.

AS 2374.6-1994 Power transformers - Determination of transformer and reactor sound levels: Defines sound power versus sound pressure and sets out the methods by which the sound power levels of transformers, reactors, and their associated cooling equipment shall be determined. Standard and reduced sound power level limits for transformers only have been added in an Australian Appendix. Technically equivalent to IEC 551:1987, with the addition of Appendix AA.

AS 2374.7-1997 Power transformers - Loading guide for oil-immersed power transformers: Provides guidance on determining the acceptable relationship between transformer rating and proposed load cycle when considering the effect of operating temperatures on life expectancy due to insulation deterioration and thermal ageing. Includes recommendations for loading above the nameplate rating and guidance for choosing appropriate rated quantities and loading conditions for new installations. It applies to the same range of transformers complying with AS 2374.1-1997. This Standard is technically equivalent to and reproduced from IEC 354:1991 and includes Australian informative appendices on determination of the thermal time-constant and indirect measurement of winding hot-spot temperature.

AS 2558-1982 Transformers for use on single wire earth return distribution systems: Relates to isolating and distribution transformers for use on SWER distribution systems, and is intended to be used in conjunction with AS 2374, which applies to SWER transformers except where its requirements are amplified or modified by this Standard.

AS 4398.1-1996 Insulators - Ceramic or glass - Station post for indoor and outdoor use - Voltages greater than 1000 V a.c. - Characteristics: Specifies requirements for the construction and performance of ceramic or glass station post insulators. It is to be read in conjunction with Part 2: Tests. It is based on and reproduced from IEC 273:1990 with the addition of an Appendix giving Australian variations.

AS 4398.2-1996 Insulators - Ceramic or glass - Station post for indoor and outdoor use - Voltages greater than 1000 V a.c. - Tests: Specifies requirements for the construction and performance of ceramic or glass station post insulators. It is to be read in conjunction with Part 1: Characteristics. It is based on and reproduced from IEC 168:1994 with the addition of an Appendix giving Australian variations.

The following additional Standards cover subjects such as protective finishes, materials and quality assurance:

AS 1100 - technical drawing (many parts)

AS 1580 - paints (many parts)

AS 1627 - metal finishing (many parts)

AS/NZS 2312:1994 Guide to the protection of iron and steel against exterior atmospheric corrosion

AS 2700-1996 Colour Standards for general purposes

AS 2768-1985 Electrical insulating materials - Evaluation and classification based on thermal endurance

AS/NZS 3750 - paints (many parts)

AS/NZS 9001 - quality systems

B.2 AS 2374: Power transformers

AS 2374, including parts 1 to 3, 5, 6, 7 and 8 (Draft), is the key standard relating to losses in dry-type and liquid filled distribution transformers. Resistance testing procedures and the calculation of losses is covered in AS 2374.1 for three-phase transformers above 5 kVA and single-phase transformers above 1kVA. With regards to issues related to efficiency and load losses, this standard is equivalent to IEC 60076.

Testing is undertaken after the transformer has been at rest for at least 3 hrs at ambient temperature, and temperatures are required to be measured during testing. Calculation of no-load losses are to include correction for temperature and to sine wave basis. Calculation of load losses are to include correction for temperature and for phase angle error.

Further guidelines on the methodology for these calculations are provided in AS 2374.8, currently in draft form (see below).

As with IEC 60076, a preliminary examination with TP-2 (US testing methodology) suggests that differences appear to include:

- the values nominated for temperature correction for copper (234.5 in TP-2 vs. 235 in IEC 60076);
- the acceptable tolerance for losses (+/- 3% in TP-2 vs. +10% total losses or +15% of each component loss provided that tolerance for total losses is not exceeded in IEC 60076);

- the treatment of reference temperatures may also differ.

However, these differences are small and unlikely to substantially impact on the test results.

Requirements for information to be displayed on a rating plate fixed to each tested transformer include:

a) Kind of transformer (for example transformer, auto-transformer, booster transformer, etc.).

b) Number of this standard.

c) Manufacturer' s name.

d) Manufacturer' s serial number.

e) Year of manufacture.

f) Number of phases.

g) Rated power (in kVA or MVA).

h) Rated frequency (in Hz).

i) Rated voltages (in V or kV) and tapping range.

j) Rated currents (i n A or kA).

k) Connection symbol.

l) Short-circuit impedance, measured value in percentage.

m) Type of cooling.

n) Total mass.

o) Mass of insulating oil.

B.3 DR00013 Power Transformers, Part 8: Application Guide

B.3.1 Scope and object

This Standard applies to power transformers complying with the series of publications IEC 60076.

It is intended to provide information to users about:

- certain fundamental service characteristics of different transformer connections and magnetic circuit designs, with particular reference to zero-sequence phenomena;
- system fault currents in transformers with YNynd and similar connections;
- parallel operation of transformers, calculation of voltage drop or rise under load, and calculation of load loss for three-winding load combinations;
- selection of rated quantities and tapping quantities at the time of purchase, based on prospective loading cases;
- application of transformers of conventional design to convertor loading;
- measuring technique and accuracy in loss measurement.

Part of the information is of a general nature and applicable to all sizes of power transformers. Several chapters, however, deal with aspects and problems which are of the interest only for the specification and utilisation of large high-voltage units.

The recommendations are not mandatory and do not in themselves constitute specification requirements.

Information concerning loadability of power transformers is given in IEC 60354, for oil-immersed transformers, and IEC 60905, for dry-type transformers.

Guidance for impulse testing of power transformers is given in IEC 60722.

B.3.2 Status

Draft. This Standard is based on, IEC 76-8:1998, *Power Transformers, Part 8: Application Guide*, and is expected to be published in the second half of 2000.

The recommendations given in this Standard are advisory and therefore not mandatory. The document is written in an advisory nature.

Clause 10 of this Standard gives guidance for the calculation of losses in transformers, however it does not lay out procedures on how to do this.

Based on this, this document is helpful but not suitable for establishing a minimum performance standard for energy efficiency.

APPENDIX C: CANADIAN STANDARDS

C.1 Background

The Energy Efficiency Act passed in 1992 provides the federal government with the authority to make and enforce regulations concerning minimum energy performance standards (MEPS) for energy-using products, as well as requirements for labelling of energy-using products and the collection of data. The first Regulations under the Act came into affect in 1995, following extensive consultations with the provincial governments, affected industries, utilities, environmental groups and others.

The Regulations apply to dealers (manufacturers or importers) who import regulated products into Canada or ship them from one Canadian province to another. The Federal Regulations do not apply to products that are manufactured and sold within the one Province. Both Ontario and New Brunswick have proposed the regulation of transformers, however it is understood that these have not been introduced to date [EES 1999]. The Federal Regulations do not take precedence over provincial regulations for locally made and sold products.

Natural Resources Canada (NRCan) has proposed minimum energy performance standards for liquid-filled and dry-type transformers. In 1997, NRCan distributed a proposal to stakeholders and has subsequently consulted widely. Key issues raised concerned the economic impact of regulation, issues relating to harmonisation with the US and amongst provinces, and the verification process. Details of the current proposal are provided below.

C.2 Purpose and scope

This Standard specifies minimum % efficiencies in order to encourage energy efficiency. This Standard applies to:

- Single-phase liquid-filled transformers rated at 10-833kVA
- Three-phase liquid-filled transformers rated at 15-3000kVA
- Low-Voltage dry-type transformers rated at 15-833kVA
- Medium-voltage dry-type transformers rated at 15-2500kVA

C.3 Definitions

The following definitions apply in this Standard:

Distribution transformer:	single or three phase transformer designed to work at 60Hz. Liquid-filled, type ONAN or LNAN (see separate definitions), rated at or below 833kVA for single phase and at or below 2,500kVA for three phase, with insulation class 34.5kV and less. Includes single phase and three phase pad mounted (further defined, basically for operation on underground distribution systems) and submersible transformers (further defined, intended for use in vault or below-ground enclosure on an underground distribution system).
Dry-type transformer:	designed to work at 60Hz, air-filled, type ANN (dry, natural cooling), rated at or below 7,500kVA

	rated at or below 7,500kVA.
Power transformer:	a three phase transformer designed to work at 60Hz, liquid filled type ONAN or LNAN, rated at or below 10kVA with insulation class 69kV and less, that is not a distribution transformer.
LNAN:	immersed in flame retardant liquid, natural cooling.
ONAN:	immersed in oil, natural cooling.

C.4 Test Conditions

The Standard specifies test conditions for each transformer type (see below).

C.5 Efficiency Levels

Minimum % Efficiency values are then presented in four tables.

Table C1: Liquid-Filled Distribution Transformers, Reference Conditions

Reference Condition	Temperature °C	% of Nameplate Load
Load Loss	85	50
No Load Loss	20	50

Table C2: Liquid-Filled Distribution Transformers, Proposed Standards

KVA	Single Phase Efficiency (%)	KVA	Three Phase Efficiency (%)
10	98.30	15	98.00
15	98.50	30	98.30
25	98.70	45	98.50
37.5	98.80	75	98.70
50	98.90	112.5	98.80
75	99.00	150	98.90
100	99.00	225	99.00
167	99.10	300	99.00
250	99.20	500	99.10
333	99.20	750	99.20
500	99.30	1000	99.30
667	99.40	1500	99.40
833	99.40	2000	99.40

Table C3: Dry-Type Distribution Transformers, Reference Condition

Reference Condition	Temperature oC	% of Nameplate Load
Low Voltage (< 1.2 KV)	75	35
Medium Voltage (> 1.2 kV)	75	50

Table C4: Dry-Type Distribution Transformers, Proposed Standards

KVA	Low Voltage	Medium Voltage	KVA	Low Voltage	Medium Voltage

15	97.70	97.60	15	97.00	96.80
25	98.00	97.90	30	97.50	97.30
37.5	98.20	98.10	45	97.70	97.60
50	98.30	98.20	75	98.00	97.90
75	98.50	98.40	112.5	98.20	98.10
100	98.60	98.50	150	98.30	98.20
167	98.70	98.70	225	98.50	98.40
250	98.80	98.80	300	98.60	98.50
333	98.90	98.90	500	98.70	98.70
500	-	99.00	750	98.80	98.80
667	-	99.00	1000	98.90	98.90
833	-	99.10	1500	-	99.00
			2000	-	99.00
			2500	-	99.10

Note that these values are the same as those published and recommended by NEMA in NEMA TP-1 taken to two decimal places, and have been used to provide for harmonization of transformer minimum efficiency levels with North America.

C.6 Test Procedure

It is proposed that the NEMA Standards Publication No. TP-2-1998 is used as the test procedure for the measurement of transformer efficiency. However, since the CSA Standards, CSA-C802.1 and CSA-C802.2, which set minimum efficiency standards and test procedures, are also under review at the present time, they may adopted as the test procedure for transformers [NCAN 1999].

The test procedures in TP-2 are closely related to those in IEC 60076, with respect to the measurement of resistance and calculation of losses. Both require testing at ambient temperatures and correction for temperature, sine wave basis and for phase angle error.

However, from a preliminary examination the differences appear to include:

- the values nominated for temperature correction for copper (234.5 in TP-2 vs. 235 in IEC 60076);
- the acceptable tolerance for losses (+/- 3% in TP-2 vs. +10% total losses or +15% of each component loss provided that tolerance for total losses is not exceeded in IEC 60076);
- the treatment of reference temperatures may also differ.

These differences are small and unlikely to substantially impact on the test results.

C.7 Implementation Date

At the present date, it appears likely that the standards for dry-type transformers will be adopted initially, and will come into effect on January 1, 2001.

C.8 Estimated Energy Savings

Annual energy savings due to the introduction of regulation in Canada are estimated to be 132 GWh (dry-type) and 0.98 GWh (liquid filled).

C.9 Verifications

Regulated transformers will have to carry a verification mark indicating that the energy performance of the product has been verified. The verification mark is the mark of a Standards Council of Canada accredited certification organization that administers an energy performance verification program for this product. NRCan will also accept labels issued by a province indicating that the product meets the provincial energy efficiency levels as a verification mark, providing that the provincial level is equivalent to or exceeds the federally regulated level.

C.10 Reporting

With the exception of requiring % efficiency to be reported rather than maximum losses, there has been no change in the reporting requirements proposed by NRCan. The energy efficiency report required for this product will include the following information:

- the product name
- the brand name
- the model number
- the manufacturer
- the name of the organization or province that carried out the verification and authorized the verification mark that will appear on the product
- the type of transformer, either dry or liquid-filled
- the kVA rating
- the phase of electric current the product uses
- the voltage, and
- the % efficiency

This report must be submitted to the Minister of NRCan before the product is imported into Canada or traded interprovincially.

C.11 Refurbishment/Retrofit Transformers

There is an active transformer refurbishment industry in Canada, however most repair and overhaul of transformers are done by or for utilities in localised areas. It is therefore unlikely that federal Energy Efficiency Regulations would apply to these transformers.

C.12 Contacts

Valerie Whelan, Equipment Standards Officer, NRCan, Office of Energy Efficiency,

580 Booth Street, 18th Floor, Ottawa, Ontario, K1A OE4.

Tel: (613) 947 1207 Fax: (613) 947 0373 Vwhelan@NRCan.gc.ca

APPENDIX D: UNITED STATES STANDARDS

D.1 Background

In the US, there are over 40 million distribution transformers in use, with an addition 10 million owned by customers. Typical residential transformers are single phase and range between 10kVA and 167kVA, with the most common being 25kVA. Transformers for commercial applications range between 75kVA and 2,500kVA.

Distribution transformers are estimated to lose approximately 61TWh of electricity per year, resulting in annual greenhouse emissions of 45Mt CO_2. Utilities purchase over 1 million new units each year, and it is estimated that if the average efficiency of utility transformers was improved by one-tenth of one percent, greenhouse emissions reductions of 1.8Mt CO_2 would be achieved over a 30 year period.

As a result, the US has put in place an Energy Star program for distribution transformers.

D.2 Energy Star Transformers Program

This is a voluntary program in which participating utilities agree to perform an analysis of total transformer owning costs, using a standard methodology, and buy transformers that meet Energy Star guidelines when it is cost-effective to do so. Currently, manufacturing partners represent over 80% of the market.

The program provides technical assistance to partners to ensure that transformers are not oversized. It also has developed a Distribution Transformer Cost Evaluation Model (DTCEM) to provide a standard methodology for the evaluation of multiple transformer bids. To compliment this tool, the program also labels transformers which conform to its standards, originally set so that 35% of units sold in 1994 would qualify.

The guidance document, "*Transforming Dollars in to Sense: The Economic and Environmental Benefits of High Efficiency Distribution Transformers*", was also produced as part of this program in addition to a marketing kit.

D.3 NEMA Guide for Determining Energy Efficiency for Distribution Transformers

The National Electrical Manufacturers Association (NEMA) publishes a *Guide for Determining Energy Efficiency for Distribution Transformers (TP-1-1996)*, covering the following range of transformers:

Table D1: Transformers included in TP-1

Voltage Class	Primary Voltage Secondary Voltage	34.5kV and Below 600Volts and Below
Liquid Rating	Single Phase	10-833kVA
	Three Phase	15-2,500kVA
Dry Rating	Single Phase	15-833kVA
	Three Phase	15-2,500kVA

In 1998, NEMA also published a standard test method for the measurement of energy consumption in transformers (TP-2), and proposes a further *Standard for Labeling of Energy-Efficient Distribution Transformers* [deLaski et al, 1998].

D.4 US Federal Energy Management Program (FEMP)

The US Department of Energy (DOE) Federal Energy Management Program also encourages government procurement of energy efficient distribution transformers. Recommended efficiency levels are included in the Table below:

Table D2: FEMP Recommended Transformer Efficiency Level, Single Phase

Transformer Efficiency Recommendation			
Single Phase Percent Efficiency			
Rated Capacity (kVA)	*Low Voltage*	Medium Voltage	
	Recommended Level	Recommended Level (Dry)	Recommended Level (Liquid)
10	-	-	98.3 or more
15	97.9 or more	97.6 or more	98.5 or more
25	98.0 or more	97.9 or more	98.7 or more
37.5	98.2 or more	98.1 or more	98.8 or more
50	98.3 or more	98.2 or more	98.9 or more
75	98.5 or more	98.4 or more	99.0 or more
100	98.6 or more	98.5 or more	99.0 or more
167	98.7 or more	98.7 or more	99.1 or more
250	98.8 or more	98.8 or more	99.2 or more

333	98.9 or more	98.9 or more	99.2 or more
500	-	99.0 or more	99.3 or more
667–	-	99.0 or more	99.4 or more
833	-	99.1 or more	99.4 or more
Three Phase Percent Efficiency			
15	97.0 or more	96.8 or more	98.0 or more
30	97.5 or more	97.3 or more	98.3 or more
45	97.7 or more	97.6 or more	98.5 or more
75	98.0 or more	97.9 or more	98.7 or more
112.5	98.2 or more	98.1 or more	98.8 or more
150	98.3 or more	98.2 or more	98.9 or more
225	98.5 or more	98.4 or more	99.0 or more
300	98.6 or more	98.5 or more	99.0 or more
500	98.7 or more	98.7 or more	99.1 or more
750	98.8 or more	98.8 or more	99.2 or more
1000	98.9 or more	98.9 or more	99.2 or more
1500	-	99.0 or more	99.3 or more
2000	-	99.0 or more	99.4 or more
2500	-	99.1 or more	99.4 or more

Starting early in 1998, the DOE began a process of research and consultation into the merits and potential levels for an efficiency standard. No firm implementation commitment has been made to this as yet, however, work is proceeding on industry-wide consultation and the development of test procedures. Possible references on which to base a standard include the ANSI/IEEE standards (C57.12.90-1993 and C57.12.91-1995) or the NEMA standard (TP-2 1998). It is envisaged that MEPS will be adopted for transformers by approximately mid 2003.

It should be noted that NEMA is currently strongly opposed to the adoption of efficiency standards for distribution transformers.

D.5 Consortium for Energy Efficiency (CEE)

The Consortium for Energy Efficiency (CEE) has initiated a program aimed at the 6 million distribution transformers (dry-type) on the customer side of the meter [CEE website], and is part of a consortium with NEMA, USEPA and others to increase information and awareness of the potential for efficient transformers [deLaski et al, 1998].

D.6 Contacts:

DOE's Federal Energy Management Program(FEMP)

Tel: (800) 363-3732

http://www.eren.doe.gov/femp/procurement

National Electrical Manufacturers Association (NEMA)

Tel: (800) 854-7179

http://www.nema.org

Consortium for Energy Efficiency (CEE)

Tel: (617) 589-3949

http://www.ceeformt.org

Energy Star Transformer Program Manager, US Environmental Protection Agency

Mail Stop 6202J, Atmospheric Pollution Prevention Division, 401 M Street, S.W. Washington, DC 20460

Tel: (202) 233 9482 Fax: (202) 233 9569

http://www.epa.gov/energystar.html

APPENDIX E: MEXICAN STANDARDS

E.1 Background

Mexico is among the most advanced of the developing countries in the enactment and implementation of MEPS and energy efficiency labelling. Much of the effort has borrowed from the USA experience, although a good deal has also been developed in response to local requirements.

The Ley Federal Sobre Metrología y Normalización (Federal Law of Metering and Standards) of July 16, 1992 defined two types of standards: Normas Mexicanas –NMX (Mexican Standards) of voluntary compliance, and Normas Oficiales Mexicanas - NOM (Official Mexican Standards) of compulsory compliance. The NOM are enacted by the Federal Secretariats according to their areas of competence and includes both the minimum energy performance levels required and the test procedure for determining the equipment performance.

The Secretaría de Energía – (SE - Energy Secretariat) has entrusted the Comisión Nacional de Ahorro de Energía (CONAE - National Energy Savings Commission) with the design and enactment of standards and labels related to energy efficiency. The reasons for the MEPS and energy labelling are mostly related to an interest at CONAE to reduce the growing demand for electricity. Energy labels are used to provide consumer information at point-of-purchase for selected products.

E.2 Energy Performance Standards

NOM-002-SEDE-1999 covers energy efficiency and safety for distribution transformers and was made mandatory in 1999 in Mexico. Tables E1 and E2 show the minimum efficiency levels for distribution transformers required, and the maximum allowed losses.

TABLE E1. Minimum Efficiencies permitted for Distribution Transformers (%)

	Capacity kVA	Insulation Class		
		Up to 15 kV	Up to 25 kV	Up to 34.5 kV
Single Phase	5	97.9	97.8	97.7
	10	98.25	98.15	98.05
	15	98.40	98.30	98.20
	25	98.55	98.45	98.35
	37.5	98.65	98.55	98.45
	50	98.75	98.65	98.55
	75	98.90	98.80	98.70
	100	98.95	98.85	98.75
	167	99.00	98.90	98.80
Three Phase	15	97.95	97.85	97.75
	30	98.25	98.15	98.05
	45	98.35	98.25	98.15
	75	98.50	98.40	98.30
	112,5	98.60	98.50	98.40
	150	98.70	98.60	98.50
	225	98.75	98.65	98.55

300	98.80	98.70	98.60
500	98.90	98.80	98,70

These efficiency standards are less stringent than those provided in TP-2, proposed for Canada and the US, however it should be noted that the Mexican standard also prescribes the maximum allowed losses, which is not the case in either the US or Canada.

Table E2: Maximum No Load Losses and Total Losses Permitted (Watts)

	Capacity kVA	Insulation Class					
		Up to 15 kV		Up to 25 kV		Up to 34.5 kV	
		No load	Total	No load	Total	No load	Total
Single Phase	5	30	107	38	112	63	118
	10	47	178	57	188	83	199
	15	62	244	75	259	115	275
	25	86	368	100	394	145	419
	37.5	114	513	130	552	185	590
	50	138	633	160	684	210	736
	75	186	834	215	911	270	988
	100	235	1061	265	1163	320	1266
	167	365	1687	415	1857	425	2028
Three Phase	15	88	314	110	330	135	345
	30	137	534	165	565	210	597
	45	180	755	215	802	265	848
	75	255	1142	305	1220	365	1297
	112,5	350	1597	405	1713	450	1829
	150	450	1976	500	2130	525	2284
	225	750	2844	820	3080	900	3310
	300	910	3644	1000	3951	1100	4260
	500	1330	5561	1475	6073	1540	6586

NOM-002-sede-1999 also prescribes the test methodologies for calculation of losses (NMX-J-169-ANCE). It also makes allowances for manufacturers whose annual total production is less than 9,000 kVA, who may appeal for a transitionary period before meeting these requirements.

E.3 Contacts

Mr Pensado, CONAE

E-mail: no@conae.gob.mx

APPENDIX F: THE SCOPE FOR ENERGY SAVING IN THE EU THROUGH THE USE OF ENERGY-EFFICIENT ELECTRICITY DISTRIBUTION TRANSFORMERS

Produced by European Copper Institute, Belgium, with the support of the EUROPEAN COMMISSION

THERMIE B PROJECT Nº STR-1678-98-BE. First Published December 1999

F.1 Conclusions

The theoretical scope for energy savings through the use of energy-efficient distribution transformers in the EU is very substantial. Despite the efficiency of individual units, up to 2% of total power generated is estimated to be lost in distribution transformers, equivalent to nearly one-third of overall losses from the power sys-tem.

The savings potential is approximately 22TWh/year, worth Ecu 1,171 million at 1999 prices. This is comparable in scope with the energy savings potential estimated for electric motors in the EU (27TWh) and domestic appliances. It is equivalent to the annual energy consumption of over 5.1 million homes, or the electricity produced by three of the largest coal-burning power stations in Europe.

Because of the long life span of distribution transformers, ultimate market penetration will only be achieved gradually. However energy-efficient units could contribute 7.3TWh of savings by 2010, representing over 1% of the European commitment to reducing carbon emissions.

As far as we have been able to ascertain, no European country has developed targets for the global warming savings potential which could result from distribution transformer programmes, nor has a formal estimate yet been made for the EU or Europe as a whole.

European countries are currently developing strategies on existing and future global warming actions. As this happens, the potential for reducing losses from distribution transformers could be promoted, to ensure that they are incorporated as a component of the plan.

Europe has considerable potential to offer world-wide in trans-former technology and experience. However, national governments and utilities lag behind the US in terms of programmes and initiatives to encourage energy efficiency.

There are no initiatives comparable to the US DOE/EPA programmes on voluntary utility agreements, or information and software dissemination. This is despite the fact that most European countries have a poor position on energy self-sufficiency. The US has also recently started a process to evaluate the role of regulation in transformer efficiency.

There is already considerable R&D and promotional effort with-in Europe aimed at reducing losses in small transformers, e.g. for domestic and office equipment, and some IEA/OECD work has been undertaken. Initiatives have included campaigns to urge consumers to switch off appliances when not in use, and the adoption of more efficient core materials. These are directed at domestic consumers, rather than utilities and professional buyers, but could assist in focusing attention on the equally significant target of distribution transformers.

It is apparent that both utilities and non-utility purchasers are difficult to influence. The transformer market is extremely competitive, and efforts to improve energy efficiency in the past have had limited success. However, the sector involves a limited number of professional buyers, already reasonably aware of the arguments for energy efficiency, and with well-established techniques for evaluating transformer performance. They are therefore likely to be receptive to rational arguments, provided that benefits are clearly demonstrated.

F.2 Recommendations

We consider that distribution transformers should be recognised as an important focus for energy efficiency initiatives within the EU, and that they represent a worthwhile area for R&D, demonstration and promotional effort. We therefore recommend the following:

- as EU and national strategies on energy efficiency, global warming, and environmental impact are developed, the potential for reducing losses from distribution transformers should be considered, to ensure that they are incorporated as a component
- a strategy should be developed to set and achieve goals for reducing losses from distribution transformers, or possibly from all power systems transformers in the EU. The strategy needs to be carefully co-ordinated and be both technically and commercially sound
- the main elements of an action plan to achieve the strategy should be identified and developed.

F.3 Energy Losses

Total losses for the EU are running at about 150TWh, representing approximately 6.5% of total power generated, or the output of 15 large power stations. However, losses have fallen steadily, from about 7.5% in 1970.

There is a significant variation between countries in reported electricity system losses, ranging between 4-11%. Obviously, distribution losses could be expected to be higher in small lightly populated rural countries than in major industrialised countries. There is some doubt about whether losses are always measured on a consistent and comparable basis.

Among major countries, Germany reports exceptionally low loss levels, has made significant progress in the period since 1970, and set ambitious targets for the next 15 years. In contrast the UK, France and Italy are showing persistently high loss levels, and with no foreseen or planned improvement.

In Central Europe, losses in the system are reported to be much higher, up to twice the average for Western Europe. Some indication of this is provided by data from Germany, where losses in the former DDR were reported at 10.0% in 1992, compared with 4.7% for West Germany, but had improved to 9.0% by 1995.

It is estimated that over 40% of the total losses in an electricity distribution network are attributable to transformers. The remainder is mainly in the cable and overhead conductor system.

F.4 Distribution Transformer Standards

Most of the characteristics of distribution transformers are specified in national or international product standards. The application of standards can be legally require, or by specific reference in the purchase contract.

Generally, the purpose of standards is to facilitate the exchange of products in both home and overseas markets, and to improve product quality, health, safety and the environment. International standards are also of importance in reducing trade barriers.

For distribution transformers purchased in the European Union, three levels of standards are applicable:

- world-wide standards (ISO, IEC)
- European standards and regulations (EN, HD)
- national standards (e.g. BSI, NF, DIN, NEN, UNE, OTEL).

European Harmonisation Documents are initiated if there is a need for a European standard. The draft HD is a compilation of the different national standards on the subject. The HD is finalised by eliminating as many national differences as possible.

When a harmonisation document (HD) has been issued, conflicting national standards have to be withdrawn within a specified period of time, or modified to be compatible with the HD. Usually, the HD is the predecessor of an European standard (EN), which must be adopted as a national standard in the EU member countries. Thus, purchase orders which refer to national standards are compatible with European standards (EN) and/or harmonisation documents (HD).

Among the many international standards for distribution trans-formers, two main European Harmonisation Documents specify energy efficiency levels:

- HD428: Three-phase oil-immersed distribution transformers 50Hz, from 50 to 2,500kVA with highest voltage for equipment not exceeding 36kV
- HD538: Three-phase dry-type distribution transformers 50Hz, from 100 to 2,500kVA, with highest voltage for equipment not exceeding 36 kV.

A separate HD is under consideration for pole-mounted transformers.

In the next Section, the efficiency limits defined in these standards are discussed. The standards however leave considerable freedom for local deviations in energy efficiency, which implies that energy loss levels may (and do) still vary across European countries. This is also discussed in the next Section.

F.5 Rated loss levels of Standard Distribution Transformers

Distribution transformers built to HD428 and HD538 have a limited number of preferred values for rated power (50, 100, 160, 250, 400, 630, 1,000, 1,600 and 2,500kVA). Intermediate values are also allowed. The two key figures for energy efficiency, the load losses and the no-load losses, are specified for each rated power.

The Table below gives the limits for load losses (often called "copper losses") for some important types of oil-filled and dry-type distribution transformers according to HD428.1 and HD538.1 for the preferred rated power range of the transformers. For oil-filled distribution transformers, the HD allows a choice of energy efficiency levels, A, B and C.

Loss values for transformers are usually, declared as maximum values with a specified tolerance. If higher losses are found at the factory acceptance test, the transformer may be rejected or a financial compensation for exceeding the loss limit may be agreed between client and manufacturer. In the same way, a bonus may be awarded to the manufacturer, mainly for large transformers, for a transformer with losses lower than the limits agreed.

The no-load losses (iron losses) for the same range of transformers are given below. For oil-filled distribution transformers, the HD offers a choice between three efficiency levels, A', B' and C' (Table below).

HD428 therefore allows customers to choose between three levels of no-load losses and three levels of load losses. In principle, there are 9 possible combinations, ranging from the lowest efficiency, (B-A') to the highest, (C-C'), which may be regarded as providing a high practical standard of energy efficiency for a distribution transformer.

The freedom for choosing different levels of energy efficiency is increased by the fact that transformer buyers can comply with HD428/538 through the use of a capitalisation formula, rather than the tabulated losses shown in the standard. In this, they are free to insert their own capitalisation values, to which no restrictions are imposed.

If high capitalisation values for losses are chosen, transformers with low losses but with higher investment cost tend to be favoured. If however capitalisation values are set to zero, a purchaser effectively eliminates energy loss evaluation from the purchase decision, which favours the cheapest transformer.

HD428.1 (part 1: general requirements and requirements for transformers with highest voltage for equipment not exceeding 24 kV) as well as other HD sections also contain phrases such as *"in the case of established practice in the market (...) the transformers can be requested and, by consequence, offered, with losses differing from the tabled losses"*, which indicates some freedom to national or local deviations.

As stated before, HD428 and HD538 represent a compilation and/or compromise on the various old standards which were used in European countries. It appears to be rather unambitious in terms of the standards set, and by allowing capitalisation formulas to be used.

Table F1: Distribution Transformer Loss Standards

	Load Losses for Distribution Transformers				No-Load Losses for Distribution Transformers			
RATED POWER	**OIL-FILLED (HD428) UP TO 24kV(2)**			**DRY TYPE (HD538)**	**OIL-FILLED (HD428) UP TO 24kV(2)**			**DRY TYPE (HD538)**
	List A	List B	List C	12kV Primary (3)	List A	List B	List C	12kV Primary (3)
kVA	W	W	W	W	W	W	W	W
50	1,100	1,350	875	N/A	190	145	125	N/A
100	1,750	2,150	1,475	2,000	320	260	210	440
160	2,350	3,100	2,000	2,700	460	375	300	610

250	3,250	4,200	2,750	3,500	650	530	425	820
400	4,600	6,000	3,850	4,900	930	750	610	1,150
630 / 4% (1)	6,500	8,400	5,400	7,300	1,300	1,030	860	1,500
630 / 6%	6,750	8,700	5,600	7,600	1,200	940	800	1,370
1000	10,500	13,000	9,500	10,000	1,700	1,400	1,100	2,000
1600	17,000	20,000	14,000	14,000	2,600	2,200	1,700	2,800
2500	26,500	32,000	22,000	21,000	3,800	3,200	2,500	4,300

Notes:

1. The short-circuit impedance of the transformers is 4% or 6%, in most cases. This technical parameter is of importance to a utility for designing and dimensioning the low-voltage network fed by the transformer. Transformers with the same rated power but with different short-circuit impedance have a different construction and therefore slightly different losses. For HD428 / HD538 compliant distribution transformers, the preferred values for the short-circuit impedance are 4% for transformers up to and including 630kVA, and 6% for transformers of 630kVA and above.

2. For 36kV transformers, different values apply.

3. For 24 and 36kV transformers, different values apply.

F.6 Characterisation of the Utility Market

Utility markets account for approximately half the installed transformer capacity in Europe. Throughout Europe, the purchasing of transformers seems to be reasonably standardised, with the utilities having open tender practices in line with European Purchasing Directives. In almost all cases, losses (iron and copper) are factored into the specification, with minimum standards in line with internationally accepted standards. However, the specifications in each country differ in relation to the load characteristics (rural/urban), the network being served or the requirements for low noise emission (e.g. in German urban areas).

Selection of the supplier is usually made on the “first cost” principle, i.e. the supplier providing the lowest cost offer that meets the specification wins the business. Few exceptions are made where a supplier offers a more efficient transformer (i.e. lower life-time cost), but at a slightly higher price. The one exception to this is the Nordic countries, where the efficiency of the transformer in specific applications is given a high priority, with the specification giving the efficiency of the transformer a very high rating.

In almost all EU countries, first cost is the driving principle. Where the utility is state owned, limitations on capital expenditure are paramount to assist in meeting the ever tightening budgets brought about by the strict monetary requirements associated with the Ecu. Where the utility is in private ownership, the availability of capital for efficient transformer purchases always competes against more attractive (i.e. quicker payback) investments that can be made by the utility in other areas.

In both cases, the lack of interest in efficient transformers is compounded by the electricity suppliers’ inability to pass the cost of any losses on to the consumer, hence removing any incentive to overall system, and consequentially transformer, performance.

Example: A utility buys transformers under ‘framework’ contracts that are competitively tendered approximately every two years. They specify the number and type of transformers that are likely to be required by the utility over the following two year period along with the technical specification. This technical specification includes copper and iron losses that are expressed using a capitalisation formula (i.e. a comparison between efficiency gains and the depreciation of capital).

Contracts are always awarded to the lowest tender that meets the specification. Although partnerships are being established between utilities and transformer manufacturers, these are developed within these ‘framework’ contracts subsequent to the initial tendering exercise. These partnerships facilitate increased dialogue between the two parties and allow refinement of the original specification, a process that sometimes leads to increased energy efficiency.

However, a counter to this has been the move towards the installation of a limited range of transformers to minimise the stock of spare parts and rationalise service requirements. This means that there are few transformer sizes to select from and consequential matching to load characteristics is likely to decrease.

The cost of distribution losses is passed from the utility to their customers. In the UK the acceptable distribution losses are calculated according a Distribution Price Control Formula, issued by the electricity regulator. The Distribution Price Control Formula includes factors that relate to energy efficiency. At present, there is no financial incentive for utilities to improve their efficiency beyond that specified by this formula.

Since privatisation, it appears that utilities are under greater pressure to reduce capital expenditure. This tends to reinforce the 'lowest first cost' policy that is prevalent. Even when the marginal capital is avail-able to meet the higher cost of a more efficient transformer, there must also be a straight payback of under five years.

The environmental policies of some utilities are driving them towards increased energy efficiency. East Midlands Electricity, UK, has an initiative in this area, although this is the exception rather than the normal situation.

F.7 Characterisation of the Non-Utility Market

The non-utility market consists of three distinct groupings, each with different characteristics and priorities:

- major energy users (e.g. large industrial plants (chemicals, oil, gas and steel), traction companies etc)
- large energy users (e.g. supermarkets, hospitals)
- smaller energy users.

The **major energy users** are aware of the issues and tend to make rational purchasing decisions. These companies retain sufficient expertise to be able to derive their own transformer specifications. Although energy efficiency and life-time cost of ownership will form an important part of these specification, other factors are also considered, e.g. the competitive cost of capital, life-time maintenance costs, potential growth capacity, etc. The overall result will be the purchase of the most cost-effective transformer to the business. This will not always be the most efficient transformer.

This group will only be influenced to buy transformers that are more efficient by external factors that change the business case. For example, rebate schemes.

Increasingly, **large energy users** are becoming more aware of the concept of transformer life time cost and its influence on operating profits. In particular, supermarkets have a high 24-hour base load, which encourages the selection of more efficient units. However, these customers rarely have the required in-house skill to specify suitable transformers effectively, often relying on a turn-key package from a contractor to an agreed overall specification. This group would therefore benefit from increased information that would allow them to make better initial specifications to the contractors. For example, labelling schemes or specification tool kits.

Smaller energy users tend to use contractors on a turn-key basis to provide premises that meet the requirements of their particular business. Specification will concentrate on meeting the business requirements, e.g. floor space available for the installation, adequate provision of utilities, infrastructure etc. The overall price of the package, perceived competence of the contractor and service levels are the key issues with the type of transformer installed being of little consequence. These customers do not have sufficient knowledge to be able to specify transformers in detail, and will be unaware of the business benefits of reduced life time costs.

As a corollary to this, contractors (including utility company contracting departments) will specify whatever the customer asks for. However, in most cases, no detailed specification will be received, because of lack of knowledge, and the contractor will simply specify the cheapest transformer available. Consequently, the provision of information on the advantages of specifying more efficient transformers and specification tool kits will allow these customers to make more informed choices.

F.8 Potential Mechanisms for Change

There appears to be several potential mechanisms that could change the buying behaviour of transformer purchasers. Each potential mechanism is briefly examined below.

F.8.1 No Change Scenario

It is possible that no action at the EU level will be required, as national governments begin to realise the implications of international commitments on CO_2 and act at national level to improve the efficiency of transformers purchased. However, realistically this is unlikely to occur, due to the long term nature of savings from transformers and the complex nature of specification and the purchasing cycle. National governments are much more likely to concentrate on simpler targets, e.g. improvements in the performance of domestic appliances, etc.

F.8.2 Enforceable Minimum Standards

Discussions have already taken place between EC DGXVII, COTREL and EURELECTRIC to discuss the possibility of voluntary agreements or a European Directive to initiate reduced losses from distribution transformers through a minimum standard.

A minimum standard of sorts already exists in the Harmonisation Document 428. This standard could be made more prescriptive and specify improved minimum losses for all types of transformer. Such a standard could then be made mandatory through an EU Directive.

Unfortunately, such an approach is likely to be strongly resisted at national level, due to the specific needs of each national distribution system and local political considerations. Further, the imposition of overall standards for efficiency higher than those already in force would cause problems, due to the variations in demand profiles from the various end use applications, e.g. rural/urban uses.

An alternative approach would be for the EU to place obligatory requirements on national regulators to include efficiency as one of their key elements when forming regulatory policy. It is unlikely that such an approach would work as, without specific guidelines, regulators are likely to simply pay lip-service to the issue. Further, the preparation of specific guidelines may impose on the principles of subsidiarity and would be difficult to draft in any case.

F.8.3 Financial Incentives

The major cause of purchases of "less efficient" transformers is the requirement of many purchasers for the lowest first cost. If some financial mechanism could be introduced, that would make the purchase of efficient transformers more attractive, it is likely to have a major impact on the marketplace. Such financial incentives appear to fall into three categories:

- rebates
- tax incentives
- increasing responsibility for cost of losses.

If a mechanism was in place to define efficient transformers (e.g. transformer labels described below), it would be possible to offer **rebates on purchases of higher efficiency units**, hence lowering the purchase cost differential between the more and less efficient units. Unfortunately, the rebate would be extremely expensive, given the number of transformers purchased across the EU annually. Further, such a scheme could only be sustained for a short period and following withdrawal, the marketplace would almost certainly revert to the original situation with no lasting market transformation.

Changing national taxation systems to make the capitalisation of transformers more attractive, e.g. shortening the allowable assets write-off period, is likely to have a major impact on the purchases made by utility buyers (other buyers are unlikely to purchase enough transformers for this to have any significant impact relative to other considerations). However, this would have to be made a national issue, as the EU is specifically excluded from direct interference with national taxation issues. As such, it is unlikely that individual member states would adopt such a policy, due to the complex requirements in drafting the required legislation and policing claims under the system.

Increasing responsibility for cost of losses. Obviously, financial costs associated with losses from transformers owned by end users are already borne by the end user. However, losses accruing from transformers owned by utilities are currently almost universally transferred to the end user as part of the cost of electricity.

This situation is difficult to change where the utility is state owned. However, where the utility is privatised, there is an opportunity to use this "cost of losses" as an incentive to improve the system. At present, if the utility improves the efficiency of the system, then the amount of "cost of losses" is adjusted accordingly, hence the utility makes little improvement in profit.

A realignment of the pricing structure, to allow a fixed amount of "cost for losses" to be passed to the consumer, with the savings from any reduction in losses split between the consumer and the utility (say on a 50:50 basis), would improve the business case for examining lifetime costing. Such a system would allow investments in efficient transformers to be more competitive against other demands on the capital budgets of the utilities. However, this is again a national issue, with the individual pricing regimes coming under the control of the national regulators.

F.8.4 Labelling system

Lack of knowledge is a significant barrier to the purchase of energy-efficient transformers. This is particularly true of large energy users, where there is a desire to use efficient transformers, but not the technical ability to specify them effectively.

A labelling system that indicated the efficiency of transformers under specific load profiles would assist this group considerably, and is likely to cause a significant movement in the market. While there are obvious difficulties in creating a labelling system for transformers, given the variability of losses depending upon application, it is possible to develop a labelling system that provides the user with appropriate guidance in most instances. Such a system is currently under development for electric motors, a product with similar difficulties in efficiency definition.

The introduction of a labelling system also provides a framework from which future minimum standards may be derived (if deemed appropriate). The framework could also be used for financial incentives, should they be required at a national level.

F.8.5 Buyer Clubs

If a number of purchasers combine, they will receive direct benefits in bulk purchasing, hence receiving lower prices from manufacturers. This in itself would not necessarily induce the purchase of more efficient transformers, but it would increase the combined knowledge of the purchasing group, and is likely to result in the more effective specification. Such groups are however unlikely to form, as buyers remain unaware of the potential.

A possible method of inducing the formation of such groups would be the funding of some demonstration activity by the EU, e.g. the funding of the establishment and promotion of a buying group by the SAVE programme.

F.8.6 Specification tool kit

Smaller users are large in number, but individually buy small numbers of transformers. However, collectively they account for a significant part of the market. Education of these users, through promotional campaigns to purchase efficient transformers, would not be cost effective. However, it would be possible to develop a simple Specification Tool Kit (or buyer's guide) that would assist them in asking the right questions of the turnkey contractors.

Such a guide could include information on ensuring that the transformer is correctly sized and has been specified to likely load characteristics. Further, if combined with a labelling scheme, recommendations could be made on the type of transformer to be specified to the contractor. If manufactures/contractors could be persuaded to distribute this guide to potential buyers, costs would remain at a manageable level, and the user would have at least the basic knowledge to make a rational purchasing decision.

APPENDIX G: CHINESE TAIPEI

G.1 Background

In August 1992 an eco-label program called “GreenMark”, was launched by the Environmental Protection Administration (EPA). This currently covers over 50 categories of products.

The GreenMark logo label may be used on product packaging, brochures or on the products themselves itself if the performance of the product meets the stated criteria and the supplier registers with the Environmental Protection Administration (EPA).

Each product has a different set of criteria, covering matters as diverse as:

- absence of certain materials (eg CFCs or toxic substances) in the product itself;
- absence of the use of certain materials in the production process;
- the use of recycled materials in packaging;
- the disclosure of information, and the accuracy of disclosed information;
- noise levels in operation;
- functional requirements; and
- energy performance requirements.

G.2 Distribution Transformers

For the energy-using products covered by GreenMark, specific energy-related criteria need to be met, however, although distribution transformers are to be included in this program, criteria have not yet been determined. It is likely that requirements will be more stringent than those in the US Energy Star program, set at a level currently met by the top 20 to 30% of manufacturers.

G.3 Contacts

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APPENDIX H: VICTORIAN REPORT ON DISTRIBUTION SYSTEM LOSSES

Prepared for The Office of the Regulator-General, Victoria, Australia

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H.1 Loss levels in Victoria

The levels of annual energy losses of the distribution networks in Victoria are presented in Table H1 below.

We would comment that the lower levels of losses incurred on the CitiPower, AGL and United Energy networks would tend to reflect the predominantly urban areas served by those networks. However there appears to be a disparity between the levels of losses incurred on the Eastern Energy and Powercor networks and, if anything, we would consider the Eastern Energy losses to be on the low side for a predominantly rural network.

We would also caution that assessment of losses is dependent on accuracy of measurement. An inherent difficulty is obtaining data on unmetered supplies and theft. (The level of non-technical losses incurred by British distribution companies is considered to vary between 0.2 and 1 per cent of units distributed.) Another factor is the accuracy to which unmetered supplies (including street lighting) are estimated.

Table H1: ENERGY LOSS LEVELS ON DB NETWORKS IN VICTORIA

DB	Year	Purchases (MWh)	Sales (MWh)	Measured losses (MWh)	Measured losses (% of purchases)	Measured losses (% of Sales)
CitiPower(a)	1996	4,621,715	4,453,785	167,930	3.63%	3.77%
	1997	4,960,304	4,741,628	218,676	4.41%	4.61%
	1998	5,073,310	4,806,824	266,486	5.25%	5.54%
Eastern Energy(b)	1995/96	5,452,090	5,261,027	191,063	3.50%	3.63%
	1996/97	5,702,487	5,480,381	222,106	3.89%	4.05%
	1997/98	5,908,392	5,620,694	287,698	4.87%	5.12%
Powercor c)	1994/95	7,844,000	7,349,000	495,000	6.31%	6.74%
	1995/96	7,963,000	7,455,000	508,000	6.38%	6.81%
	1996/97	8,369,000	7,782,000	587,000	7.01%	7.54%
	1997/98	8,778,000	8,175,000	603,000	6.87%	7.38%
AGL (d)	1995/96	3,677,549	3,533,615	143,934	3.91%	4.07%
	1996/97	3,781,610	3,668,090	113,520	3.00%	3.09%
	1997/98	3,907,342	3,774,649	132,693	3.40%	3.52%
United Energy	(e)	1995/96	6,463,635	6,126,668	336,967	5.21%
	1996/97	6,766,068	6,329,343	436,725	6.45%	6.90%
	1997/98	6,906,184	6,490,774	415,410	6.02%	6.40%
All DBs	1995/96	28,177,989	26,830,095	1,347,894	4.78%	5.02%
	1996/97	29,579,469	28,001,442	1,578,027	5.33%	5.64%
	1997/98	30,573,228	28,867,941	1,705,287	5.58%	5.91%

Notes:

a. CitiPower letter to the Office dated 20 June 1999; energy purchases data available by calendar year only.

b. Eastern Energy provided data of energy purchases in its e-mail dated 9 July 1999; units distributed (sales) data is from the Office's records.

c. Powercor e-mail dated 9 July 1999

d. AGL e-mails dated 1 and 6 July 1999

e. United Energy's sales data is from the Office's records; loss levels are from United Energy's submission dated 16 June 1999.

A further point to be noted is that there is an overall trend for loss levels to grow with increase in load as shown in Table H2 below. This trend varies between DBs however. Nevertheless overall and for the three years for which data is available, the increase in losses would correspond to about 1.2% for a 10% increase in sales.

The increase of losses with load would tend to indicate that the networks are being used more intensively. We note that VPX forecasts that energy consumption is expected to increase. The extent to which losses may increase depends mainly on the corresponding development of the distribution networks and the trends in load factors. Nevertheless we would consider that the loss levels overall to be of the level that we would expect.

Load factors. From data provided in the VPX Annual Planning Review and an estimate of the aluminium smelter load (800 MW) supplied directly from the transmission system, we calculate the distribution maximum demands and load factors as in the table below.

Table H2: DISTRIBUTION LOAD FACTORS

Year	Summer MD (MW)	Smelter Demand (MW)	Distribution MD (MW)	Energy purchased by DBs (TWh)	Distribution load factor
1995/96	5496	800	5146	28.2	0.50
1996/97	7139	800	6339	29.6	0.53
1997/98	7237	800	6437	30.5	0.54

H.2 Technical Measures to Optimise Levels of System Losses

We summarise below technical measures than can be employed to optimise system losses.

- Low loss transformers (i.e. low fixed or magnetising loss) – particularly in the case of distribution transformers where transformers with different loss ranges are offered by manufacturers
- Re-conductor overhead lines with larger cross-sectional area conductors; use of lower resistance conductors such as all aluminium alloy conductor (AAAC).
- Installation of cables having larger conductor sizes.
- Use of cables and capacitors with lower dielectric losses
- The use of a higher sub-transmission system voltage further into the network, alternatively (and where possible) uprating of 11 kV networks to 22 kV working.
- Reactive power compensation (in practice the installation of (generally switched) shunt capacitor banks, either at substations or on the network (pole top capacitors)
- Tariffs with maximum demand and/or power factor clauses for medium and large customers thereby encouraging correction of power factor at source (we note that power factor limits are specified in the Electricity Distribution Code)
- Reconfiguration (normally open points) of HV feeders to reduce system losses, commensurate with other operational requirements
- Balancing of load between phases on feeders
- Load shifting – reduction of maximum demand through the of off-peak tariffs
- Use of energy efficient lighting (within zone substations)

Procedures for capitalisation of losses, as used for transformer design purposes for example, are well established and appear in many textbooks and reference papers. Losses should generally be valued at the long run marginal cost (LRMC) of power and energy at the point in question on the network. Discount factors should reflect the opportunity cost of capital and losses should be capitalised at the expected loading levels over the lifetime of the plant in question. (In Victoria we would expect energy costs to be relatively low, however). Distribution transformers may be manufactured in different ranges according to (fixed or magnetising) loss levels and are sometimes referred to as standard or low loss transformers accordingly. A new development in the United States is the amorphous core distribution transformer with very low fixed losses but higher capital costs than conventional units. Amorphous core distribution transformers are invariably single phase units but have not attracted much interest in Europe to date.

In our experience costs of losses are unlikely to be a prime driver for asset replacement but may be a contributory factor in bringing forward the replacement of a high-loss transformer, for example. Networks with high losses also tend to be characterised by having excessive voltage drops and conversely networks with voltage drops within design limits tend to have low losses.

Good network design practice should ensure that the overall lifetime costs are optimised by taking into account the costs of losses as well as capital and other operating costs. We would suggest that the planning processes in the Distribution Businesses could be reviewed on this point, either as part of the Electricity Distribution Price Review or as part of the audit process. (One ready indicator of the policies of the Distribution Businesses would be to compare the maximum permitted levels of losses in the purchase specifications for distribution transformers). From the Regulatory Technical Audit reports commissioned by the Office we note that in one case the auditor has observed that costs of distribution losses are taken into account in the business case analysis for project identification and approval. At the time of writing this report (on Distribution System Losses) the auditors had been asked to clarify the policies of the other Distribution Businesses with respect to losse*s.*

H.3 Lack of incentive measures on distribution networks in Victoria

We note that the regulatory regime in Victoria does not at present provide for incentive measures to drive the Distribution Businesses to optimise distribution system losses. We also note that this situation would appear to be in contrast to the policy on the transmission system. VPX, in section 2.3 of its Annual Planning Review 1999, states that the scope of its planning role includes the commissioning of extensions or modifications to the Victorian network, inter alia, to reduce the costs associated with losses in the existing network.

A further point is that at present retailers (suppliers) and customers pay for the losses incurred.

H.4 Conclusions

We present below the conclusions of this report.

H.4.1 Data submitted by the DBs to the Office

We identify shortcomings in the responses of three of the DBs to the Questionnaire (section 2.2. and Appendix B).

We make recommendations for the Office to obtain from the DBs additional information on bulk purchases of energy, system maximum demands and the analysis of energy supplied by DLF level (section 2.2).

H.4.2 Loss levels

We note that over the last three years for which data is available (1995/96 to 1997/98), the increase in (energy) losses is about 1.2% for a 10% increase in load, both percentages being with respect to energy sales (section 2.1.1).

We note that the levels of losses on the distribution networks in Victoria are lower (5.91% of sales in 1997/98) than those in Great Britain and compare favourably with those on European networks that are predominantly rural in nature (sections 2.3.2 and 2.3.3). We also note that as losses on distribution networks in Great Britain are level with load growth, the variation of losses with load depends on other factors as well as load growth, particularly system development and load factor.

We provide a summary of technical measures that can be employed to optimise system losses and draw attention to one measure in particular, namely the use of low loss distribution transformers (section 2.4).

We note that the regulatory regime in Victoria does not at present provide for incentive measures to drive the Distribution Businesses to optimise distribution system losses. We review the incentives and shortcomings in the distribution price control formulae in New South Wales and Great Britain (section 2.5). We also draw attention to the need to ensure that systems for measurement and estimation of loads are sufficiently robust and standardised to ensure that DBs would be properly rewarded for loss reduction otherwise unearned benefits might ensue. We suggest that the Office should establish a technical/financial working group to further analyse the available loss reduction regime incentive options and provide recommendations for the regime to be adopted in Victoria. We also suggest that the practicality of using the PB Power Technical Model as a mechanism for setting targets for (technical) losses against which the actual performance of the DBs over the review period would be measured be examined (section 2.5.4).

H.4.3 DLFs

On the basis of a limited comparison of measured ("top down") and calculated ("bottom up") losses, we would consider CitiPower's and AGL's DLFs to be reasonable whereas United Energy's to be low. We express the view that the major part of the differences between the measured and calculated losses, namely the non-technical losses, should not exceed 1% of sales (section 3.2).

We would consider that the methodology used (based on the Distribution Losses Working Group Report) to calculate DLFs is in general reasonable with the qualifications that (section 3.3.3)

- as metering is available, a check could readily be made between the actual and calculated losses for the subtransmission line components of each DB
- more substantiation should be provided of the calculations of DLFs for the HV lines
- apart from CitiPower, no formal methodology appears to exist for calculating DLFs for LV networks and
- losses on service connections and meters should be taken into account and
- the choice of the value of k in the LLF formula should be justified (section 3.3.4).

From a benchmark comparison of individual network loss components, we would make the following observations (section 3.4.1):

- there would appear to be a discrepancy between the individual network component losses and hence DLFs for Eastern Energy and Powercor and
- there are differences in the LV line losses of Eastern Energy and Powercor and between those of AGL and United Energy, both of which we would expect to be similar to each other and
- losses in LV networks in Great Britain (and apparently in Queensland and in South Australia) are higher than those indicated from analysis of the DLFs of the Victorian networks (section 3.4.4) and therefore
- a review is required of the methodology of calculating DLFs on LV networks.

We would suggest that as a direct relationship between load growth and losses does not necessarily apply, increases in DLFs should not be directly linked to load growth. We would suggest instead that, pending the submission by the DBs of load modelling studies to support an increase in DLFs, a comparison between measured and calculated losses may be a suitable method of checking proposed values of DLFs. In any event such a procedure would require more information from the DBs than is currently gathered for approving DLFs (section 3.5).

APPENDIX I: REPORT ON MINIMUM ENERGY PERFORMANCE STANDARDS FOR DISTRIBUTION TRANSFORMERS

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I.1. Comments on the MEPS Report

The report is based to a great degree on a North American (United States and Canada) response to the problem of transformer efficiency. Because of this there are some aspects which are perhaps not fully relevant to the types of transformer and their operational aspects in the Australian situation. There are, in addition, some aspects, which are of some importance in the opinion of this author, which are not fully covered in the USEPA report. These should perhaps be considered for possible inclusion in the Australian document.

In particular the following list contains some areas which need some clarification or additional emphasis.

- The potential for use of amorphous metal cores in transformers
- The most common types of distribution transformers in use in Australia

- The effects of harmonic content in load current on transformer losses
- The effect on the proposed US efficiency values of the frequency difference between 50 and 60 Hz (as used in North America and Australia)
- Improving the loading factors of distribution transformers
- The energy impact of power factor improvement of loads supplied by transformers

I.1.1 Amorphous metal core transformers

Traditionally, transformers have used silicon steel as the magnetic material for cores in transformers. Over the last twenty years or so, so-called amorphous metal (also called glassy metal) with magnetic properties have been proposed and tested for application as transformer core metal. The advantage is that such materials exhibit lower losses than silicon steel core material.

Although there is a very substantial decrease in the losses when using amorphous metals for transformer cores, there are nevertheless some substantial constraints, apart from the higher cost, which make their potential general use in Australia a little problematic and less potentially rewarding than may be the case in North America. The major constraints on its use are discussed below.

(a) Amorphous metal cores have a lower saturation magnetic flux density than the silicon steel normally used in transformer cores (the comparative numbers are 2.0 versus 1.5). The peak flux density achievable in the core is perhaps the most important design feature of transformer cores and the aim is to use core materials with as high a value of flux density as possible. The lower flux density in amorphous metal cores means that to achieve similar levels of total core flux as in normal transformers, the amorphous core must be larger in cross-section. (This problem is exacerbated by a poorer core packing density of amorphous metal when compared with silicon steel). A larger core cross-section means more winding conductor length with an increase in resistance and hence an increase in the winding copper losses which detract from the decrease in core losses.

(b) Because of the rather specialised process needed to manufacture the amorphous metal (an extremely rapid cooling of molten metal is required) it can only be produced in very thin and long strips. Typically, amorphous magnetic metal comes in a strip which is about 100 mm wide and about 0.02 mm thick. The material is relatively brittle and cannot easily be cut to shape. As such, the basic structural form is a very poor material to manufacture transformer cores with. It can only really be used to make cores which are wound from helical layers of the continuous strip. While such wound-cores are suitable for single phase transformer cores, it is quite a difficult problem to use them for three phase transformer core construction where there must be a number of legs of the core constructed, one for each phase.

    This is an important difference between North America and Australia (and Europe). In North America (and Japan) the majority of distribution transformers are single-phase units. However in Australia and Europe the majority of distribution transformers are three-phase units, so that there is less potential for the use of amorphous cores in Australia.

    Three phase cores require stackable laminations to construct them. While there have been some relatively successful attempts to make stackable transformer laminations from layers of amorphous metal, the handling is much more difficult and adds significantly to the cost of manufacture.

(c) The amorphous metal core must be conditioned prior to its installation in transformers and the application of the windings. The normal magnetic state of the material is not sufficiently developed for it to be used in a transformer as it is produced. The metal has to be conditioned by heating it to a temperature above its Curie temperature (where magnetic materials becomes non-magnetic) and then cooling it slowly over some hours in the presence of a conditioning DC magnetic field. This then orientates the magnetic domains in the amorphous material. This procedure adds further to the cost of manufacture of such transformers.

(d) Amorphous metals have a much lower Curie temperature (about 400 K) than silicon steel transformer cores (about 1000 K). At the Curie temperature magnetic materials become non-magnetic and there is a decrease in the magnetisation between the Curie temperature and absolute zero. This puts an upper limit of about 150 C on the working temperature of amorphous metals for magnetic use, compared to an upper limit of about 650 C for silicon steel. While core temperatures of 150 C are not attained by transformer cores in normal situations, it is not out of the question for them to occur.

Because of these constraints it is unlikely that the use of amorphous materials will become common for standard distribution transformers in Australia. It is more likely that they will be best utilised in the limited special markets of small (up to 25 kVA) single phase rural transformers, perhaps including single wire earth return (SWER) transformers. In such relatively simple designs they could be manufactured a little more economically and their low losses will be of some benefit.

I.1.2 Single phase vs three phase transformers

There is some indication in the USEPA report that single phase distribution transformers are more common than three phase units in North America. This is not the case in Australia except in the fairly limited numbers of transformers in the more isolated areas of the rural electrical system. There is some economy of scale in the Australian system of preference for three phase units of higher rating where the efficiency of power transfer is somewhat higher.

It may be that adoption of larger three phase units to serve multiple consumers may give some economy of scale by improving power efficiency. However this may be balanced by higher line losses with longer distribution lines and this may also cause increased voltage regulation problems.

I.1.3 Effects of harmonic content on transformer losses

The power losses in transformers are frequency dependent and increase substantially with increase of frequency. The frequency dependence is particularly strong in the core losses and stray losses, but there is also some frequency effect on the load (copper) losses in the transformer windings.

The design and operation of transformers assumes that they will be operated at one single frequency of sinusoidal excitation. In Australia and Europe the frequency is 50 Hz while in North America it is 60 Hz. However the presence of one single frequency is an ideal case which does not occur in practice. There will always be some harmonic frequencies present in addition to the fundamental 50 or 60 Hz.

The increasing use of non-linear electrical loads such as the power electronic devices is a major culprit. These devices include switch mode power supplies for TVs and computers, adjustable speed motor drives, AC-DC rectifiers, DC-AC inverters and energy saving lamps with electronic ballasts. The result is that there is an increasing presence of harmonic content in the current taken from distribution transformers. Harmonic content means that, instead of the current having the single frequency of 50 Hertz, the current contains components with frequencies higher than the normal 50 Hz supply frequency. For example there may be components of 150 (third harmonic), 250 (fifth), 350 (seventh), 450 (ninth), 550 Hz (eleventh) and higher. Traditionally the harmonics were the odd ones but there is now also some even harmonics as well so that a nominal 50 Hz transformer current may now have 100, 200, 300 Hz etc components in addition to the odd harmonics.

Because the losses in the transformer scale up approximately with the square of the frequency, it can be seen that even a small component of say 150 Hz can have a significant effect by increasing losses in the core. For example, a comparison of the losses generated in a core by a pure 100% 50 Hz current and a current which has 95% of 50 Hz and 5% of 150 Hz shows that the losses will increase from an arbitrary 100 units at 50 Hz to 140 units at 50/150 Hz, an increase of 40 %. In some industrial systems it has been found that the seventh (350 Hz) and eleventh (550 Hz) harmonics have very substantial levels in the load current. At these frequencies the associated transformer losses will mean a substantial reduction of energy efficiency.

In addition to core loss the higher frequency components will also increase the stray losses (in the steel tank walls etc) and the winding conductor losses. In the latter case the losses will increase because the higher frequencies will generate some skin effect in the conductor which will lead to a higher effective resistance for the higher frequencies. This will be discussed further later in this report.

Although the harmonics in the current are generally low in percentage terms and there are some requirements to keep them within limits, particularly in the utility supply, their disproportionate effect on losses and their increasing prevalence means that some steps may need to be taken to prevent them from adding to existing distribution transformer losses. This may require some specified filtering of loads which are non-linear in their electrical characteristics.

I.1.4 Increasing existing transformer load factors to improve efficiency

At present, most small distribution transformers used to supply domestic premises have very poor load factors in that they are designed to cope with heavy peak loads that exist only for relatively brief periods perhaps once a day. At other times of the day the transformers are very lightly loaded, but nevertheless have core losses which are the same as at peak load. As a result, the efficiencies of such transformers at light loading are quite poor and energy is wasted.

There needs to be some attention given to improving this load factor, perhaps by increasing the number of consumers per transformer and effecting some form of demand side management to keep peak loading levels within the limits of the transformer. The other alternative is to allow the transformer to be overloaded for the short peak load periods. This will have the problem that the increased temperature will reduce insulation lifetime and the risk of transformer failure will be increased.

Improving the load factor is a very difficult problem but is one which should be addressed to assist in reducing transformer losses. This is a major contributor to transformer energy losses.

I.1.5 The effect of load power factor on losses

It is well known that a low load power factor can cause significant loss increase in electrical conductors which have to carry the full load current, which does not provide full real power at the load. By reducing reactive power requirements the current is reduced and the losses are reduced. Most utilities have some form of penalty in their tariff structure if the power factor is too low. This gives an incentive to consumers to improve their power factor. The incentive is only economic: there is no regulatory requirement on minimum power factor levels.

Such low power factor operation also increases the load losses in transformer windings and thus reduces the transformer efficiency. If the consumer were to be required to increase power factor to limit load current magnitude then this would improve losses in the transformer as well as in the connecting lines.

I.2. Effect of frequency variation on transformer losses

I.2.1 Transformer Losses

Both the magnetic core and the current carrying conductors in the windings of the transformer generate heat during transformer operation. These are irrecoverable waste energy losses which act to reduce the efficiency of power transfer of the transformer. A substantial part of the losses occur whether or not the transformer is supplying power to a load or not.

There are two separate components to the transformer losses: these are core losses (or no-load losses) in the magnetic core circuit of the transformer and the load losses (copper losses) in the metal conductors which make up the current carrying windings of the transformer.

Core Loss

The core losses in the magnetic material of the transformer core comprise two quite separate components: the magnetic hysteresis loss and the eddy current loss. Although both produce heat in the core material they do this in quite different ways. Hysteresis loss is a magnetic loss process whereas eddy current loss is an electrical loss process.

(a) Hysteresis loss

The hysteresis loss is associated with thermal energy generation caused by the frictional movement of magnetic domains in the core material as they attempt to move to follow the direction reversals of the alternating magnetic field applied to the core by the magnetising current in the transformer windings. Hysteresis losses are strongly material-dependent. For example silicon-steel has much lower hysteresis loss than normal steel, but mu-metal has a much lower hysteresis loss than silicon steel (it is also much more expensive). The hysteresis loss can be reduced substantially by processing the magnetic material before use. Thus, cold rolling and grain orientation and laser treatment techniques developed for silicon-steel has reduced its hysteresis loss very substantially in recent years.

Because the hysteresis loss results from friction as the magnetic domains attempt to follow the change in the alternating applied magnetic field, the faster and more often these reversals of directions occur, the more heat is produced. Thus hysteresis loss is dependent on the frequency of the applied magnetic field. An increase in the frequency of the exciting current will increase the hysteresis losses by giving more reversals per second. The generally accepted relationship is that hysteresis losses scale up linearly with the frequency, but there is some evidence that the scaling rate of the losses is a little faster, probably varying with frequency to the power of about 1.3.

(b) Eddy Current Loss

The other energy loss mechanism occurring in core material is that due to eddy current loss. Any electrically conducting material which is subjected to an alternating magnetic field will have eddy currents induced in it by the varying magnetic field. These eddy currents then generate heat in the same way that any electric current flowing in a conductor will, namely by ohmic heating (I^2R) generation.

The method of limitation of the core eddy current heating is to limit the magnitude of the induced eddy current 'I' and this can be done by using a core made up of laminations which are insulated from each other to prevent gross eddy current flow in the whole core volume. The eddy currents will be limited to the thin laminations which present a high electrical resistance, 'R'. Typical lamination thickness of silicon steel varies depending on requirements, but is typically about 0.2 –0.4 mm. Use of a higher resistivity metal also limits eddy current magnitude and one of the functions of silicon in steel is to increase the inherent electrical resistivity to reduce eddy current levels.

The magnitude of the induced eddy currents scales linearly with the frequency of the magnetic field (from Faradays law) and as the eddy current heating scales with the square of the current, the eddy current heating has an exact square law increase with the frequency of the exciting current of the transformer.

(c) Temperature dependence of core losses

There is little variation of hysteresis losses with temperature over the normal operating range of temperature in transformers. However the eddy current loss has significant temperature dependence. It decreases with temperature increase. This is because the electrical resistance of the core material will increase with temperature and thus will mean that the magnitude of the induced current will decrease and its heating effect will thus also decrease.

(d) Frequency dependence of core losses

The frequency dependence of the total core loss has some important ramifications for energy efficiency in two particular areas.

- If there are harmonics of the fundamental frequency (50 Hz) present in the transformer current, these harmonics (for example at 150, 250, 350, 450 Hz etc) will cause an increasing contribution to both components of loss because of there higher frequencies. Harmonic content is an increasing problem with electrical loads in that the use of modern power electronic devices as part or all of the load will generate substantial harmonic content in the current through the load. As this current is supplied by the distribution transformer, the winding current producing the magnetic field will also have the same harmonics present. These will then act to generate additional losses at a level appropriate to their higher frequency.

  While the percentage content of the harmonics may be low, although they are increasing all the time, the frequency scaling of their associated losses means that they have a disproportionately high component of the total loss. For example a 5 % magnitude of fifth harmonic will increase the overall losses in a core by about 40%. As a result the transformer has to be de-rated to operate at a lower loading level, where the normal efficiency level of power transfer is reduced.

  Prevention of harmonic generation by loads is thus required to limit the increased transformer energy loss that accompanies their presence.

- Transformer cores are designed for a specific frequency of operation. The core size, the peak magnetic flux density in the core and the winding voltage per turn around the core are all interrelated with the frequency of excitation. Thus, any change in this frequency of excitation for specific cores will affect the transformer operation. In particular the core losses will be affected by a frequency change. For a specific core, if the frequency is increased, then the losses will be greater than designed for, but if the frequency is reduced, then the losses will decrease and will be less than designed for. In the latter case the transformer core will be, in effect, oversized.

This will be the case when 50 Hz excitation frequency is used on a transformer core designed for 60 Hz. Similarly, any data pertaining to 60 Hz design will need to be adapted for 50 Hz operation. This is particularly the case for the losses in the core. At 50 Hz a transformer core designed to cope with losses at 60 Hz will have losses that are about 30% lower than at 60 Hz. This will lead to some increase in efficiency of power transfer.

I.2.2 Line (copper) losses

The other form of losses which occur in transformers and act to limit their efficiency are ohmic heating losses in the conductor material of the windings. They are commonly called “copper losses”.

These are generated by the heating effect in the conductor resistance of the load current passing through the windings. As ohmic heating (I^2R) losses they scale as the square of the current or load level supplied by the transformer. At full load the copper losses typically account for about 80% of the total losses in a normal silicon steel core transformer. The core losses and some other (very minor) stray losses make up the rest. Using the square law variation of the copper losses and the approximate 4:1 ration of copper to core losses at full (100%) load, at about 50% load the core and copper losses are about equal. When the two loss components are equal, the transformer has its maximum efficiency of power transfer. At lower loads the constant core loss is the dominant component, while at higher loads the copper losses are the dominant component.

The copper loss magnitude is determined by the winding resistance and the current magnitude in the winding conductor. The conductor resistance is dependent on the material used, but as this is invariably copper there is little possibility of improvement available there. The only better (lower resistance) conductor material would be silver.

The resistance of the conductor has a substantial temperature dependence and increases with temperature so that when the conductor is operating at about 80 C, the copper resistance is 26% higher than at 20 C. Full load copper losses are always quoted at the normal elevated operating temperatures for full load.

[It should be noted that the current, ‘I’, in this case will not be affected by the resistance increase of the winding in the way that the core resistance increase with temperature decreased the core eddy current losses.]

Effect of frequency on copper loss

There is also some increase in conductor resistance due to the presence of the “skin effect” at higher frequencies. The skin effect in conductors is caused by eddy currents generated within a conductor by the magnetic field of its own alternating current. These eddy currents act to change the total overall current distribution in the conductor, causing the current to concentrate near the conductor surface, or “skin”. The result of this re-distribution is that there is an effective increase in the resistance of the winding conductor. This will act to increase the copper losses.

The skin effect becomes more pronounced with increasing frequency and becomes a problem if harmonics are present in the winding current. Normally, at 50 and 60 Hz there is no significant skin effect generated and thus no impact on the copper losses. However, if higher frequency harmonics are present in the current, the effective resistance to these harmonics of the current can be quite high and the heating effect intensified. This is particularly a problem with large transformers where the winding conductors are of large cross-section and are normally made up of transposed sub-conductors even at 50Hz. This effect will have some importance for situations where transformer currents have significant harmonic content, but will be of no consequence when comparing 50 and 60 Hz operation of transformers.

I.2.3 Effect of operating frequency on transformer power efficiency

At constant frequency, the total combined core loss is essentially constant whenever the transformer is energised by the generation of an alternating magnetic field in the core. It is the presence of the magnetic field in the core which creates the core losses and even if the transformer is not supplying any power to a load, the magnetic field must be present and will thus generate core losses. For this reason the core losses are often referred to as “no-load losses”. As the efficiency of power transfer of a transformer is dependent on the losses the constant core losses represent a limitation to the power efficiency level.

Maximum efficiency of a transformer occurs when the no-load losses are equal to the load losses and as the full load losses are typically about four times no-load losses the maximum power transfer efficiency occurs at about 50% of full load. This efficiency will typically be about 98% for a standard distribution transformer. The efficiency will vary a little with rating and higher power rating transformers will have higher efficiencies.

For a particular transformer operating at higher loads than the 50% where efficiency is a peak, the efficiency will decrease very slightly. For example the peak 98% listed above may decrease to about 97.4% at full load and to about 95.6% at 200% of rated load. However, at less than 50% of rated load the energy efficiency will decrease much more rapidly. At 10% of rated load the efficiency will be only about 94.7% and will be about 90% at 5% of load rated load. There are thus significant advantages in minimising waste energy by keeping the load factor of the transformer high.

I.3. Adapting the Canadian and US 60 Hz efficiency levels to 50 Hz operation

Distribution transformer design principles, manufacturing procedures and general operational practices are quite international and universal. The same materials are used for the cores, winding conductors, tanks and for electrical insulation purposes. With use of the same materials the designs use identical specifications such as the peak flux density in the core, the electric field stresses and also the temperature limitations of the insulation material, which determine the loading capacity of the transformer. The only difference in the design specifications between the USA-Canada and Australian design and manufacture is the frequency of operation, being 60 Hz in the USA/Canada and 50 Hz in Australia. This operating frequency difference will mean that there is some difference in the level of core losses, but these differences are quite quantifiable.

In view of the similarity of design and manufacture, it is quite valid to use specified US and Canadian transformer efficiency levels for application in Australia, provided that the effect of the frequency difference on the losses is taken into account. Thus, the Canadian recommended efficiency levels have been used as the basis for determining comparable efficiencies levels for use in Australia.

The Canadian requirements assume an operating frequency of 60Hz, but there will be some reduction of losses when applied to 50 Hz operation and so the proposed efficiency levels for Australia should be increased slightly to account for the lower core losses.

The efficiency levels taken from the Canadian proposals have been adapted to 50 Hz and the results are shown in the tables below.

There is not a full correspondence with the Canadian values because some of the transformer ratings listed there are not standard ratings used in Australian distribution transformers. Similarly some standard Australian ratings are not on the Canadian list. The table below includes only transformers listed in the Electricity Supply Association of Australia (ESAA) document on standard distribution transformer ratings. [S(b)13 – 1978: Guide to the Specification of Distribution Transformers – 5 kVA to 1000 kVA]. There may be a later version of this document but it should not have changed the standard ratings.

I.3.1 Transformer Specifications

(a) ESAA standard transformer power ratings

Single phase units

10 kVA, 15kVA, 25kVA

Three phase units

25kVA, 50kVA, 100kVA, 200kVA, 300kVA, 500kVA, 750kVA, 1000kVA

(b) ESAA specified voltage ratings

Single phase units:

6.6kV/500-250V

11kV/500-250V

22kV/500-250V

33kV/500-250V

Three phase units:

6.6kV/433-250V

11kV/433-250V

22kV/433-250V

33kV/433-250V

There are also a number of standard SWER transformer ratings listed in the ESAA document, but such transformers are not specifically addressed in the Canadian proposal and thus there are no efficiency recommendations listed there they have not been included here. However as SWER transformers represent a significant component of remote rural supply in Australia, they should be included in a list of proposed minimum efficiency standards. In the absence of any efficiency data in the Canadian proposal for SWER units, some of them could tentatively be included in the Liquid Filled section, as part of the single phase group of rating 10, 15 and 25 kVA. However the rather specialised nature of the SWER transformer may require some further analysis to determine appropriate efficiency levels.

(c) Calculations

The tables attached use the recommended efficiencies of the Canadian figures for 50% transformer loading and adjusts the 60 Hz core loss component to 50 Hz and then recalculates the efficiency for 50 Hz.

The following assumptions were made for the calculations:

- The copper loss component is assumed to be constant with frequency
- The load power factor is assumed to be unity
- The core loss hysteresis and eddy current loss components are equal at 60Hz
- The core loss and copper loss are equal at 50% loading
- The eddy current core loss scales of frequency squared
- The hysteresis loss component scales as frequency to the power of 1.3

Where the USEPA do not have an identical rating to the ESSA range, the 60 Hz efficiency values have been interpolated graphically from the USEPA data and then adapted to 50 Hz.

The USEPA low voltage efficiency data for dry-type transformers have not been included here as these 690V primary voltage are significantly different to typical Australian distribution transformers and have no specific relevance.

I.3.2 Efficiencies

Table G1: Liquid filled transformers

Power rating [KVA]	Efficiency proposal % [Canada: 60 Hz]	Efficiency proposal % [50 Hz operation]
Single phase units [50% load] [Including SWER Transformers]		
10	98.30	98.5
15	98.50	98.7
25	98.70	98.9
Three phase units [50% load]		

25	98.20	98.4
50	98.50	98.7
100	98.80	98.9
200	99.00	99.1
300	99.00	99.1
500	99.10	99.2
750	99.20	99.3
1000	99.30	99.4
1500	99.40	99.5
2000	99.40	99.5
2500	99.4 (*US)	99.5

Table G2: Dry-type transformers [Medium Voltage applications]

Power rating [KVA]	Efficiency proposal % [Canada: 60 Hz]	Efficiency proposal % [50 Hz operation]
Single phase units [50% load]		
15	97.60	97.9
25	97.90	98.3
Three phase units [50% load]		
25	97.20	97.6
50	97.70	98.0
100	98.05	98.3
200	98.40	98.6
300	98.50	98.7
500	98.70	98.9
750	98.80	99.0
1000	98.90	99.0
1500	99.00	99.1
2000	99.00	99.1
2500	99.10	99.2

Note on Author

Trevor Blackburn has been the Associate Professor, Electrical Engineering, at the University of New South Wales since 1995. Between 1993 to 1997 he was Head of the Dept. of Electric Power Engineering at UNSW. His teaching areas include:

- *High Voltage and High Current Phenomena*
- *Power System Equipment*
- *Electrical Insulation*
- *Gaseous Discharges*
- *Electromagnetic Theory and Applications*
- *Electric and magnetic fields*

- *Industrial Electrical Systems*
- *Electrical Safety*
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Trevor is an acknowledged expert on transformers and related technologies and issues, and is the Australian representative on the international CIGRE study committee SC15 - Materials for Electrotechnology.

In addition, Trevor has been highly involved in the development of standards in electrotechnology in Australia. He is a member of the Electrical Assessors Panel of the National Association of Testing Authorities (NATA), and of several Standards Committees, including EL7/2/1 covering insulation coordination in low-medium voltage systems.

APPENDIX J: REPORT ON IMPACT OF VOLTAGE CHANGES & POWER QUALITY ON MEPS LEVELS, AND DISCUSSION OF TEST METHODOLOGIES

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J.1 Summary

This report examines three particular aspects associated with the efficiency of distribution transformers and the impact that these three factors will have on the proposed minimum energy performance standards (MEPS) program for transformers .

The three areas examined in the report are:

- The effect of the voltage change from 240 to 230 volts on transformer efficiency
- The effect of power quality on energy efficiency in transformers
- The methods of test of transformer losses and the possible use of on-line testing

It was found that the voltage change will have an effect on the efficiency of existing 240 volt transformers, with the overall efficiency being lowered slightly because of increased copper losses in the transformer at the lower secondary voltage. This effect may require some adjustment of the proposed MEPS efficiency levels for existing 240 volt transformers. Quantitative details of such variations will not be able to be determined until the exact method of achieving 230 volts is decided by the distribution utilities.

New transformers designed for 230 volt operation will still use the original efficiency levels stated in the MEPS proposal.

Power quality is an increasing problem in electrical systems because of the increasing use of non-linear loads with power electronic operation. The aspect of power quality of importance here is the harmonic content generated by the loads. This will act to increase the losses in transformers supplying the loads.

However, it is not feasible or desirable to have transformer design changed in an attempt to maximise the efficiency for typical harmonic loads. The onus must be put on the consumer to keep the harmonic content within manageable levels at the point of supply by the utility transformer. There is a potential problem with large industrial installations in that these may contain distribution transformers supplying loads which cause very inefficient operation of the transformers. These may not be subject to the same power quality scrutiny as obtains at the point of supply.

To this end, some development of test methods which enable determination of transformer losses and hence efficiency under load are desirable. The present test methods are very restrictive and unrepresentative of current supply- load conditions.

It is suggested that modern power electronic inverter supplies can enable efficiency testing of transformers with any desired harmonic content to be achieved. Such a test source would provide much better simulation of typical operating conditions.

Further, the use of an on-line monitoring system for transformer power loss measurement and efficiency determination would provide a useful technique for assessing the energy efficiency of loaded transformers in industry. The technology for such an on-line techniques is available and has been demonstrated to be able to perform such a function.

J.2 Effect of the change of general supply voltage to 230/400 V

J.2.1 Changes in nominal voltage

In recent years there has a general move, first proposed by the International Electrotechnical Committee (IEC) in 1983, to have a general and uniform standard of distribution voltage level for all countries with the possible exception of North America. The standard voltage level proposed by the IEC was 230/400 volts, with the 230 volts being the single phase and 400 volts being the three-phase voltage. There is currently a range of different nominal voltages in use in various countries, including 220/380 volts, 230/400 volts and 240/415 volts. The date nominated by the IEC to achieve this uniform voltage was 2003 [1].

As an active member of IEC, Australia is moving towards an increasing compliance with IEC electrical standards and has put such a plan for a change in the standard voltage level into place. Thus, in 2003, the standard single phase supply voltage in Australia will be 230 volts.

As part of this move, a new Australian voltage Standard, based on the existing IEC standard, was published in February 2000. This new standard is **AS60038 – 2000: Standard Voltages**. The parent document of AS60038 is the IEC standard document IEC60038 (1983): Standard Voltages.

The existing general **Australian supply voltage** level and the normal tolerances in current use are:

- 240/415V, +6%, -6%: thus the variation is 226 – 254 volts (a 28 volt range).

The proposed **IEC supply voltage** and tolerances are to be:

- 230/400V, +10%, -10%, the voltage variation is thus 207 – 253 volts (a 46 volt range)

Associated with the IEC supply voltage will be a **utilization voltage** and tolerances of

- 230/400V, +10%, -14%, a voltage variation of 198 – 253 volts (a range of 55 volts)

The new **Australian supply voltage** and tolerances will be:

- 230/400V, +10%, -6%, a voltage variation of 216 – 253 volts (a range of 37 volts)

with a corresponding **utilization voltage** and tolerances of

- 230/400V, +10%, -11%, a variation of 205 – 253 volts (a range of 48 volts).

The supply voltage will be the level as supplied at the consumer's terminals by the distribution utility.

The utilization voltage will be the level of voltage supply as achieved effectively at the appliance outlet in the consumer's installation. The change in the minimum voltage level in the new Australian system, from –6% in the supply voltage to –11% in the utilization voltage (or from 226 to 205 volts at the outlet point), will allow for a 5% voltage drop in the consumers installation wiring. This allowable drop is consistent with the allowance of a 5% drop specified in the Wiring Rules, Australian Standard AS3000. The IEC allows only a 4% drop in the consumer's installation but the lower voltage tolerance at the appliance level is 205 volts in Australia as opposed to 198 volts for the IEC.

The change to a definition of both supply voltage and utilization voltage in the new Standard is a new development and is done to allow some flexibility in the use of appliances, which are either 230 or 240 volt rating, during the changeover to the new voltages.

J.2.2 Effect of the voltage changes

The change in general voltage supply and utilization levels will have a number of potential effects on electrical distribution power supply systems.

The items of equipment which will be affected by the change are:

- Electrical appliances and general equipment taking power from the mains
- Distribution and utilization transformers

- Distribution feeder lines and cables

Appliances and equipment

Of these entities, the most affected items will be the electrical appliances and equipment, with many 240 volt appliances having to operate at 230 volts, or 4.2% below their nominal rated voltage. This will require, in some cases such as motors, additional current flow to maintain the rated power levels. The additional current of about 4% will thus increase the resistive heating effect of the current in the motor windings by about 8%. The end result will be some increase in operating temperature which may well mean a shorter life due to accelerated thermal deterioration of the insulation.

For such appliances and equipment items there will be no possible means of counteracting the decrease of supply voltage. They will have to continue to operate at lower than rated voltage for the remainder of their operational life.

Transformers

The change of voltage will have some potential effects on the power losses of utility distribution transformers. The exact form of the effect on the losses will depend on which approach is taken by the electrical supply utilities to achieving the required voltage reduction.

One option is to achieve the voltage decrease by an appropriate reduction of the voltage level of the overall 11 kV distribution system. This can be done by changing tap settings on 132/33kV transformers, for example, and using the current tap settings on the existing 11kV/415V transformers.

The result will be lower volts per turn in the transformer and a lower magnetic flux density (and hence flux) in the transformer core. This will have some implications for transformer losses, both core and copper, as will be discussed later. It will also affect in a similar way the transformers of any industrial and commercial customers who take their electrical supply at 11kV.

The other option is to have the voltage reduced on the transformer 415V (secondary) side by using lower tap settings on the 11kV/415V transformers. In this case the core flux density and volts per turn will be unchanged, and core losses will not change, but the winding currents will be higher and the copper losses will thus increase. Thus, this will also have an impact on transformer losses, as will be discussed later.

Feeder lines and cables

The lower supply voltage will mean a general increase in current level in equipment to order to maintain the same power levels at the new lower voltage. This will mean that there will be increased resistive heating in the feeder lines and cables between the supply and the load. This will mean increased energy loss and will also mean an increased voltage drop between the supply and the appliances and equipment. As in the case of the appliances and similar equipment, an increase of about 4% in the current will mean an increase of about 8% in the power and energy loss in feeders and cables, with a corresponding increase in their operating temperature.

J.2.3 Effect of a voltage reduction on transformer losses

Decrease of the 11kV level

In the option of a 4% decrease in the 11kV supply voltage combined with use of existing transformer tap settings for the 11kV/415V units, the overall result will be a reduction of the magnetising ampere turns of the transformer. This will cause a consequent decrease in the core flux density, probably by something less than 4%, about 3%. The relationship will be somewhat non-linear because of the magnetising curve non-linearity at the operating point.

The lower core flux density will mean lower cores losses, which scale approximately with the square of flux density. Thus, typically, the core losses (both hysteresis and eddy current) will decrease by about 6% with a 3% decrease in core flux density.

The magnetising current of the transformer will also decrease and this component of the overall current will thus reduce resistive losses in the windings. However, the resistive copper loss associated with the normal level of magnetising current is always a relatively insignificant component of the overall copper losses. The magnetising current is typically only about 5% of the full load current and so the contribution to total resistive losses in the windings is only about 0.25% of the total.

The overall copper loss will increase because of the increased load current required to compensate for the lower voltage to achieve the same power. The increase in load current level of about 4% will give an increase in resistive power loss in the windings of about 8%. Thus, overall there will be about 8% increase in the transformer losses in this case.

In addition to the core losses the reduced flux density and flux in the core will also reduce the level of external eddy current losses in the transformer tank and other metal components. The reduced flux will also reduce leakage inductance and thus voltage drop, although the inductive decrease in voltage drop will be counteracted by the increase in resistive voltage drop in the windings.

Decrease of the secondary voltage

In the other option of a maintained 11kV supply at the current level and a lower tapping setting on the transformers, the result will be no change in the core conditions and hence no change in core losses. However the lower secondary voltage will mean an increase in copper losses as before, with again about an 8 % increase in losses in the transformer. The increase in losses will also mean an increase in winding temperature and this will cause an increase in winding resistance, which will further exacerbate heat loss and voltage drop.

Thus, there will be a significant increase in the losses and heating of existing transformers. In the case of typical ONAN (naturally cooled) transformers the increase in losses will mean some reduction of the peak rating level as there will be no way of increasing heat dissipation. In the case of ONAF (forced external air cooling) transformers the increase in losses will mean increased use of the cooling fans and thus a decrease in the overall efficiency of the transformer.

Effect on transformer efficiency

In terms of the overall power and energy efficiency of the transformer, the voltage changes will mean a variation in the ratio of the copper loss to core loss and this will affect somewhat the loading levels which give maximum transformer efficiency.

The option with a decrease in core losses will be the more energy-efficient option because of the lower core loss which will give a continuous reduction.

In terms of improving design of transformers to maintain the efficiency level of new transformers, there is no difficulty in a simple design change to give a lower voltage which will maintain efficiency levels. It is likely that the only design change required would be a simple change in the tapping points to give the appropriate voltage levels.

Reconfiguration of the existing transformers is not necessarily an easy option. It may be that there will be adequate lower voltage tap points that will allow the achievement of the lower voltage, but this is not necessarily the case always. It is possible that the increased current required may take the transformer into the saturation region of the magnetisation curve, which will cause other problems.

The most likely option to be taken by the utilities to achieve the voltage reduction will be the second option of using lower tap settings [2]. Thus the main impact on losses will be the increase in copper losses, with the core losses remaining much the same.

It should also be noted that there are second order effects which will occur in the transformer when operating at lower voltage. The increased current from the secondary will increase the temperature of the windings and this will increase the resistance and thus lead to higher losses and to increased voltage drop. At the same time the increase temperature of the core will mean an increased resistance of the core laminations and a decrease in the resistance and hence of the eddy current magnitude. Thus the core eddy current loss will decrease. It can be seen that the overall effect of the voltage change on losses will be a complex result of a number of sometimes offsetting effects.

It should also be noted that in many cases in densely electrified areas such as the Sydney CBD, the 11kV system is already operating at low voltage levels by virtue of the transformer loading and voltage drops. Any further increase in load due to further voltage reduction will cause problems with core saturation.

In the case of consumer transformers which are more heavily and constantly loaded, the decrease in transformer efficiency will be greater than for the utilities and will represent a greater energy loss.

In differentiating between oil-filled and dry-type transformers, the inherently higher core losses in the dry type and the accompanying lower copper losses will mean that they will fare a little better efficiency-wise than oil-filled transformers. If the core losses are kept at the same levels, but the copper losses are increased then the dry-type transformers will fare a little better in the efficiency stakes than the oil-filled type.

J.2.4 Measurement of losses

The losses due to decrease of voltage will provide a similar loss structure to the standard losses in the transformer and will thus be able to be measured in exactly the same way as transformer losses are normally measured. The voltage of the transformer will be the normal 230 volt level and the losses will be measured by wattmeter, with the usual correction terms and estimation of uncertainties that are normally performed. These will be discussed later.

For existing transformers the normal tables of efficiency variation with loading and with power factor will have to be adjusted because the mixture of core loss and copper loss will vary at the lower voltage and thus these values may need to be re-calculated for optimisation of maximum transformer efficiency.

J.3 Effect of Power Quality on Transformer efficiency

The increasing use of power electronic devices such as switch-mode power supplies, rectifiers, inverters, phase-controlled switches, integral cycle switching controllers etc have caused a substantial decrease in the quality of the electrical supply. This diminution of quality is not a fault of the utility supply but is primarily caused by the consumers loads. Harmonic content in the 50 Hz power supply is imposed on the utility supply by the non-linearity of consumer loads with power electronic circuits and components. The result of such load effects are a substantial increase in the harmonic content of the electrical supply, and in particular on any current from a transformer.

Generally the harmonics are primarily odd orders such as the third, fifth, seventh, ninth, eleventh, thirteenth etc, with corresponding frequencies of 150, 250, 350, 450, 550, 650 Hz, etc. There are now an increasing level also of the even harmonics, second, fourth, sixth etc at 100, 200, 300 Hz etc. The magnitude of the harmonic components decreases with increasing frequency.

The effect of these high frequency harmonics is to increase the losses in the transformer. Core losses in particular are very frequency dependent, scaling effectively with the square of the frequency. Copper losses are also frequency dependent but to a lesser extent than core loss.

J.3.1 Effect on Core losses

As a typical example of core losses, the harmonic content in a non-linear load such as a rectifier converter may, instead of having 100% current at 50 Hz, have 20% in magnitude of fifth harmonic (250 Hz) current and 14% in magnitude of seventh harmonic (350 Hz) current in addition to the 50 Hz fundamental. In such a case, using the square law loss relationship, calculations show that the core losses would be increased by 24% with the harmonic levels stated.

J.3.2 Effect on copper losses

There will also be an increase in the winding conductor resistance due to the skin effect. The skin effect is very frequency dependent and causes a non-uniform redistribution of current within the conductor. The end result is that the current crowds into the surface (skin) area of the conductor with the result that effective resistance increases because of the less effective use of the conductor cross section.

This increase in resistance is difficult to quantify as it depends on the winding conductor diameter and the “skin depth” which will have different values for different frequency harmonics. However the increase will be significant in large cross-section conductors. The secondary windings of high power transformers (for example 1000 kVA rating) will be rated at about 1400 amps with quite large conductors (admittedly in Roebel configuration to combat skin effect at 50 Hz). The skin effect with fifth and seventh harmonic will be significant and can amount to an increase in the effective AC resistance of about 10% at 250 Hz and about 30% at 350 Hz for a 10mm x 4mm copper winding section.

Overall this will mean an effective resistance increase of about 2% at 250 Hz, plus 4% at 350 Hz or 6 % overall increase for the distorted current waveform. This resistance increase will give an increase of about 6% in resistive heating in the winding at the same overall current magnitude as a pure 50 Hz current.

If the core loss is 20% of the total and the copper loss 80% of the total transformer losses, the total increase in heat loss, including the effect of the increase in the load current and the increase in resistance, would be about (0.8 x 6 + 0.2 x 24) = 9.6% increase at full load and about (0.2 x 6 + 0.2 x 24) = 6% at 0.5 per unit load.

In addition to the core loss and copper loss increase, the external eddy current loss will also increase due to the increase of frequency. The leakage reactance and hence the internal voltage drop in the transformer will also increase.

J.3.3 Level of harmonic content in the supply

The level of harmonic content which impacts on the utility supply voltage is strictly controlled by requirements laid out in the Australian Standards **AS2279, parts 1-4 [Disturbances in Mains Supply Networks]** which cover domestic and industrial electrical systems. The Standard which is most relevant is **AS2279.2 [Part 2: Limitation of Harmonics Caused by Industrial equipment]** which governs the harmonics generated by equipment in industrial electrical systems. This latter standard is currently being revised [3]. It will ultimately be the document which provides the major specifications which will ensure that the harmonic content at the "point of common coupling" (POCC) of the system is within appropriate limits which will not disturb other customers unduly. The point of common coupling is that connection point which includes the supply and other consumers and thus any harmonic content will affect other consumers.

In terms of the effect on the transformer losses, the non-linear load will cause the transformer to supply a distorted current waveform with the harmonic content determined by the load non-linearity. This current with its harmonic content will then affect the transformer losses by the impact of the high frequency interactions.

The specified upper limit of the harmonic content at the point of common coupling is a total harmonic distortion (THD) level of less than 5% of the fundamental for supply voltages less than or equal to 33kV. This voltage classification will cover all normal distribution transformers. The THD will include all harmonics up to greater than about 35. However the general trend is that the magnitude level of the harmonics is roughly inversely proportional to the harmonic number.

In general the major contribution will be from the lower odd harmonics: the fifth, seventh, eleventh and thirteenth (excluding the triplen harmonics of third, ninth etc). There may also be some even harmonics but these are not as high as the odd harmonics. The 5% will include 4% for odd harmonics and 2% for even harmonics.

Because the harmonic mix will depend on the particular load, it is not possible to determine what a total harmonic distortion of 5% will mean in terms of additional transformer losses. However if the THD is taken as being due entirely to fifth harmonic, the best case, the heat loss will be increased by about 10% in the utility distribution transformers.

The Standard requires that the level of 5% THD in a consumer's load be the level at the point of common coupling with other customers. This then limits the effect of the harmonics on the supply to the other customer from the same source. The consumer will be required to install some means of reducing the level of THD if it is above this specified evel at the POCC.

However, there is no requirement that the consumer keeps to such limits of THD within his own installation. The only requirement is that the THD should not impact adversely on other consumers connected at the same point. While there may be some effort to limit the harmonics at the POCC by use of filters etc, there is generally no such enthusiasm to control the harmonic levels in the rest of the installation. Thus it is often the case that the THD in an industrial situation may be greater than 5%. If there are transformers owned by the industrial customer, then the high THD may well give very substantial increases in the losses due to the harmonics.

In general the harmonics generated by domestic loads are not very significant in terms of the THD level. Compared to industry the effect of domestic loads on transformer losses will be quite small.

In summary, the effect of harmonics due to non-linear loads has the potential to significantly increase the transformer losses. While the harmonic standard for electrical supply will limit this increase in the utility transformers, there will be no such limitation in transformers owned by the consumer and not located at the point of common coupling. Thus there is a considerable potential for industry to operate with increased losses in transformers, unknowingly, in all probability.

J.3.4 Measurement of increased losses

The loss measurement on this case requires somewhat more sophisticated equipment than that used in the case of the relatively simple losses due to voltage change. The harmonics may give frequency components up to some thousands of hertz and the usual instruments for power measurements, electrodynamic wattmeters will not respond to these frequency levels. Electronic wattmeter instruments must be used in such cases and if the voltages and currents are high and require instrument transformers to reduce the magnitudes, the instrument transformers must have an appropriate frequency response to cover the highest harmonic present. This requirement may have some implications if on-line power and energy use monitoring is to be attempted on the transformer.

Because the increased losses are very load-dependent, the losses and the operating efficiency cannot be easily determined from simple measurement of voltage as in the case of the reduced voltage losses. The load current must be monitored (at the required frequency response) and the efficiency should be computed on-line. This cannot be done with manual instruments. Digital techniques and some software processing are required. This will be discussed later.

J.3.5 Voltage disturbances

Power supply quality, in addition to emphasis on the harmonic content, also includes voltage fluctuations within the “quality” definition. These may include voltage surges, sags, impulses and similar transient events. In general they are very short-lived, typically only about a few seconds at most and microseconds at the least. Because of their short duration they have no effect on the overall losses of the transformer.

Voltage fluctuations are not important in the context of energy efficiency and will not be considered further.

In summary, the increasing incidence of non-linear loads and the associated harmonic content has very considerable potential effect on the losses and the energy efficiency of transformers. While Standard requirements limit the THD in supply transformers, there is a significant effect there. In addition the case of consumer transformers may be much worse in that the THD limits will not necessarily be complied with there and the losses may be much higher because of the harmonic content.

J.4 Loss Measurements

To be able to quantify continuously the power and energy losses in transformers, it is necessary to monitor the losses and to then compute the efficiency of the transformer under on-line conditions. This requires the measurement of the power loss and the use of loading data (load level, power factor and duty cycle) to compute the efficiency continuously.

At present there is little information available in this regard, even in the area of simple load monitoring. It has been stated by distribution utilities that there is no load monitoring at present on their distribution transformers. Thus any loss monitoring and efficiency determinations would require installation of such monitoring equipment on all transformers. Whether this is an economic option will not be discussed at this stage. Instead the options for loss measurements, both in the test area and in the field will be discussed.

Power loss and efficiency determination are two separate calculations, with the efficiency determination requiring the data on loading and duration to extend the power loss measurements to energy loss and hence efficiency determination.

J.4.1 Power loss measurement

Power loss measurement on transformers is normally done only in the test laboratory or on the factory floor. The standard procedure is to use a short circuit test to determine copper losses and an open circuit test to determine the core losses. The tests are done at rated current and rated voltage respectively to provide the overall losses at rated voltage and current. However while they may be done at rated voltage and current, the current waveform used will not necessarily represent that which will be used in service. This is particularly the case if the real load is non-linear with significant harmonic generation.

As a result of this lack of simulation of true load, the losses measured in the laboratory test area may not be representative of those which will be seen in service. In this case the losses will be inevitably higher in service and the efficiency lower. Thus in-service monitoring is much preferable to use of test data.

The traditional laboratory test method is to use a wattmeter, appropriately connected to give most accurate measurement of the losses [4,5]. This is important if the wattmeter is an analogue electrodynamometer type. If a digital wattmeter is used (as is more common in current practice) the possible errors from voltage drop in the meter or current diversion in the meter are much less. The typical uncertainties of power measurements are dependent on the instrument used. Uncertainties of better than 2% in power measurements are easily achievable with modern instruments. Traditionally there has been some increased error for low power factor measurements in analogue type instruments but this is not a problem with digital instruments. For laboratory tests, an uncertainty of 1% in a laboratory test will provide an accuracy of about 0.02 % in the calculation of power efficiency for a typical 500 kVA rating transformer.

However it must be stressed that while the power efficiency measured in the laboratory is a useful guide for the transformer compliance with stated loss efficiencies, it is the power efficiency under actual load that is the important quantity and this can be done only on-line. On-line measurements are much more difficult to perform. These measurements will be covered later.

While there is very good accuracy achievable with basic wattmeter instruments, it is often the case with high voltage and high power rating distribution transformers that instrument transformers must also be used. Instrument transformers will provide current and voltage levels which are within the acceptable input ranges of the basic wattmeter instruments. In this case the accuracy of the instrument transformers must be included in the determination of the overall uncertainty. While the ratio errors of such devices are usually adequate, their phase angle errors may lead to some increased uncertainties in the power measurements. Thus the instrument transformers must be carefully chosen to provide adequate accuracy.

As discussed in section 2, the presence of harmonics is a significant factor in the power losses and the instruments used must be able to measure the effects of frequencies up to about 20 kHz. This will put some further limitations on the current transformers in particular.

The basic procedures of laboratory power measurements and loss measurements are outlined in the documents [5,6,7]. They will not be discussed in detail here.

J.4.2 Power loss measurement on-line

If the overall power and energy efficiencies of transformers are to be continuously monitored then this can only be done by power measurement in on-line situations where the real supply waveforms, including any harmonic content from the load, are present. Energy efficiencies can only be determined from the power measurements integrated over time and taking loading level into account.

On-line power loss measurement is a much more difficult proposition than measurements on the laboratory or test area floor. The laboratory test must be done as two separate tests to detail the individual copper and core losses, and these tests are performed with no load on the transformer. Thus the load no-linearity is not a factor in the tests area. In on-line measurements the transformer load is present and it is not possible to do the short circuit and no-load tests. A single measurement must be done in such a way as to produce the overall transformer loss measurement. It will not be possible to separate the core and copper losses without doing some further tests at different load levels.

Further complications that will affect the uncertainty of the on-line tests are the temperatures of the windings. In power loss measurements in the laboratory, the loss measurements must be adjusted for the winding operating temperature when the measurements are done at a standard temperature in the laboratory, usually the ambient value. [5,8]. In on-line applications the winding and core temperatures are unknown and have to be approximated. It is not an easy task to measure them.

The net result of these problems is that the measurement uncertainty in on-line testing will be significantly higher than in the laboratory tests, even if the technology of measurement is available.

In fact the technology does exist to measure the losses in the transformer on-line but the procedure would be complex and expensive to install on individual transformers and the economics in terms of energy efficiency data would be questionable.

On-line measurement method

The basic approach to on-line monitoring would be to measure the transformer input power and the output power and to subtract them to find the total transformer loss. This would then give the information also needed to calculate the transformer power efficiency. The energy use and efficiency could then be achieved by integration over time.

While the above appears simple in concept, it would be very difficult and complex to achieve in practice. A recording wattmeter arrangement at both terminals would be required. However such instruments are very expensive if the full harmonic spectrum of current is required to be used. The best approach would be to measure and record digitally the input voltage and current and the output voltage and current and to determine the real power levels at each side of the transformer from them. The real can be determined in either of two ways.

The phase difference between the voltage and current in the two sets of terminal quantities can be used to generate the power from the voltage and current phasor magnitudes using the usual formula $VICos\phi$. The real power at each terminal can be determined and the output subtracted from the input to find the net power loss in the transformer. The subtraction, the determination of $VICos\phi$ and the efficiency calculations can be done by microprocessor and the results can be either stored for later downloading or transmitted directly to a display if required.

The other alternative is to multiply the instantaneous voltage and current waveform functions together and to take an average of the product to obtain the average power from the instantaneous power. This will be able to avoid the determination of the phase difference ϕ and the use of it in the calculation. [It will be accounted for in the multiplication and averaging process]. With significant harmonic content the determination of ϕ may be difficult to obtain accurately and the result of the calculation will not account for all harmonics. The latter method avoids these problems and will include the true RMS determination. The averaging and multiplication can be done by digital electronic methods.

For overall energy efficiency, the power losses must be integrated over time and thus a record of the loading current pattern should be also recorded to determine energy use and hence energy efficiency.

In both of the above options the data can be recorded or transmitted to some central site for monitoring. A telephone modem could be used to allow monitoring of power loss, efficiency and loading at any time.

It should be noted that such a system which records transformer load variation with time can also be of considerable use in assessing the insulation deterioration of a transformer. The ageing of a transformer is dependent on the insulation temperature and this, in turn, is dependent on the winding and core temperatures which are load dependent. Thus, a continuous record of transformer loading will provide some means of estimation of loss of life from the insulation temperature [9] derived from the loading. Such load records are desirable to improve the asset management of transformers, but there has been little in the way of adoption of such records by distribution utilities. The only common load recorder on transformers is a peak load meter which simply records maximum demand on the transformer and is used only to indicate whether further capacity is required.

Feasibility of on-line monitoring

Such an on-line monitoring system would be an expensive adjunct to a distribution transformer for permanent connection and some form of mobile use to cover a number of transformers would be better able to give an economic return.

The on-line monitor would require voltage and current transformers with the required frequency response to cover all possible harmonics. These would be required for both input and output terminals of the transformer. Analogue to digital converters would be also required with microprocessors and electronics to perform the various mathematical operations needed. Ideally a three phase system of monitoring with three separate units would be used, but there would be little lost if only one phase were monitored. The energy efficiencies of all phases would be similar unless there were substantial phase loading imbalance.

A different form of monitors using such techniques are already in use for on-line operation in measuring the dielectric dissipation factor (DDF) of the insulation in high voltage current transformers [10]. The dissipation factor is a measure of the dielectric heating power loss in the insulation dielectric in transformers. The dielectric heating is simply an electric field analogue of the hysteresis power heating in magnetic materials (such as a core) by the magnetic field.

The DDF monitors act to track continuously the level of power loss in the insulation and the operation is very similar to the requirements needed to measure transformer power loss on-line. The monitors operate in the same way as described above, by measuring voltage and current and using digital techniques to find the phase difference and then using that to calculate a power loss. A typical monitor for HVCT insulation is described in [10]. The technology thus exists for on-line monitoring, recording and interrogation. It must be added that this technique has been applied primarily to very high voltage (eg 330 kV) current transformers in transmission systems rather than distribution systems. Thus the presence of harmonics was not significant.

The other technique of using multiplication of instantaneous voltage and current waveforms and averaging to obtain real power without using Cosϕ has been performed in our laboratory and has been found to be successful.

A fast digital oscilloscope with in-built software was used to obtain voltage and current waveforms of a discharge light source. The oscilloscope was programmed to multiply the digital waveforms together and to obtain a simple average of the product. The resulting real power determination gave quite satisfactory results and there is no reason why it could not be implemented for on-line monitoring. Such implementation would not require an oscilloscope but could use fast analogue to digital converters that are now available, such as the Acqiris types.

J.4.3 Accuracy of loss measurements

As the overall aim is to provide some minimum energy performance standards for transformers, the efficiency tests must be done using some standard conditions which should include:

- Standard voltage supply waveform
- Uniform specified temperature – windings and core
- Minimal electromagnetic interference
- Specified measurement uncertainties
- Standard test procedure [eg NEMA, IEC]

Under these conditions the loss measurements obtained will be able to be used for classification of transformers according to their losses and power transfer efficiency. However such requirements as above can only be achieved in laboratory or test situations. They cannot be achieved in on-line applications.

The on-line monitoring system will be subject to the effects caused by voltage variation, temperature variations, harmonic content and unbalance of three phase loads. These could be very significant and mean that such data will be inappropriate for comparison of transformer efficiencies. However the data would be of considerable use in determining energy efficiencies of specific transformers in specific applications, and may allow some possible remedial programme to be put in place to improve efficiency, for example increased filtering to limit harmonics. The loading record will also provide extremely useful information to the asset manager on the ageing rate of the transformer insulation. This will determine the ultimate life of the transformer, but such monitoring is not apparently in use at present.

J.5 Discussion of the impact on MEPS

J.5.1 Voltage change

The change to a new voltage level of 230 volts instead of the existing 240 volts will have some impact on existing transformer losses. In the most likely event of maintenance of the existing 11kV level and change of the transformer tappings to achieve 230 volts, the general result will be an increase in the transformer secondary current. This will lead to an increase in the copper loss component of the losses, with the core loss remaining essentially constant. In some cases where the transformers are already fully loaded at rated current it may mean that the core will move into saturation, producing other undesirable features.

In terms of the minimum efficiency standards for transformers this voltage change will mean that the transformer efficiency will decrease slightly from the 240 volt operational level. This may require, for existing transformers only, some reduction of the minimum efficiency values specified in the MEPS report.

For example, a typical 1000 kVA transformer operating at 240 volts will have an efficiency of 99.4% at full load and 99.67% at 50% of full load. If the secondary voltage is reduced by 4% to 230 volts and the current increased by 4% with the core loss held constant, the transformer efficiencies at 230 volts will be 98.9% at full load and 99.65% at 50% of full load.

In view of these figures it may be necessary to adjust the proposed minimum levels for existing 240volt transformers operating at 230 volts. However until the exact method by which the voltage change will be achieved is known, it is not possible to revise the proposed figures in the MEPS report. The method of achieving the voltage change will have a different mix of losses in the transformer and this will affect the minimum efficiency levels.

There will be no effect on the efficiencies of new transformers as they will be designed to accommodate the new voltage and will be able to operate at the same minimum efficiency levels.

J.5.2 Power quality effects

The efficiency tests on transformers do not accommodate the effect of any harmonic content in the supply. The requirement for the power loss tests is that the supply be essentially pure 50 Hz only. However the core loss and, to a lesser degree, the copper loss, are both frequency dependent and thus the losses will increase with increased harmonic content.

The increase can be significant, as was outlined in the previous section on power quality. However the increase in harmonic content of the load is not a factor that can be uniformly incorporated in the transformer design to improve efficiency in such cases. In general, the onus is on the consumer to maintain the total harmonic distortion within the specified levels at the point of common coupling.

It is possible to improve the efficiency of transformers with harmonics present, but the harmonic content of loads is so variable that it would not be rational to try to design a transformer with increased efficiencies for all load types. The better procedure is to put the onus on the consumer to comply with harmonic standards at the POCC which will limit the effect of the harmonics on the transformer efficiency.

However, while there is some requirement to maintain such THD levels at the POCC, and this will assist in limiting the added harmonic power loss for utility transformers, there may be a problem with consumers' transformers within their own system. Their compliance with the 5% THD may not be strict. In such systems there may be some need to monitor transformer losses and efficiencies.

J.5.3 Testing of transformers

The current method of testing transformers for power efficiency is based on laboratory tests under well-defined conditions of power supply, temperature and measurement accuracy. Such tests do not take any account of varying load power quality. In particular there is no inclusion of harmonic content in the power loss tests. The result of this is that the stated efficiencies will be significantly lower when used in situations where the load has significant harmonic content.

The efficiency of transformers under non-linear load conditions is not normally measured or monitored in any way. There may thus be some case, in the cause of energy efficiency, to have test procedures available which could be used to determine the operating efficiencies of transformers when supplying a typical highly non-linear load.

This would require a new test method with modifications to the open circuit and short circuit tests to incorporate a typical harmonic content in the supply. This would then give the core loss and the copper loss under conditions more appropriate to actual in-service operation. The development of modern high power electronic inverter systems now allows AC supplies to be obtained with any specified degree of harmonic content and thus there would be no problem whatever in providing such a supply voltage. In fact the test supply and harmonic content could be adjusted to any level representative of the ultimate use of a transformer.

Such testing would perhaps not be required for utility supply transformers where the THD is limited to a known level. However harmonic testing may be of considerable benefit where transformers in industry are to be used in conjunction with highly non-linear loads. The effect of the load on the energy efficiency may indicate some necessary remedial action to improve the energy efficiency of the transformer, using filtering for example.

In such industrial situations, some development of means of on-line monitoring to determine transformer efficiency in situ would be of some potential value. However it is not feasible to have such dedicated monitoring on all transformers. Rather, such monitoring systems should be portable.

J.6 Summary and Conclusions

Changes to the voltage level from 240 to 230 volts will have an effect on transformer efficiency in those units designed for 240 volts. The effect will be some decrease in the efficiency levels and there is a case for the recommended levels to be adjusted to take account of this factor. At this stage the changes are not able to be quantified as they will be dependent on the way in which utilities affect the change in voltage.

New transformers designed for 230 volts will not be affected and the recommended efficiency levels will still apply.

The impact of power quality, and in particular the harmonic content, of loads on transformers will be of some significance in the transformer efficiency. However in this case the onus should be on the consumer to install equipment to limit the harmonic content as seen at the point of common coupling. If this is done the utility transformers will have a quantifiable effect on the efficiency, determined by the measured THD at the transformer. It may be useful to measure the efficiency at such THD levels in the laboratory.

The greatest impact of power quality on transformer efficiency will be in the area of industrial use of consumer-owned transformers within larger installations. The likelihood of non-linear loading is increased in such cases and the efficiency impact is likely to be substantial. Some means of monitoring the efficiency in such installations would be of substantial use.

The effect of harmonics on efficiency is not able to be quantified accurately enough at present to be able to include the impact in some modification of the proposed MEPS levels of efficiency. It may be that if better test procedures are developed to simulate THD effects then some adjunct figures for efficiencies under specified typical harmonic loads may be able to be added to the basic MEPS proposals.

The current test methods of transformer efficiency are predicated on the use of a pure 50 Hz supply and thus they do not take account of any harmonics in their efficiency determinations. There is some need to develop techniques of efficiency determination which will enable it to be monitored and calculated under typical load conditions. Such tests can be done in the laboratory with simulated supply representative of non-loads. In addition, there is technology currently available which will allow monitoring of transformer losses and efficiency on-line. These will be able to provide continuous on-line monitoring of transformer energy loss.

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