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

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In the new Fifth Framework ENERGIE R&D programme, the European Commission has set a target to reduce the losses in transmission and distribution networks within the European Union by 2-4% of total electricity generated. In this context, a project team has quantified the energy losses from distribution transformers in the EU.

Although transformers are among the most efficient machines ever designed, total losses in the network are still relatively high, estimated at 50 – 60 TWh / year. This is understandable since electricity passes through several stages of transformation between generation and end-user.

The scope for saving energy in the EU through the use of energy-efficient distribution transformers, has been estimated at 22TWh/year, worth €942 million at 1999 prices. Despite the efficiency of individual units, up to 2% of total electricity generated is estimated to be lost in distribution transformers, nearly one-third of the overall losses from the transmission & distribution system. This is comparable in scope with the energy savings potential estimated for electric motors and classes of domestic appliances. It is equivalent to the annual energy consumption of 6 million homes, or the electricity produced by three nuclear power stations in Europe.

Because of the long life span of distribution transformers, ultimate market penetration will only be achieved gradually. Despite this, energy-efficient units could contribute 7TWh of annual savings by 2010, representing 1% of the European commitment to reducing carbon emissions.

There are no technical barriers to realise this potential and strong economics to drive the investment in energy efficient distribution transformers.

Considering this savings potential and the high attention currently given to energy efficiency and climate change mitigation in Europe, distribution transformers are insufficiently considered as an option in national and European energy policy. Comparing investment cost with contribution to climate change mitigation, distribution transformers are an attractive energy policy option:

Distribution transformer rating	Investment cost / kWh energy saved	Investment cost / tonne CO_2 emission reduction
100 kVA	0.015 €	29 €
400 kVA	0.011 €	23 €
1,600 kVA	0.010 €	19 €

TABLE - Cost and climate change contribution for energy-efficient distribution transformers

Most European electricity utilities are at present prepared to accept the losses from distribution transformers. Energy-saving transformers cost more than less efficient designs, and it is difficult to justify the higher purchasing price using short-term financial evaluation criteria.

However, distribution transformers, like other network assets, are extremely long-lasting items of equipment, and the investment in energy-efficient plant can usually be economically justified. Internal rates of return range between 11% and 70% and payback periods between 1.4 and 8.6 years. Europe is a technology leader in the field of distribution transformers, and has the potential to reduce transformer losses by over 70%. Based on the above figure of 50-60 TWh / year for distribution transformer losses, this sets the upper limit for the (technically achievable) savings potential at 35-42 TWh / year.

After completion of the deregulation cycle, in a well-designed regulatory environment, energy efficiency in transmission and distribution may well become a competitive vector for distribution utilities.

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INTRODUCTION

In the new Fifth Framework ENERGIE R&D programme, the European Commission has set a target to reduce losses in transmission and distribution networks by 2-4% of the total electricity generated. Under the earlier THERMIE programme [1], a project team has quantified the energy losses from distribution transformers in the EU, and estimated the energy savings potential as 22 TWh / year. This is equivalent to almost 1% of electricity generated in Europe. Considering this savings potential, and the high attention currently given to energy efficiency and climate change mitigation in Europe, distribution transformers receive too little attention as an option in national and European energy policy.

Although transformers are among the most efficient machines ever designed, total losses in the network are still relatively high, estimated at 50 – 60 TWh / year for Europe. This is understandable as electricity passes through several stages of transformation between generation and end-user.

Most European electricity utilities are at present prepared to accept the losses from distribution transformers. Energy-saving transformers cost more than less efficient designs, and it is difficult to justify the higher purchasing price using short-term financial evaluation criteria.

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With the ongoing deregulation of the European electricity industry, utilities face increasing competition and reduced income flows. Capital budgets are being rationalised, sometimes in preparation for companies to go public. There is only limited evidence of utilities working towards lower engineering standards in distribution networks, resulting in higher losses.

METHODOLOGY

There is surprising little information in the public domain regarding transformer populations and loss levels.

The THERMIE project therefore started with a characterisation of Europe's transformer population in a number of typical ratings:

- 100 kVA, small / rural
- 400 kVA, average / urban
- 1,600 kVA, industrial
-

For each rating, a number of transformer designs with varying levels of energy efficiency have been performed:

- level AA' according to CENELEC HD428
- level CC' according to CENELEC HD428
- A-Am: amorphous core and A-level load losses
- C-Am: amorphous core and C-level load losses

Levels A, A' and C, C' correspond to the CENELEC HD428 levels of load and no-load losses (table 1 & ref 3).

	Load loss (W)		No-load loss (W)	
kVA Rating	A	C	A'	C'
100	1,750	1,475	320	210
400	4,600	3,850	930	610
1600	17,000	14,000	3,800	2,500

TABLE 1 - A & C-class load and no-load losses for 3 transformer ratings according to CENELEC HD428

Typical load profiles for these various ratings were used, to enable the operational efficiency of transformers in the distribution grid to be estimated. Extrapolation of the range of losses in individual units over the European transformer population yields the total savings potential (Tables 2-4).

Transformer	Yearly peak load	Running time, load	Loss time
100kVA (small, rural)		1,500 h	750 h
lightly loaded average loaded heavily loaded	10% 40% 120%	1.6% 6.5% 20%	
400kVA (average)		2,500 h	1,500 h
lightly loaded average loaded heavily loaded	20% 55% 110%	5.5% 15% 30%	
1,600kVA (industrial)		3,500 h	2,500 h
lightly loaded average loaded heavily loaded	30% 50% 110%	9.5% 16% 32%	

TABLE 2 - Typical load profiles, Distribution transformers, Europe

Rating (kVA)		100	400	1,600
Energy transmitted (MWh / year)		57	523	2,240
A-A’	Energy loss (kWh)	3,013	10,234	33,401
	Efficiency (%)	94.7	98.0	98.5
C-C’	Energy loss (kWh)	2,017	7,091	23,642
	Efficiency (%)	96.4	98.6	98.9
A-Am	Energy loss (kWh)	736	3,401	13,954
	Efficiency (%)	98.7	99.4	99.4
C-Am	Energy loss (kWh)	703	3,149	12,429
	Efficiency (%)	98.8	99.4	99.5

TABLE 3 - Average load and efficiency

Distribution transformer rating	% contribution to losses	% contribution to savings potential
Low 100 kVA	45	20
Medium 400 kVA	45	60
High 1,600 kVA	10	20
Total	50 – 60 TWh/year	22 TWh/year

TABLE 4 - EU-wide distribution transformer losses by unit size

The project findings were verified, with 200 stakeholders in the issue of transformer efficiency throughout Europe. A workshop held in Oxford on September 23, 1999 confirmed these project findings.

TECHNICAL APPRAISAL

Energy efficiency standards for distribution transformers in Europe are contained in CENELEC specifications HD 428 (Oil-cooled) and HD 538 (Dry type). HD 428 sets 3 levels for load (A, B, C) and no-load losses (A', B', C') yielding 9 different combinations, ranging from BA' (least efficient) to CC' (most efficient). There appears to be a “league table” of national standards for distribution transformer losses specified by the electricity utilities of the various European countries. Switzerland and Scandinavian countries are said to set the highest standards, with France and Italy amongst the lowest (A-A’). Others are somewhere in the middle (table 5).

Country	**Utility Distribution Transformer Loss Levels**
Belgium	C-C’
France	A-A’ and B-B’
Germany	A-C’ and B-A’ and C-C’
Italy	B-C’
Netherlands	Better than C-C’
Spain	50% meet C-C’
UK	Uses capitalisation values

TABLE 5 - ‘League table for distribution transformer efficiency levels in Europe’

None of the 9 loss-levels, as specified by HD 428, are technically challenging. There is considerable scope for moving beyond level CC’, with amorphous iron transformers setting the benchmark of what is technically achievable for no-load losses (table 6).

	No-load loss (W)			
Rating	A’	B’	C’	Amorphous
100	320	260	210	60
400	930	750	610	150
1600	3,800	2,200	2,500	380

TABLE 6 - range of possible no-load losses for CENELEC HD428 levels A’ – C’ compared to amorphous cores

Few amorphous transformer have been installed in the EU. A quick review identified 161 installations so far, in 8 countries, on a total transformer population of 4 million. This is primarily due to lack of familiarity and lack of demonstration as well as economic considerations.

Adding the load and no-load losses in table 1 gives a total loss of typically 1-1.5% at full load. However, load losses vary with the square of the load. No-load losses occur 8,760 hours per year when the transformer is energised. At light loads, the importance of the no-load losses, as a percentage of energy transmitted increases dramatically (fig 1). Transformers have minimum losses at about 50% load.

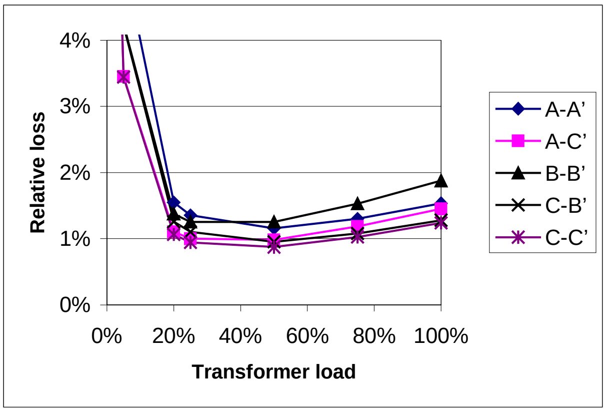

FIGURE 1 - Variation of relative loss (% of energy transformed, as a function of load) - 400 kVA transformer

Beyond the existing CENELEC HD428 CC' and amorphous transformers, there is a wide spectrum of possibilities for further reducing distribution transformer losses. A 15-20% reduction in losses, compared to CC' is a step in the right direction, and currently being studied by CENELEC TC14.

Using typical load profiles, operational efficiencies for the HD428 levels range between 95 – 99% (fig 2). Amorphous iron transformers consistently have operational efficiencies exceeding 99%.

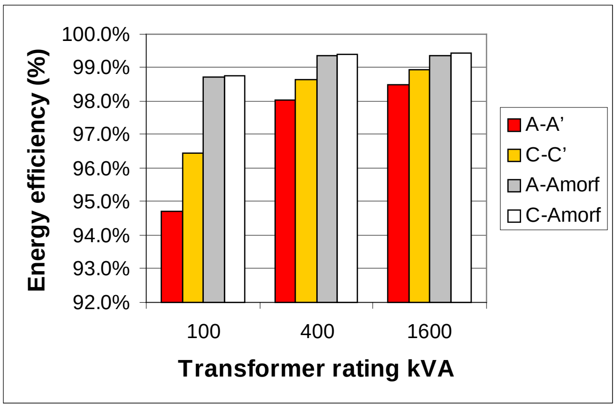

FIGURE 2 - Energy efficiency in operation for distribution transformers, based on annual load

In the USA, consideration is being given to set minimum standards for distribution transformer losses. NEMA TP1, sets a minimum efficiency standard for oil-cooled transformers at 50% load. Fig 3 compares NEMA TP1 against CENELEC HD428, as well as the Chinese minimum standard (S9). Based on these international benchmarks, level CC' is a suitable minimum level for a European energy efficiency standard for distribution transformers.

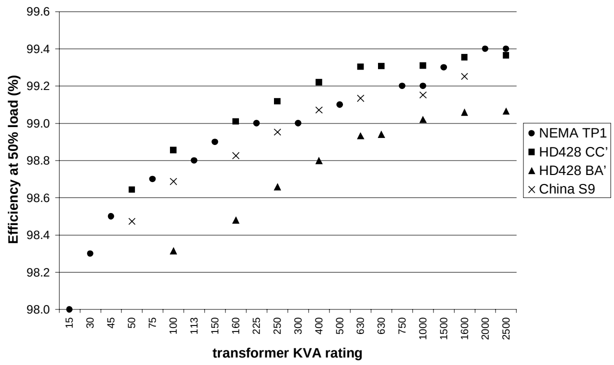

FIGURE 3 - CENELEC CC' and BA' compared to minimum standards in US (TP1) and China (S9).

ECONOMIC APPRAISAL

Combining the energy savings potential for various transformer designs with a simple model for transformer populations yields the graph below. This is based on the same parameters as tables 2-4. Over a 30 year horizon, energy-efficient transformers could save 22 TWh annually or a cumulative amount of 335 TWh in the European Union. Considering a 10-year horizon, relevant for the EU's Kyoto commitments, these figures become respectively 7 and 37 TWh.

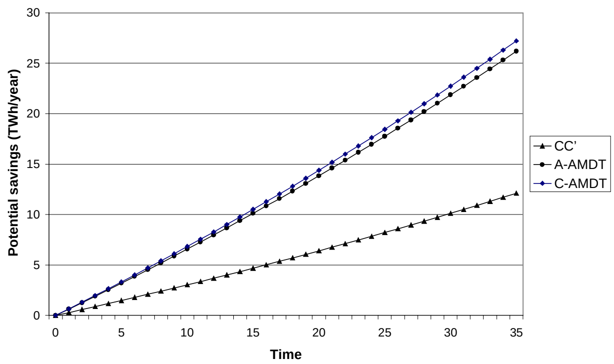

FIGURE 4 - Energy savings potential for Europe in moving to various levels of transformer efficiency

There is a challenge to convince customers that, although initial prices are higher, the lifetime owning cost of energy-efficient distribution transformers can be lower.

Buyers often prefer to calculate the pay-back period, which may not be the best way to evaluate transformers, a capital item with a very long life span. Some are uncertain about variables such as actual transformer lifetimes or future energy prices. Transformers are often purchased using a 'lowest first cost' criteria.

When comparing two transformers with different purchase prices and/or different losses, one must take into account that the purchase price is paid at the moment of purchase, while the cost of losses come into effect during the lifetime of the transformer. Usually the costs are converted to the moment of purchase by assigning capital values. When transformers are compared with respect to energy losses, the process is called loss evaluation (1).

$$CC = Ct + A \times Po + B \times Pk \qquad (1)$$

with:
CC = capitalised cost
Ct = purchase cost
A = assigned cost of no-load losses per watt
Po = value of the no-load losses in watt
B = assigned cost of load losses per watt
Pk = value of the load losses in watt

Euro / Watt	A (NLL)	B (LL)
Netherlands	4.0	1.2
Germany (86)	4.0	1.0
Germany (93)	11.3	4.0
CH	7.5	1.9
China	5.0	0.7
Sweden	4.0	0.5

TABLE 7 - Sample A and B values for selected countries

For every value of A & B in above table, and for the 4 efficiency levels considered, the C-C' type transformer specified in CENELEC HD428 will have the minimum capitalised cost, as shown in the example fig 5. The capitalised cost for amorphous transformers is slightly higher than for CC'. Moreover, a curve of capitalised cost versus efficiency is quite flat between CC' and amorphous, allowing the use of investment capital to save energy.

Above calculations do not consider full lifetime costs. Non-cash benefits, all favourable for efficient transformers, include:

- improved reliability and lifetime
- increased flexibility for future load growth
- decreased loading of transmission and distribution grids
- reduced capacity (kW) requirements.

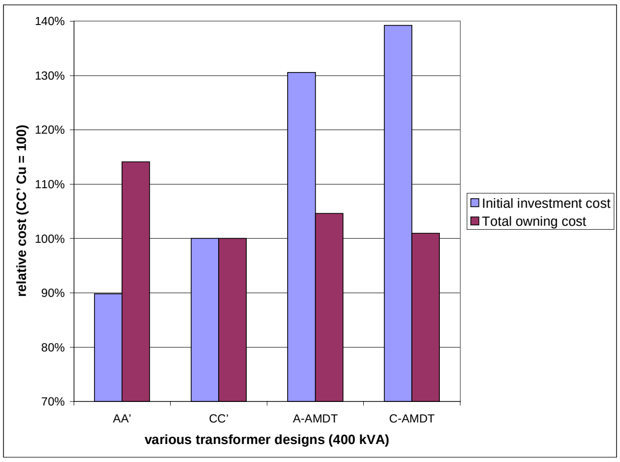

FIGURE 5 - purchase & capitalised cost (400 kVA designs)

Reliable data on the actual loading patterns of installed distribution transformers, for example the way in which demand varies in factories, commercial offices and residential neighbourhoods, is scarce. There may be an opportunity for an electricity utility to avoid making a new investment in power generation by installing energy-efficient transformers. Similarly an electricity purchaser may be able to reduce his maximum demand tariff.

An economic evaluation for investing in efficient transformers at typical load profiles demonstrates payback periods in the range of 1.4-8 years, with a return on investment of between 11-70%. The question remains whether more sophisticated financial models are needed to make a more realistic evaluation of investments in distribution transformers, with lifetimes of more than 25 years.

CLIMATE CHANGE MITIGATION

A greenhouse gas emissions rate for Europe, suggested by the International Institute for Energy Conservation (IIEC) is 0.4kg CO_2/kWh. Electrical energy savings of 22TWh will provide emissions savings of 8.8 million tonnes of CO_2. The European Union is committed to a reduction of 8 per cent on 1990 levels (266 million tonnes) by 2008-2012.

By 2010, the savings potential of 7 TWh / year achievable by energy-efficient distribution transformers is equivalent to 2.8 million tonnes of CO_2, or approximately 1% of the total European commitment.

To put the overall potential saving of 22TWh into perspective, this is equivalent to the annual energy use of over 6.2 homes or the electricity produced by three large nuclear power stations in Europe.

Comparing investment cost with contribution to climate change mitigation, distribution transformers are an attractive energy policy option:

Distribution transformer rating	Investment cost / kWh energy saved	Investment cost / tonne CO_2 emission reduction
100 kVA	0.015 €	29 €
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TABLE 8 - Cost and climate change contribution for energy-efficient distribution transformers

Distribution transformers have not yet been the focus of energy saving measures. If developed, they could also contribute significantly to European targets for reduction in greenhouse gas emissions.

CONCLUSION

The scope for saving energy in the EU through the use of energy-efficient distribution transformers, has been estimated at 22TWh/year, worth €942 million at 1999 prices. Despite the efficiency of individual units, up to 2% of total electricity generated is estimated to be lost in distribution transformers, nearly one-third of the overall losses from the transmission & distribution system. This is comparable in scope with the energy savings potential estimated for electric motors and classes of domestic appliances. It is equivalent to the annual energy consumption of 6 million homes, or the electricity produced by three nuclear power stations in Europe.

Because of the long life span of distribution transformers, ultimate market penetration will only be achieved gradually. Despite this, we estimate that energy-efficient units could contribute 7TWh of savings by 2010, representing 1% of the European commitment to reducing carbon emissions.

There are no technical barriers to realise this potential, and strong economics to drive the investment in energy efficient distribution transformers.

However, utilities in deregulated markets are faced with reduced capital budgets. Regulators are giving low priority to energy efficiency in transmission & distribution, and hence there is little incentive for utilities to invest in more expensive equipment.

Europe has considerable potential to offer world-wide in transformer technology and experience, but national governments and utilities appear to lag behind the US and China in terms of programmes and initiatives to encourage energy efficiency. There is a need for promotion initiatives, to raise awareness by end-users and smaller utilities. Another policy option is the raising of the HD428 levels, for which Europe has ample technical capability to produce more challenging, i.e. efficient designs.

After completion of the deregulation cycle, in a well-designed regulatory environment, energy efficiency in transmission and distribution may well become a competitive vector for distribution utilities.

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