METHOD FOR CALCULATION OF COST OF ELECTRICAL POWER SYSTEM LOSSES

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SUMMARY

The method for calculation of costs of electrical losses (CEL) is presented. Network companies use the calculated CEL values to establish life cycle costs (LCC) for components or system elements when a change in the power supply system is evaluated. The calculation of CEL values in Norway is based on socio-economic principles, since the energy act of 1991 states that transmission and distribution (T&D) should be optimised using a socio-economic approach.

Electrical losses in one part of the power system have to be generated in power stations connected to the grid, and transported through the network down to the relevant area where projects are compared. Figure 2 illustrates the problem; the electrical losses in the local area have to be generated in and transported through the upstream power system.

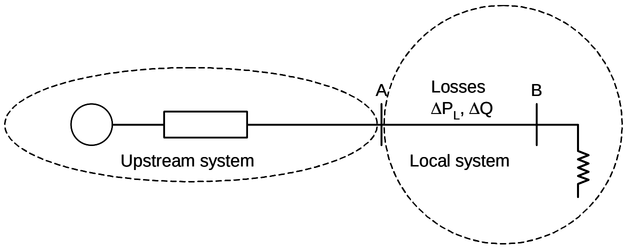

Figure 1 Problem formulation.

The CEL consists of a capacity component and an energy component. The energy component reflects the forecasted value of variable costs related to future power generation, while the capacity component consists of both the cost of additional capacity in power generation (fixed costs) and the incremental costs in the T&D system. This equation shows how the specific, annual CEL is calculated:

$$C_{loss} = c_p \cdot \Delta P_{\max} + \int c_w(t) \cdot \Delta P(t) dt \qquad (1)$$

where

C_{loss}	-	cost of losses	[NOK/year]
$c_w(t)$	-	energy cost	[NOK/kWh]
c_p	-	capacity cost	[NOK/kW year]
ΔP_{max}	-	peak power losses	[kW]
$\Delta P(t)$	-	power losses	[kW]

The methodology includes load diversity and loss compounding factors, interest rate and estimated economic lifetime for various components.

By using average values for loss utilization times, equivalent CEL values are calculated (eCEL). The resulting eCEL values [NOK/kW] are to be multiplied by the peak load losses [kW]. Equation (1) can be converted to:

$$C_{loss} = (c_p + c_w \cdot T_l) \cdot \Delta P_{\max} \qquad (2)$$

$$C_{loss} = c_{equi} \cdot \Delta P_{\max} \qquad (3)$$

where

T_l	-	utilization time for losses	[h/ year]
c_{equi}	-	equivalent cost of losses	[NOK/kW year]

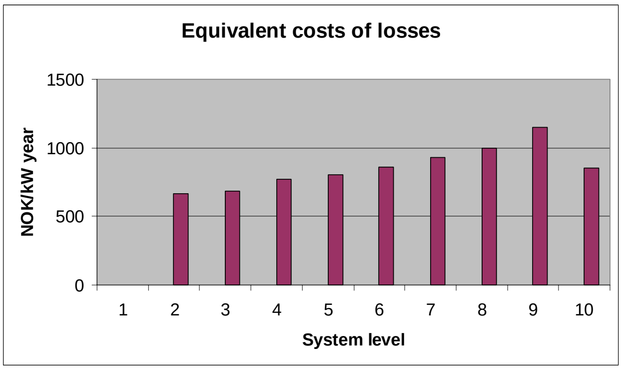

Figure 2 Equivalent specific cost of losses at stage 2001

Figure 2 shows the level of the equivalent cost of losses at the different system levels for stage 2001. System levels are numbered from generation as no 1, and e.g. HV distribution OH-lines(cables as no 7. It is the relative low loss utilization time at level 10 that gives a reduced eCEL at that level.

CEL values from different countries have been compared. The significant variation indicates that different methodologies are used. The great variation in the ratio between cost of no-load and load losses means e.g. that the dimensioning criterion for substation transformers varies a lot from country to country.

Experience shows that it is also important to prepare guidelines on how CEL values should be used in power system planning. Hence a detailed application guide with examples on how to use the specific CEL values have been prepared and distributed in the T&D Planning Handbook that is used by most network companies in Norway.

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ABSTRACT

This paper presents how costs of electrical power losses are calculated in Norway. Network companies use the calculated values for cost of electrical losses (CEL) to establish life cycle costs (LCC) for components or system elements when a change in the power supply system is evaluated. The LCC is comprised of inter alia investment costs, maintenance costs and interruption costs. The calculation of CEL values in Norway is based on socio-economic principles, since the energy act of 1991 states that transmission and distribution (T&D) should be optimised using a socio-economic approach.

The CEL consists of a capacity component and an energy component. The energy component reflects the forecasted value of variable costs related to future power generation, while the capacity component consists of both the cost of additional capacity in power generation (fixed costs) and the incremental costs in the T&D system. The values are presented in tables where the columns contain values for different system levels, with one line per year.

By using average values for loss utilization times, equivalent CEL values are calculated (eCEL). The resulting eCEL values [NOK/kW] are to be multiplied by the peak load losses [kW]. The methodology includes load diversity and loss compounding factors, interest rate and estimated economic lifetime for various components.

CEL values from different countries are presented and compared. The significant variation indicates that different methodologies are used. The great variation in the ratio between cost of no-load and load losses means e.g. that the dimensioning criterion for substation transformers varies a lot from country to country.

INTRODUCTION

The value of electrical losses in power networks is comparable with other cost elements, see figure 1. Statistics show that costs of electrical losses in Norway in 1996 approximated half the investment costs. It is therefore important to establish specific CEL values that ensure proper validation of future

Investigation of CEL values used in different countries shows that the level varies significantly, and it seems that there is no systematic explanation for the variations

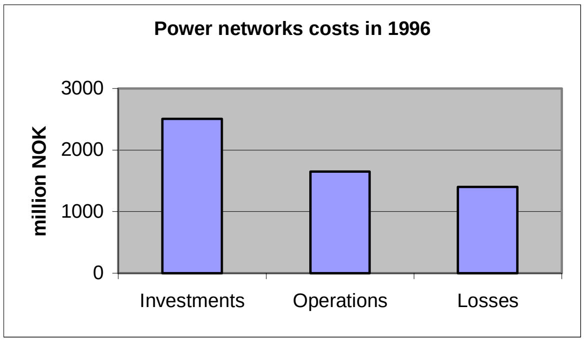

Figure 1 Comparison of power network costs.

observed. A comparison of the methods and presumptions, and a discussion on these matters would be interesting, and was one of the motivation factors for presenting this paper.

The transmission and distribution system is optimised by minimising the life cycle costs (LCC) consisting of inter alia:
a) investment costs, b) cost of operations, c) cost of losses, d) interruption costs and e) congestion costs.

To choose between alternatives with different peak load losses, the correct cost of losses has to be developed. The Norwegian energy act of 1991 states that the transmission and distribution (T&D) system should be optimised from a socio-economic point of view. All network companies in Norway operate under concessions given by the Norwegian Water Resources and Energy Directorate (NVE), the regulator in Norway.

Electrical losses in one part of the power system have to be generated in power stations connected to the grid, and transported through the network down to the relevant area where projects are compared. Figure 2 illustrates the problem; the electrical losses in the local area have to be generated in and transported through the upstream power system

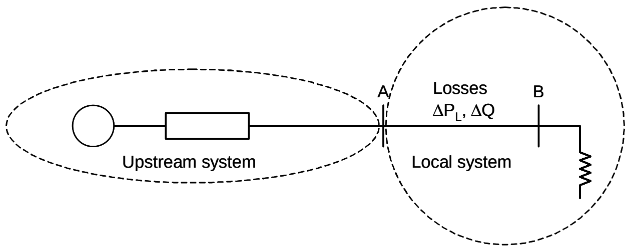

Figure 2 Problem formulation.

POWER SYSTEM IN NORWAY

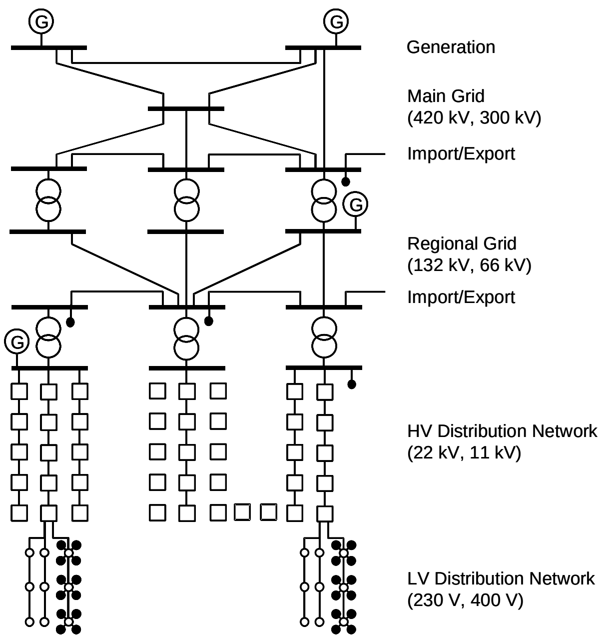

Figure 3 Model of the power system in Norway.

Figure 3 shows a schematic model of the power system in Norway. Approximately 40 % of the generation is connected to the main grid, 40 % to the regional grid and the remaining 20 % is connected directly to the distribution network. The main and regional grid system is typically a meshed system while the distribution network is normally operated in radial mode.

Seen from the generation and transmission system both increased normal load and increased electrical losses contribute to the extra burden on the system. However, the electrical losses have a lower utilization time (load factor), and therefore the cost implications can not be compared directly. Each and every increase does not necessarily result in investment needs, but in the long run all incremental increase will be partly responsible for the required capacity increase.

SIMPLIFIED POWER SYSTEM MODEL

The cost structure of the power system in Norway shows that the main part of the costs lies in the distribution system. Obviously there are geographically differences in the supply system that give variable cost of losses in different parts of the country. There is a surplus of generation some places, while a deficit other places results in different transmission lengths. The study of the cost structure revealed, however, that the cost level of the transmission level is relatively low compared with the differences in the distribution network. The amount of losses in the distribution system is approximately two times the losses in the main and regional grid system, hence the importance of representing the distribution network properly.

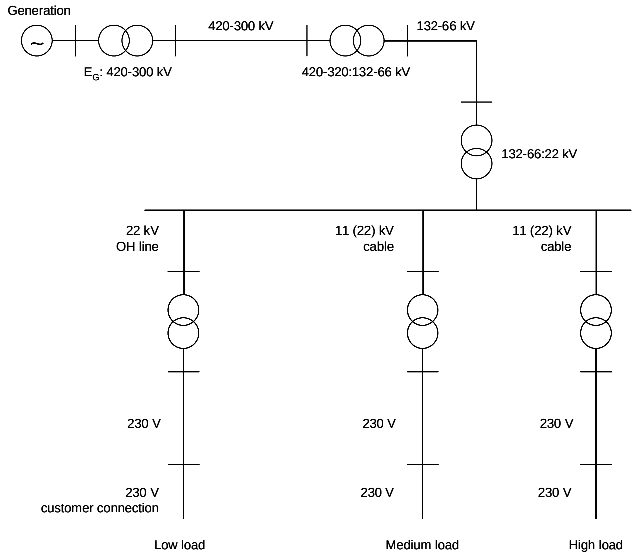

Figure 4 Simplified model for calculation of cost of electrical losses.

The variation in load density leads to a great variety in the design of the distribution network, and hence the associated costs. Therefore the distribution network had to be represented by three different models, one representing urban areas with high density load, one representing densely built-op areas in rural areas (medium density areas) and the last typical for the scattered housing found at the countryside in Norway.

The resulting simplified model is shown in figure 4. It is comprised of 10 levels; five different voltage levels with transformation between these. Generation represents level no. 1, and e.g. HV distribution is no. 7.

METHODOLOGY FOR CALCULATION OF COST OF LOSSES

The following equation shows the two main elements comprising the cost of losses (on an annual basis):

$$C_{loss} = c_p \cdot \Delta P_{\max} + \int c_w(t) \cdot \Delta P\,(t) dt \qquad (1)$$

where

C_{loss}	-	cost of losses	[NOK/year]
$c_w(t)$	-	energy cost	[NOK/kWh]
c_p	-	capacity cost	[NOK/kW year]
ΔP_{max}	-	peak power losses	[kW]
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Equation (1) can be converted to:

$$C_{loss} = (c_p + c_w \cdot T_l) \cdot \Delta P_{\max} \qquad (2)$$

$$C_{loss} = c_{equi} \cdot \Delta P_{\max} \qquad (3)$$

where

T_l - utilization time for losses [h/ year]

c_{equi} - equivalent cost of losses [NOK/kW year]

The equivalent cost of losses (eCEL) has been calculated by using typical loss utilization times. The tables with eCEL values can be used when the topical load is comparable with the "average" load profile.

INCREMENTAL COST VALUES IN THE POWER SUPPLY SYSTEM

In the following a description of how the cost figures used as the basis in calculating CEL is given. The general principle is to conjecture how the supply system will develop in the future, and to estimate the associated incremental costs.

Generation. The cost of generation is divided into two elements; one is the forecasted cost of generating the additional energy needed to cover incremental load and the other is the cost of the additional capacity investment needed to cover incremental load. Currently the most probable technology for further generation expansion in Norway would be gas fired power plants. Therefore the forecasted gas price and variable operation costs are used to calculate the energy cost element, and the fixed investment cost is used to calculate the capacity cost element. A prediction of the development of the investment cost depending on the technology in the future is included before the annual cost figures are decided.

Main Grid. The incremental cost for the main grid is elaborated by investigating the statistics [1] on expansion of the system combined with the peak power increase over the past 10 – 15 years. Approved and proposed investment projects together with a qualitative assessment of the long term trend is used to arrive at the future marginal cost.

Regional Grid. The same method as for the main grid is used to find the incremental cost for the regional grid. The consequence of a possible change in the power supply structure due to transition to more distributed electricity generation has to be taken into account.

Distribution Network. Calculation of the incremental cost in the distribution network is performed differently since it normally is operated in radial mode. The cost difference between typical components with different capacity is compared with the capacity increase to find the incremental cost on these voltage levels.

Transformers. For all transformer levels typical specific cost-values are used, in NOK/kVA, adjusted for normal capacity utilization.

OTHER PARAMETERS

Diversity factors. Extensive consumer measurement programmes over many years have been performed in Norway. Results from these measurements are used to calculate typical diversity factors.

Loss utilization times. The same measurements were the fundament for calculation of typical loss utilization times. In Norway it is more common to use utilization time than load factor to signify capacity utilization.

Loss compounding. Loss compounding is calculated by this equation:

$$(1+\Delta p_{jx}) = (1+\Delta p_{jj}) \cdot (1+\Delta p_{(j+1)(j+1)}) \cdots (1+\Delta p_{(x-1)(x-1)}) \quad (4)$$

where

j and x are the two levels between which loss compounding is evaluated.

The total electrical losses at peak load amount to approximately 15 % of generated power. The losses at each level are needed to calculate the loss compounding effect.

Interest rate. The Ministry of Finance [2] has worked out guidelines for interest rates to be used in socio-economic evaluations. For power supply where the risk element is relatively low and the investment costs are to a large extent irreversible, the recommended interest rate is set to 6% p.a.

Economic lifetime. Various components have different economic lifetime. They vary from 25 years for cables to 40 years for hydro power plants.

RESULTS

Specific cost of losses is calculated for the next 35 years, both the energy component and the capacity component. The capacity component is in addition calculated for all 10 different levels.

Figure 5 shows the level of the equivalent cost of losses at the different system levels for stage 2001. It is the relative low loss utilization time at level 10 that gives a reduced eCEL at that level.

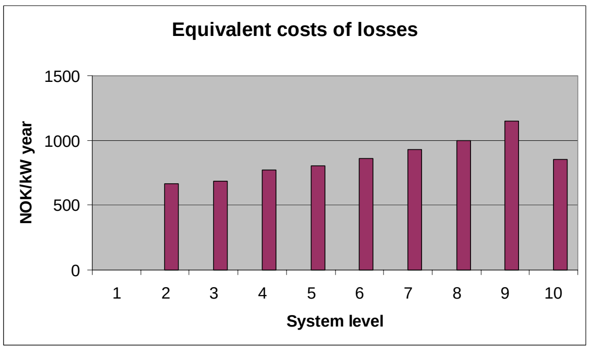

Figure 5 Equivalent specific cost of losses at stage 2001.

APPLICATION

Experience shows that it is also important to prepare guidelines on how CEL values should be used in power system planning.

The network planner introduces alternative solutions when planning the future network. Through load flow analyses the total losses for all alternatives at peak load are calculated at different future stages. The corresponding loss utilization time is evaluated, depending on actual mix of customer categories and their load profiles. The annual costs of losses are calculated by using equation 1, for all stages in the period of analysis.

For simple calculation where load variation is not taken into account the tables with pre-calculated specific net present values can be used.

A detailed application guide with examples on how to use the specific CEL values have been prepared and distributed in the T&D Planning Handbook [3] that is used by most network companies in Norway.

DISCUSSION

Since the development of hydro based large power plants comes to an end in Norway, the future generation increase has to be based mainly on other energy sources. The costs of future generation, both the energy and the capacity component, are based on gas fired power plants.

The energy component of the CEL values for the first years is based on simulations taking into account the reservoir filling and import/export possibilities. In an ideally working competitive market the price of energy reflects the short-term socio-economic cost of energy. Therefore the variable cost for the most probable energy source of a certain amount in the future was chosen as basis for the energy component. Consequently the fixed specific cost for gas fired power plants is used as the future capacity component for generation.

There has been a discussion in Norway whether existing network tariffs could be used for valuation of electrical losses. In theory the network tariffs should reflect the socio-economic value of the supply system, at least when the regulations worked out for network companies are optimal. However, the main objection is that tariffs are based on the cost of the existing network, while the intension behind the calculation of specific CEL values is to arrive at the cost of the future losses generated in the power system.

It is obvious that the calculated costs of losses are approximate, since they are based on average cost figures for the prospective supply system in Norway. Estimations have to be done regarding future load increase and the resulting cost of power system expansion. In reality there are obviously geographical differences due to different regional load density and distance to generation but sensitivity analyses show that these variations do not have major impact on the CEL values since the cost of the main grid and the regional grid is low compared to the distribution network.

Compared with some eCEL values from different countries the values in Norway are close to the average of the available values. Table 1 shows however that the eCEL values differ substantially, both between countries but also between various utilities in the same country. Also the ratio between the specific values for no-load losses and load losses vary greatly. Even if specific investment costs vary, the great variation indicates that the methods used to valuate the electrical losses are different.

TABLE 1 - Comparison of eCEL values from different utilities in different countries

Country/ Utility	No-load losses	Load losses	Ratio
# / #	€/kW	€/kW	
Norway	4,0	1,0	4,0
2 / 0	4,4	0,7	6,4
2 / 1	4,9	2,0	2,5
2 / 2	3,4	0,5	6,5
2 / 3	6,2	1,3	4,7
3 / 0	4,4	0,2	20,0
3 / 1	5,5	1,1	5,0
4 / 0	2,6	0,9	3,0
4 / 1	2,6	1,7	1,5
4 / 2	5,5	1,4	4,0
5 / 1	3,7	0,4	10,0
5 / 2	3,2	0,3	9,5
Max	6,2	2,0	20,0
Average	4,3	1,0	6,5
Min	2,6	0,2	1,5

REFERENCES

1. Norway statistics 1999, Energy and Electricity statistics

2. NOU 1998:16 Cost/benefit analyses in the public sector, Ministry of Finance in Norway (in Norwegian)

3. T&D Planning Handbook, 1993 (updated 2000), SINTEF Energy Research (in Norwegian)