ESTIMATION OF DISTRIBUTION NETWORK LOSSES AND THEIR VALUE IN COMPETITIVE ELECTRICITY MARKET

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Abstract
Network losses represent a considerable cost component. If the local legislation allows to add it to tariffs also the regulator is interested on their value. A loss coefficient model for estimating hourly losses in a distribution system was developed. It was demonstrated by real data of six network companies. The value of losses was estimated by applying these hourly losses for three different power exchange products. Thus some approximation for a maximum level for costs of losses could be obtained.

INTRODUCTION

Distribution losses have become an interesting and important matter in the open electricity market. Electricity distribution companies themselves also and the regulator are interested to know the annual amount of losses and the cost of the loss energy as well. Electricity distribution companies themselves can estimate the annual losses by using commercial measurements, or computationally with suitable software for network calculations. The ability for estimating the annual losses varies between companies but in general, electricity distribution companies have a good knowledge of their annual loss energy. The hourly variation of loss energy is less well known than the annual loss energy itself. Unlike electricity distribution companies, the regulator does not in every case have the required information for detecting the loss energy.

There are different possibilities to carry out the regulation task. In many countries regulation is done beforehand meaning also a massive in advance data collection from the electricity distribution companies. In Finland the regulation is done afterwards meaning that the companies report relevant data for the regulation purpose for the past year only. For more exact inspections the regulator (The Energy Market Authority) has to ask more detailed information from the companies.

Knowing the amount of loss energy and the cost of losses is important for the regulator when it defines the allowed profit for the company. Among other technical and commercial data that electricity distribution companies have to report for the regulator for control purposes, the companies also report their annual loss energy. The problem with the reported data is that it is not in every case so reliable. Reasons for that are for example different methods detecting losses, human errors or even intentions to mislead.

In this paper, this problematic situation and determining the correct amount of loss energy is discussed in general. Also a model for estimating annual losses and the hourly variation of losses will be introduced. This model can be used by the regulator and electricity distribution companies. This model is relatively simple consisting only of no-load losses of the transformers and the power losses of the transformers, underground cables and overhead lines.

The other matter that is discussed in this paper is the cost of losses. At present, in Finland there is no actual limit for the reasonable cost of losses introduced. The regulator should determine the level for reasonable cost of losses and the method how it will be calculated. To be able to do that, the regulator has to be able to determine a reference cost of losses in which the cost of losses of any electricity distribution company will be compared. Each electricity distribution company has its own method to buy the loss energy and usually the cost of losses is not based on competition. Even if the cost of losses in some cases is competition based, it is very rarely dependent on the hourly variation of the loss energy. In this paper results of a case study of market based cost of losses are presented. At this case study, market based cost of losses means that energy losses are purchased from the power exchange by using hourly loss load curves and different variation of power exchange products. Also, the effects of different matters on the cost of losses, such as the form of the loss load curve or the different power exchange products that are used in purchase of loss energy, are discussed.

ROLE OF LOSSES

Losses in the open market

Unlike the energy business, the network business is typically a monopolistic activity even after the liberalisation reforms. Distribution tariffs and quality must therefore be controlled in some way in order to ensure satisfactory quality of supply for all customers at an acceptable price.

In open electricity market conditions energy losses have an important role. In Finland, according to the Electricity Market Act, electricity distribution network companies are responsible for buying the amount of loss energy that is required in their network area [1]. There are different possibilities for buying the loss energy. One of the simplest method is that the network company estimates the loss energy to be a certain percentage of the whole energy delivered and make a contract that they pay equal amount of money for every kWh of loss energy. Another, more sophisticated possibility to buy losses is to try to determine their variation.
in time and take that in to account when making the loss purchase contract.

Since electricity distribution network companies are allowed to operate as monopoly companies in their distribution area, the law [1] regulates their possibilities to make profit. According to the Electricity Market Act, in order to be allowed to make profit, the total costs of the electricity distribution network companies, including also the cost of losses, have to be reasonable.

Electricity distribution network companies are allowed to charge their customers all the reasonable operational costs, also the cost of losses. This brings up the question how to define the reasonable cost of losses. So far in Finland, this question has not been answered properly. When determining the reasonable cost of losses the regulator has to be able to determine, at least in some accuracy, the correct amount of losses for distribution companies operating in different conditions. Additionally, the regulator has to be able to determine also the reasonable upper limit of cost of losses.

The Finnish regulator monitors operational costs of electricity distribution companies and the cost of losses is one part of these operational costs. Companies operating effectively, are allowed to have higher profit than less effectively operating companies. By declining their operational costs, for example by declining the cost of losses, companies can increase their efficiency and are allowed to take higher profit. On the other hand, it is possible that there is a temptation for the network business area of the company to buy losses from the energy business area of the same company at the price that clearly exceeds the market price. The regulator should be capable of detecting such a malpractice. Estimation of annual and hourly losses and their market price is thus needed.

To be able to make an opinion of the reasonable cost of losses the regulator should be able calculate the annual loss energy in case it wants to check out the figures that the distribution companies report. The regulator should also have some kind of practice how to create the reference level for the reasonable cost of losses. The market based cost of losses make a good reference for the reasonable cost of losses. For the market based cost of losses the regulator should also be able to calculate or other way estimate the hourly variation of the costs of different electricity distribution companies.

Model of estimating losses

There are different possibilities to calculate the loss energy and the hourly variation of losses in electricity distribution networks. Usually the electricity distribution companies have stored their network information in a network information system (AM/FM-GIS) [2], which is applied for technical calculations, assets management and map drawing. In Finland, this is linked with the customer information system and is often also connected to a real time distribution management system. In such technical calculations, the load flows through each cable and transformers are calculated. If the load information is handled as load curves, the results e.g. losses can be obtained on hourly basis.

If the network information and the load information is limited, a more simple model for calculating losses is needed. The simple model with a limited amount of source data can not be as accurate as a network information system, but reasonably accurate result can be obtained also with it. The loss calculation model, named as the loss coefficients model that is used in the simulation of the cost of losses later in this paper is shortly presented here.

The loss coefficients model is presented in (1). Losses of the main transformers, the medium voltage network, the distribution transformers and the low voltage network are modeled separately.

\[ P_L(t) = P_{0,MT} + P_{0,DT} + (k_{MT} + k_{MV})P_{MV}(t) + (k_{MV} + k_{LV})P_{LV}(t) \]  \( (1) \)

The idea of the model is that the no-load losses of the main transformers (e.g. 110/20 kV) \( P_{0,MT} \) and the medium voltage transformers (e.g. 20/0,4 kV) \( P_{0,DT} \) are taken as a source information directly from the distribution companies and are considered constant. Power losses of the main transformers, the medium voltage transformers, the medium voltage network and the low voltage network are modeled as proportional to the square of the load. The proportionality coefficients for the main transformers, the medium voltage transformers, the medium voltage network and the low voltage network are \( k_{MT}, k_{DT}, k_{MV} \) and \( k_{LV} \) respectively.

In (1) the hourly load information of a medium voltage network \( P_{MV}(t) \) and a low voltage network \( P_{LV}(t) \) is needed. For the hourly load information the measurements or the load curves can be used. If there is no better knowledge of the power in the low voltage network it can be estimated as \( P_{LV}(t) = \alpha P_{MV}(t) \). And in every case \( \alpha \ll 1 \). For the model, all the coefficients \( (k_{MT}, k_{DT}, k_{MV} \) and \( k_{LV} \) for different distribution networks have been estimated. The estimated coefficients are mean values of many coefficients calculated for the reference networks. The model presented in (1) can be rewritten in a even simpler form as (2) and (3).

\[ P_L(t) = P_{0,MT} + P_{0,DT} + (k_{MT} + k_{MV})\alpha^2(k_{MT} + k_{MV})P_{MV}^2(t) \]  \( (2) \)

\[ P_L(t) = P_{0,MT} + P_{0,DT} + (K)P_{MV}^2(t) \]  \( (3) \)

The coefficients are time variable but also time invariant coefficients can be used. The problem of coefficients variation in time is not discussed here further. This model has been tested with the small amount of distribution companies and the error in loss energy is in most cases less than 10 %. Reasons for the error in the loss coefficients model are the small amount of source information that is required in the model and the simplicity of the model itself. In the model, losses of the whole network are modeled in the same simple way than the losses of an individual power line and the network based correction coefficients are used to correct the
result. More detailed description and discussion of the loss coefficient model is presented in [3], [4].

**Problem related to the cost of losses**

The idea behind the reasonable level of the cost of losses is that even if the customer by himself can not have an effect on the cost of losses, the costs still stay in a reasonable level. The reasonable cost of losses should be either a cost that is formed through competition or a market based cost. In the open electricity market where the price of electricity is determined through the competition by the market itself, it also would be fair that the price of loss energy would be determined through competition. For example the power exchange would be one possible place where the price for loss energy could be determined.

Power exchange has a selection of different products which can be used for buying the loss energy. The number of power exchange products is reasonably small but there are almost an unlimited number of possibilities to use these products in purchase of the loss energy. It is possible to choose what or which power exchange products to use in purchase in general and if one uses more than only one product what is in that case the amount of loss energy that is bought with each product. In addition, some of the power exchange products have a time value and that means that concerning these products the cost of losses depend on what day the loss energy has been bought. One can use certain products to buy at least a part of the losses for years before the actual usage. This, almost unlimited, variety to have a different price of loss energy depending on what day to do the purchase, gives electricity distribution companies a possibility to speculate but also creates a need for price hedging [5], [6].

For the authority, which tries to decide how to form the reasonable level for the cost of losses for the comparison usage this variety gives no clear answer. To be able to come up with some solution with this problem, it is important to know what effects the different power exchange products have on the average cost of losses and what is the role of loss load curves of urban and rural electricity distribution companies. In the case study these questions are examined more detailed.

**COST OF LOSSES**

**Simulation**

Here the simulation of the cost of losses consists of few case studies. The idea of these studies was to test how much the cost of losses can vary and how much does the different methods that are used in purchase of the loss energy, affect to the cost of losses. All the methods that were used in this study are based on the Nord Pool power exchange standard products [7]. This means that all the values that are presented as cost of losses are actual market based values of the loss energy for certain years that were used in the case studies. The cost of losses can and will vary through the time as the amount of losses and the price of different power exchange products varies. The interesting value that is examined here is the average value of the costs. The results of case studies presented here should give some ideas how the method for calculating the reference cost of losses could be formed.

The simulation of the cost of losses is done for six different urban and rural Finnish electricity distribution companies (e.g. the same distribution companies that were examined also in reference paper [3]). One goal of this study was to find out if there is any influence on the cost of losses on the matter if the loss load curve of an urban or rural electricity distribution company is used. Two different years (1999 and 2001) were used in the case studies to examine the effect on the cost of losses of a possible changes in prices of power exchange products over the years.

Three different purchase strategies were used in this study. In strategy one, only the spot market product called Elspot was used. In strategy two the Elspot product and three different Forward contracts, Winter 1, Summer and Winter 2, were used. Finally, in strategy three all the products in previous strategies and additional a Future contracts for one week period were used.

There are many other possibilities to arrange the purchase of a loss energy but the purchase strategies that have been used in this study, cover a wide range easiest and most commonly used ways to purchase losses with a market price. These three strategies cover both a short term, in a way risky, purchase and also a long term, in a way hedging, purchase.

**Different loss load curves**

From the six different urban and rural Finnish electricity distribution companies which were used in the simulation three are urban and other three are rural in nature. The companies are referred here as A, B, C, D, E and F. In Fig. 1. there are loss load curves for one year time of one urban and one rural electricity distribution company. The annual loss energy of these urban and rural companies is close to each other and is 31,7 GWh and 30,3 GWh respectively. The loss load curves in Fig. 1. and in the case studies have been formed with the loss coefficient model. Normally the shape of loss load curves varies at least a little over the years, but at these case studies same, company based, loss load curves were used in both years. This method allows us to examine the effects of price changes of different power exchange products to the average cost of losses without having the effect of the changing loss load curve.
There is a clear difference between the loss load curves of an urban and rural electricity distribution networks. Both of them seem to have nearly equal amount of no-load losses but the shape of the power losses is clearly different, likely because of the different load structure.

**Different power exchange products**

All together three different Nord Pool power exchange products were used in the case studies. The Elspot product was used to buy loss energy for every individual hour with the market price. In the case study in purchase strategy one only Elspot product was used in purchase of loss energy. The average cost of annual losses \(AC_L\) in strategy one are presented in (4). In (4) \(W_L\) is the annual loss energy, \(P_L(t)\) is the hourly loss power determined with the loss coefficient model and \(C_L(t)\) is the hourly price of the Elspot product.

\[
AC_L = \frac{1}{W_L} \sum_{t} P_L(t)C_L(t) \tag{4}
\]

In purchase strategy two, three different Forward products were used, Winter 1 contract for four first months of the year, Summer contract for the next five months and finally Winter 2 contract for the last three months of the year. The idea of Forward products is that a fixed amount of power is bought every hour for as long as the contract is valid, for example in the case of Winter 1 contract four months time. How big is this fixed amount of power related to each of these contracts has to be decided according to the smallest amount of power needed during this period. In purchase strategy 2 the rest of loss energy that was not bought with Forward products was bought with the Elspot product. The average cost of annual loss energy in purchase strategy 2 is presented in (5). In (5) \(P_F(t)\) is the amount of power that is bought with one of the Forward contracts and \(C_F(t)\) is the price of the Forward contract.

\[
AC_L = \frac{1}{W_L} \sum_{t} \left[ P_L(t)C_C(t) + \[P_L(t) - P_F(t)\]C_F(t) \right] \tag{5}
\]

In purchase strategy three, one more product besides of Elspot and Forward products was used, Future product. The idea of a Future product is that the amount of power that is bought \(P_F\) and the cost of power \(C_F\) are constant for one week time. Futures were used to buy as much of loss energy over the amount of energy bought with Forwards as possible. The amount of energy purchased with Futures is decided according to the minimum amount of power in one week time. The rest of the loss energy after Forward and Future products was bought with the Elspot product. In (6) the average cost of annual loss energy when using the purchase strategy 3 is presented.

\[
AC_L = \frac{1}{W_L} \sum_{t} \left[ P_L(t)C_C(t) + P_L(t)[P_F(t)-P_L(t)]C_F(t) \right] \tag{6}
\]

Forward and Future contracts can be made for some time before the actual due time, in Forward contracts case even several years in advance. This means that it is possible to buy energy, for example loss energy, in advance and this way fix the price. If the price of electricity changes over the time and if different power exchange products are used in purchase of loss power, it is possible that the total loss power is bought as a mixture of different loss power shares in different prices.
These figures show that the price can change over the hours in Elspot product and over the weeks in Future products and more important that it can vary over the different years.

Fig. 4. Usage of different power exchange products in purchase strategy three.

In Fig. 4, the loss load curve of one example electricity distribution company and the usage of different power exchange products in purchase strategy three is presented. Fig. 4 shows how the different power exchange products are used in purchase of the loss energy in one year time. Almost the half of the annual loss energy is bought with the Forward-products.

Results of the case study

Three different purchase strategies have been applied in purchase of loss energy for a one year time for six different urban and rural electricity distribution companies. In Table 1, there are results of a case studies presented.

TABLE 1 - Average cost of losses (€/MWh) with the three different purchase strategies in year 1999 and 2001.

<table>
<thead>
<tr>
<th>Year</th>
<th>Electricity distribution company</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strategy B</td>
<td>17.2</td>
<td>17.5</td>
<td>17.3</td>
<td>17.5</td>
<td>17.4</td>
<td>17.3</td>
</tr>
<tr>
<td></td>
<td>Strategy C</td>
<td>17.2</td>
<td>17.6</td>
<td>17.4</td>
<td>17.6</td>
<td>17.5</td>
<td>17.4</td>
</tr>
<tr>
<td>2001</td>
<td>Strategy A</td>
<td>23.9</td>
<td>23.4</td>
<td>23.6</td>
<td>23.5</td>
<td>23.5</td>
<td>23.6</td>
</tr>
<tr>
<td></td>
<td>Strategy B</td>
<td>20.1</td>
<td>19.0</td>
<td>19.5</td>
<td>19.0</td>
<td>19.2</td>
<td>19.6</td>
</tr>
<tr>
<td></td>
<td>Strategy C</td>
<td>20.0</td>
<td>18.8</td>
<td>19.4</td>
<td>18.9</td>
<td>19.0</td>
<td>19.5</td>
</tr>
</tbody>
</table>

The results show that the company type, urban or rural, has almost no influence on the average cost of losses. The second notice is that the purchase strategy has a clear influence on the average costs but if the strategy contains products where contracts, like Forward-contracts, are made long time before the actual due date the cost of losses will remain almost unchanged over the strategies. The year that is examined seems to have the biggest influence on the average cost of losses. The price of different power exchange products can change quite a lot from year to year and this fact had, at least in these cases, the biggest influence on the average cost of losses.

Discussion of the results

The results of case studies show that the purchase strategies two and three led more or less to the same average cost of losses. Only with the purchase strategy one the average cost was clearly different. The reason for this kind of result is that in this case there were not much differences in the prices of Forward and Future contracts. The other reason is that the amount of loss energy purchased with the Forward contract is in both strategies same and cover almost half of the whole annual loss energy. The average cost in strategy one did change more than in other strategies between the two tested years. When using purely Elspot products one gets the advantages of possible low prices as in year 1999 but exposes himself also to the risk of higher prices as in year 2001. Normally the Elspot product is not used in purchase of whole energy, merely only covering some peak demands.

Between the two years examined in the study, the price of different products changed at some amount and this is the reason why also the average cost of the same strategy changed over the years. In these cases, the price changes over the two years was quite reasonable, but also bigger changes are possible. Depending on the energy production structure, the market price of electricity can be dependent for example on the water resources and vary quite a lot. For example the Elspot product can easy double or triple its price. In Finland, for example the price changes of Elspot product during the year 2002 have been really huge. If the price changes are bigger than in these cases, the role of a purchase strategy becomes more important.

In reality, the electricity distribution companies have to make a decision of the amount of loss energy that they want to purchase before the actual energy is needed. As the price of energy can change over the time, it is important for the companies to avoid the price risk and to purchase at least part of the total loss energy beforehand with the fixed price.

CONCLUSION

Regardless of the market party whose concern the loss energy is, it has an important role in the market and in the future the role of losses is not likely to decrease. The attitude toward losses can vary in different countries but in every case there are some, either market based or estimated, costs to be linked with losses. In functional electricity market also the loss energy should have a fair market based price.
The Finnish regulator objective is to determine the highest reasonable level for the cost of loss energy. At the moment however, there is no recommendation or regulation for the reasonable cost of loss energy. This is Partly the reason why in Finland there is no settled practise for the purchase of the loss energy.

The changes in market price of electricity creates pressure to plan the purchase of electric energy, also loss energy, more carefully and also, in order to hedge from the unfavourable price changes, in advance. At the moment it seems that the market price of electricity will continue its fluctuation and that the changes can be quite remarkable. Therefore a good purchase strategy for the loss energy is needed.

REFERENCES


