INTRODUCTION
This article describes how the grid company should set the tariffs in an optimal way. The targets are to give incentives to consumers and producers to optimal location and in that way minimize the grid companies’ costs and maximizing the grid companies’ profit. The grid is dimensioned from the balance between investments, maintenance, losses, interruption costs, and bottleneck costs. How should these costs be reflected in the tariffs?

1. THE GRID AS A NATURAL MONOPOLY
The costs for transmitting electricity are so high that it would never be profitable to build a parallel grid for a customer. Natural monopoly is characterized as an industry where the most efficient production is through a monopoly, and as defined as a situation where the nature of that product or service makes a single supplier more efficient than multiple, competing ones, so called subadditivitet in the costs. It is inefficient to have several electrical distribution systems covering the same area.
If economics of scale occur where only one product/service is being produced subadditivitet, hence natural monopoly, will always follow. The investments are also irreversible and significant described as ”sunk cost”.

1.1 Dimensioning Of The Grid
The grid is dimensioned from the users’ need and the balance between investments, maintenance, losses, interruption costs, and bottleneck costs. In comparison to a dynamic market the grid tariffs have another economic approach. The dimensioning criteria for the grid can be illustrated in figure 1.

![Figure 1](image.png)

1.2 Cost Elements
Under normal operation the grid has two cost elements:
- The costs depending on the usage and operation of the grid (like electrical losses, bottlenecks interruption costs)
- The costs not depending on the operation (like investments)

The question is how can these cost elements be covered in a social-economical optimal tariff?

2. OPTIMAL TARIFFS OF OPERATIONAL COSTS
The general social economical principle for optimal pricing of operational costs is [3];
- Each user of the grid should pay the price that reflects the cost they inflict on other users.

2.1 Electrical Losses
The cost of transferring energy mainly consists of the electrical losses in the regional and local grid. You get the right tariff principal for costs of losses if you look on the electrical losses marginally. Calculated by looking at the loss increase if the consumption increases 1 kW at a given bus bar. If the users of the grid (both production and consumption) are to get the right signals, the marginal loss element must depend on where the users of the grid are placed electrically. The tariff of marginal losses will then depend on each bus bar with symmetrical marginal losses. For example in an area with more consumption then production the marginal loss tariff for production can be –5% and then it will be +5% for consumption. Figure 2 shows the marginal loss principal for one bus bar in an area with surplus of consumption.

![Figure 2](image.png)
This methodology based upon a set of regulations is used in the central, regional and local grid in Norway today. These tariffs have been operational in Norway for 4 years. The same type of tariff could be implemented taking care of tariffs of reactive power.

The marginal loss principal is valid in all power grid systems. The tariff is given by the following formula:

\[
\text{Tariff} = (\text{Consumption or production}) \times (\text{Marginal loss \%}) \times (\text{System price})
\]

2.2 From Principal To Model
To have a marginal loss \% for each bus bar might not be practical in all cases. A simplified model can be designed to take into account a city that has one marginal loss percentage on all the bus bars. To have a marginal loss each hour is also not practical. The marginal losses in the central grid are calculated every 2 months with one percentage for daytime and one percentage for nighttime and weekends. For regional and distribution grid the marginal loss are as a minimum calculated for winter day, winter night and weekends, and a third percentage for summer.

2.3 EU Legislation
The marginal loss principal is supported by EU legislation on cross border exchange [1]

Where appropriate, the level of the tariffs applied to producers and/or consumers shall provide location signals at European level, and take into account the amount of network losses and congestion caused, and investment costs for infrastructure. This shall not prevent Member States from providing location signals within their territory or from applying mechanisms to ensure that network access charges borne by consumers (‘load’) are uniform throughout their territory.

It is a bit strange that the electricity directive not contains the same paragraph. The paragraph could be read as a guide for national location signals and thereby marginal losses on a national and local level valid for both regional and distribution grid.

2.4 Practical Size Of Customers
How small can the customers be to get a marginal loss tariff? It might be practical to tariff only the large customers after this principal but it can be used for all customers that have hourly metering.

2.5 Incentives
The tariff first gives incentives to the operation of both production and consumption. In day-to-day operation it is the most flexible producers and consumers that can profit on this model. The limits of the losses in Norway is typical from –10\% to +10\% of the power price multiplied with the consumption or the production, but often the power price is much more decisive for both production and consumption.

Secondly the marginal losses give stronger incentives to establish new production in areas with surplus of consumption and bottlenecks in the grid. A potentially 20\% different marginal loss tariff for new producers are so significant that it gives location signals especially for new production. It has been examples that new industry has used this signal when deciding where to locate. This is very positive for the grid companies and might postpone and limit grid investments and increase the profit.

The third important effect of the marginal losses is that it limits the amount that should be taken on the kWh price. Typically from 20 to 30 \% of the income cap depending on the system price. The rest of the tariff should not be taken inn on kWh price but on peak pricing pr kW or on other mechanisms.

2.6 Tariff Related To Interruption Costs
To attain the goal of an optimal capacity utilization and upgrading of the grid in the short-and long-term, the tariffs should obviously focus on the dimensioning criteria. The losses as per tariff are made visible through marginal loss tariffs. Interruption costs is also an operational cost. How should these costs be reflected in the tariffs?

For most grid companies there is economical motive to reflect interruptions costs in the tariff because these costs are the customer’s costs. However in Norway and several other countries that have been deregulated with an income cap regulation the grid companies are getting penalties for poor quality. In Norway the penalties are used to compensate the customers for poor quality. The compensation it is on average for Norwegian grid companies only 5\% of the income cap, but it still gives incentives, for the grid companies to have optimal quality differentiated with regard to the customers interruption costs.

2.7 What Is A Compensation Arrangement?
A compensation arrangement is an arrangement where the customer in monetary terms is compensated for Energy Not Supplied (ENS). The compensation can be given as a direct refund to the customer or as a tariff reduction. The following formula gives the right dimensioning criteria regarding interruptions: [2]

\[
C = ENS \cdot k_w
\]

where

- \( C \) = The compensation in NOK
- \( ENS \) = Estimated sum of Energy Not Supplied
- \( k_w \) = Specific cost for ENS in NOK/kWh

ENS is given by the length of the interruptions and the customer load, while the specific interruption cost \( k_w \) is a function of the type of customer, the length of the interruption, time of the interruption and whether or not the interruption is notified to the customer in advance.
To prevent an unsatisfactory quality of the grid services within a regulatory regime, or a regime that provides incentive for under investments, all grid companies are given their own KILE-regulatory framework (KILE = Compensation for Energy not Supplied) and will be punished for power interruptions.

2.8 How To Tariff The Power Interruption Cost?
A part of the tariff is then to compensate the customers directly or over the tariff next year. The different customer groups have different cost for the ENS set by the regulator. The grid company and the customer can make their own individual agreements with a lower interruption cost. This agreement must be based on the customer’s real interruption costs. The grid company might be spared the expense of developing the grid if the customer agrees to an individual interruption cost lower then the regulators tariff.

So tariff power interruption costs through individual compensation for power interruptions give the customer a lower cost if interruptions occur and the grid company might avoid major grid investments.

3. OPTIMAL TARIFFS OF FIXED COSTS

A social-economical optimal capacity utilization requires that the fixed costs are covered in such a manner that disturbances of the capacity utilization in relation to marginal cost prices are kept to a minimum. It is also an essential condition that the major financial contributions to cover fixed costs are charged to areas where the demand for transmission capacity is least affected by high prices.

- From the social-economical point of view, the price policy aiming at natural monopoly leads to a taxation problem.

Optimal price setting for grid usage requires that the prices should be differentiated in relation to the qualities of the market demand. This is achieved by differentiation of price mark-up ensuring the coverage of fixed costs in relation to the price sensitivity of the demand. The major financial contributions to cost coverage should be inflicted upon the markets or the customer groups where the grid usage is least influenced by the price. Customers having high price elasticity should therefore be priced lower than customers having low price elasticity. This theory was first described by Frank P. Ramsey, and is often used today. For example companies in a country is lower taxed then the individuals, because companies can move more easily to another country then people. Companies have higher price elasticity and are therefore taxed lower.

Taking into consideration the fact that the tariff should send signals about optimal long-term capacity development and upgrading of the grid, the grid company should establish obligations and options for the customers that are offered lower tariffs. Since the capacity is being developed on a “leap”-basis, the tariff gives the grid company possibilities to influence the consumption significantly.

- The tariff’s residual element should therefore be differentiated with regard to the customers’ price elasticity and supply flexibility

Both short and long-time elasticity should be reflected in tariffs through grid relevant criteria. These customers can be divided into two groups

1. Customers that have a short-term elasticity, means customers that are willing to disconnect for shorter periods and be flexible momentarily or on a short time notice, when it is a lack of capacity for seconds or a few hours
2. Customers that have long time elasticity, means customers that that they can disconnect for some months or half a year, when it is a lack of capacity for longer periods
3. Customers that are in both above groups

3.1 Short-Term Elasticity

Customers with short-term elasticity can disconnect on frequency, voltage or disconnection in the balance regulation. Among these parameters there are local and global parameters. The voltage is a typical local parameter and should be a compensated individually to the customers. With regard to the frequency and the balance regulation these are global parameters that the grid company can buy in a bidding competition using option mechanisms. In these completions both consumption and production should participate. The most efficient way of making the tariffs on the global parameters are a bidding competition revealing the customers elasticity/flexibility. In Norway there is a bidding competition on the balancing market but not yet on the frequency regulation.

3.2 Long-Term Elasticity

Costumers with long-term elasticity are typical customers with an alternative power source, like oil, gas or other fuels but it can also be for example Ferro industries that can put down the production for months and start again when the capacity is back. This can also be a semi global parameter that it is possible to use bidding competitions to get the most efficient tariff in this field.

3.3 Tariff Incentives For Flexibility

Tariff structure depending on the flexibility and short and long term elasticity are shown in table one.

<table>
<thead>
<tr>
<th>Customer group</th>
<th>Cost [kr/kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prioritized</td>
<td>150.0</td>
</tr>
<tr>
<td>Disconnection within 15min duration 2h</td>
<td>112.5</td>
</tr>
<tr>
<td>Disconnection within 2h duration permanent</td>
<td>37.5</td>
</tr>
<tr>
<td>Disconnection within 15 min duration permanent</td>
<td>7.5</td>
</tr>
</tbody>
</table>

The customers that can disconnect permanently on a notice of 15 minutes have only 5% of the peak power cost, 25% for
those that can disconnect permanently on a notice of 2 hours. 75% of the peak tariff for those customers that can disconnect on 15 minutes notice but only for 2 hours.

The customers that choose the lowest tariff are giving the grid company the right to disconnect if there is a lack of capacity. The customers will pay a part of the grid cost when there is a capacity. This is a Ramsey approach using grid relevant criteria.

3.4 Tariff Incentives For Localization And Usage Time
The prioritized consumption in the Norwegian central and regional tariff are further differentiated for each bus bar in the following formula:

\[ \text{Cost} = K \times F \times \text{Tariff} \]

where:

- Tariff = Peak powerprice [kr/MW]
- PII = Power intensive industry [MW]
- F = PII + Ordinary consumption [MW]
- Pt = Available power production on peak

\[ K = \left( \frac{F}{Pt + F + PII} \right) \]

PII have to have a time of usage of more than 7000 h and more than 15 MW as a peak value.

This formula gives incentives to place power production on the same bus bar as consumption. It also gives customers incentive to have a high time of usage. Both a high time of usage and a power production on the same bus bar as consumption benefits the grid company. The last formula has also a Ramsey approach, not on the location of power production, but on the high time of usage for power intensive industry. The correlation between high time of usage and long-term elasticity are assumed to be high.

4. CONCLUSION
If the aim with the tariffs are to give incentives to consumers and producers to optimal location and in that way minimize the grid companies’ costs and maximizing the grid companies’ profit, the tariff-setting should bring a strong focus to dimensioning criteria.

Under normal operation the grid has two cost elements:
- The costs depending on the usage and operation of the grid (like electrical losses, bottlenecks interruption costs)
- The costs not depending on the operation (like investments)

cost they inflict on all the other users. This means that the losses in the grid, i.e. the variable costs, should have tariffs according to the marginal loss principle. The tariff on each bus bar is then set to what the last kWh cost in losses.

In every income cap regime the grid companies should pay a penalty for power interruptions. The best way of making tariffs are to compensate customers directly for power interruptions based on their real interruption costs. Through such a tariff system the grid company can avoid major grid investments.

The tariff’s residual element should be differentiated with regard to the customers’ price elasticity and supply flexibility. Price elasticity and flexibility can be established by tariff contracts where the grid company retains the right to reduce the power load to prevent grid dimensioning, which may take a few seconds to protect the grid or be permanent when facing a lasting capacity problem.

The grid is not a market and does therefore not have an optimal price setting mechanism. Still there are many things that can be done to get an effective pricing. For example on global parameters like frequency and balancing regulation the most efficient way of making the tariffs are a bidding competition reveling the customers elasticity/flexibility. For local parameters like disconnection because of voltage drop the tariff can reflect the value this customer have for the system.

Ramsey’s theory from the social-economical point of view, the price policy aiming at natural monopoly, leads to a taxation problem. This leads to the lowest transmission tariff for customers with highest price elasticity. This can also be argued according to the objective grid-based criteria. Customers with high price elasticity are often the most flexible. The correlation between high time of usage and long-term elasticity are assumed to be high.

Using grid relevant dimensioning criteria in the tariff have many parallels with Ramsey pricing and should be used for all grid companies.

5. REFERENCES
[3] SNF Rapport 01/02 Nettregulering, Von der Fehr, Hope Hagen, 2002