FINAL REPORT

Capacity-based grid tariffs

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Preface

Sweden's electricity mix is almost completely fossil-free, but there are still major challenges ahead where flexible resources will be a very important piece of the puzzle in the larger context but also from a local perspective where we as residents have a greater opportunity to act and be participants in the energy transition that needs to happen very quickly.

Electricity grid tariffs have great potential for impact as they affect us all. Compared to electricity trading, relatively blunt tools are used in today's electricity grid tariffs, and there is great potential to be able to provide incentives for more flexibility.

This project is based on being able to show what benefits a completely new way of thinking can create for electricity grid tariffs going forward. How can we maximize the benefits down to a detailed level in relation to what really happens out in the grid stations, rather than a flat-rate charge guaranteeing cost coverage for expansion?

If we do not succeed, there is a risk that the opportunity will be stopped for subscribers to continue to be active and follow the spot price. We see an electricity grid tariff that complements the spot price and is adapted to local challenges as a solution.

The project addresses all the problems we have identified in our monitoring of the market with a tariff that continues to enable subscribers to be active – which both strengthens the market for green energy and contributes to efficient grid utilization.

The tariff and its dynamic energy fee stimulate balance in both the large and the small. For example, it provides an incentive for more generation in areas dominated by use, and also an incentive for more corrective energy from energy storage at times when the grid is particularly strained. Electricity generation and utilization are equated, with the primary focus instead being which direction of power is currently straining and corrective.

Looking ahead, we also see a need to create a more cost-reflective and fair distribution of grid costs for different customer groups. We also see a great need for automation and customer customization.

Project manager for Tariff 1.0 and technical project manager at Energicentrum
Magnus Jennerholm, Visby, 2025-01-20

Summary

This report describes the results of the Tariff 1.0 project, which aims to develop capacity-based electricity grid tariffs to create a more resource-efficient energy system. The project has been implemented on Gotland through a collaboration between Energicentrum Gotland, Gotlands Elnät AB, Plexigrid and Ngenic. The goal has been to create the conditions for testing a tariff model based on real-world circumstances in the electricity grid. The focus has been on promoting flexibility, reducing grid costs and supporting the transition to renewable energy.

In accordance with the Energy Market Inspectorate's regulations, the proposed tariff model has four components: fixed fee, energy fee, customer-specific fee and power fee. All except the customer-specific fee have been designed to create incentives for better use of the electricity grid's capacity. Subscribers are thereby offered the opportunity to act flexibly based on dynamic price signals. The price signals consist of a cost or compensation in öre per kilowatt-hour, for utilization (imports) and generation (exports). An AI-based engine has been used to generate price signals, tailored to the forecasted station load at each grid station. A customized interface then communicates these price signals to the project's test pilots.

The project has identified several regulatory hurdles that need to be addressed, including allowing the use of location signals in pricing. The results presented indicate that the model can lead to significant socio-economic benefits, including reduced grid expansion needs and increased opportunities for variable renewable energy to be integrated into the system.

The conclusions underline the importance of continuing to develop and increase the maturity of the model through the next phase, Tariff 2.0, where the model will be tested for 12 months under real-world conditions.

Content

Explanation of terms

AI-engine	The most central function of the project is an “engine” or program whose task is to learn to predict how energy and power flow in the electricity grid. The AI engine is based on artificial intelligence (AI).
Capacity ceiling	The maximum power a grid station can handle before the risk of damage or operational disruptions arises.
Core losses	In grid stations, transformers are installed to adjust voltage levels through their windings. When a transformer is connected to the grid, alternating current and voltage induce eddy currents and cause energy losses in its iron core. These losses, known as core losses, occur even when the net energy flow through the transformer is zero. They are constant and independent of the load.
Corrective transfer	Energy transferred in the non-dominant power direction.
Ei's regulations EIFS 2022:1	Regulations from the Energy Market Inspectorate for the design of electricity grid charges with the aim of promoting an efficient and sustainable electricity grid.
Grid benefit compensation	Compensation awarded to those who contribute with corrective power, which reduces costs and load on the electricity grid.
Load	A general term to describe strain due to the flow of power through the grid. It can also be defined as strain caused by grid connected equipment utilizing electricity.
Location signals	Price signals that reflect geographical load differences in the electricity grid and create incentives for energy efficiency at local levels.
Loss equivalents	A way of expressing energy losses and forward-looking costs in relation to the station load.
Mirrored price signals	The price signals for straining and corrective energy mirror each other, where a cost for a straining transfer is always matched by an equal compensation for corrective transfers. The price for transferring energy is therefore zero at zero load, which means that the subscribers' electricity utilization is equal to its generation. For electricity grid prices, it is therefore secondary in the tariff assessments whether it concerns generation (export) or utilization (import).
Non-ideal and ideal losses	Energy losses occur in ordinary electricity lines even if they are optimized for the task. Such energy losses are called ideal, while all energy losses beyond this are called non-ideal.
Power tariffs	Pricing model where subscribers pay based on their power usage to promote more even load and reduce the need for grid expansion.
Reactive and proactive forward-looking costs	The term proactive is added to distinguish costs that are required for a planned grid development, while the term reactive is used for forward-looking costs that are only charged when the real-time and location-specific situation in the electricity grid is strained. The reactive forward-looking cost can be represented by an ongoing load-dependent insurance premium to the electricity grid company itself or to an external insurance company.

Residual costs	Costs that cannot be directly attributed to individual subscribers, such as capital costs for an already built electricity grid.
Shared and individually used parts of the electricity grid	The shared parts of the electricity grid are parts that are used jointly, where the interaction between different subscribers matters for the strain it causes on the grid. In the individually used parts, the load cannot damage the electricity grid provided that it is correctly dimensioned for the subscriber's connection power and that the subscriber complies with their electricity contract.
Station Load	A measure of balance or imbalance in a grid station, where a positive station Load indicates higher utilization (imports) than generation (exports), and vice versa.
Straining transfer	Energy in the dominant power direction.

Project description

The Tariff 1.0 project is part of Energicentrum Gotland's work within the hub Storage and flexibility for a more resource-efficient society. The project is run with funds from the European Regional Development Fund, through the Swedish Agency for Economic and Regional Growth, and with 1:1 funds through Region Gotland, financed by the state. The project period is 17 months, starting on 1 September 2023 and ending on 31 January 2025. Energicentrum Gotland is the project owner and Gotlands Elnät AB is the project partner.

The goal of the project is to develop at least one tariff model that solves parts of the Swedish electricity grid challenges. A key idea has been that it is therefore required that the tariff is based on real conditions in the electricity grid, and that it is both location- and time-specific.

The project has been carried out within a defined area with 10 test pilots who have been given the opportunity to be active subscribers, both autonomously and manually.

The project has used advanced technology to implement the tariff model. Smart meters were installed early in the trial area on eastern Gotland, where both customer meters and metering in grid stations enabled the collection of data for at least a year. This data was used to create location- and time-specific price signals based on the station load at each grid station.

Target groups

The project's target group is small and medium-sized companies and private individuals who want to continue to be active subscribers by contributing to demand flexibility.

One aim of the project is to demonstrate that the project's solution is possible to implement today. Both from a technical, regulatory and social context. The electricity grid industry and decision-makers are therefore also a target group.

Scope

The project's test area is limited to subscribers below a distribution station in Östergarnslandet, Gotland. Below this distribution station (70/10 kV) in Kräklingbo, there are approximately 1700 subscribers and approximately 150 grid stations that transform the voltage down to the end customers' low-voltage grid (400 V). Ten test pilots are participating, distributed across five different grid stations in the area. The low number of test pilots covers both the time and financial budget for the most important need for automation and customer adaptations.

Load control is limited to controlling heating, defrosting periods for larger freezers, electric car charging, and battery storage. Software from Ngenic and Home Assistant is used as the customer interface. Heating, defrosting, and battery storage can be controlled fully automatically in the project. For example, charging electric cars requires manual control.

The test pilots consist of small and medium-sized companies, mainly agricultural companies of varying sizes, a wastewater treatment plant, a smokehouse, and a grocery store.

The work in the Tariff 1.0 project has been limited to primarily designing a tariff model and the associated control system – including grid analysis, data communication, and customer interface – where the station load for each grid station results in a functional and cost-reflective price signal that is sent to subscribers the day ahead.

As the Tariff 1.0 project nears its conclusion, Tariff 2.0 will take over for a rigorous 12-month long-term test, scheduled to begin on February 1, 2025, and conclude on April 30, 2026. Ahead of the Tariff 2.0 test, all preparations are complete: the tariff model with price signals from the established system, and the test pilots from Tariff 1.0, whose control equipment is fully operational and ready to support flexible use and cost optimization on their behalf.

The Tariff 1.0 project did not incorporate voltage as a control variable in the price signal mechanism, as it was determined that load control should be prioritized as the initial focus. However, voltage could become a consideration in Tariff 2.0, starting with data analysis as a basis to identify potential solutions. For example, such signals might be integrated through a local flexibility market.

Methodology

The work within the Tariff 1.0 project has been conducted through a structured and iterative process involving several actors and areas of expertise. The methodology has been interdisciplinary and included technical development, grid analysis, implementation of control systems and cooperation with test pilots and external actors. The work process is described in detail below:

Project management and organization

Energicentrum has the main responsibility for project management and coordination. A project coordinator is employed specifically to develop at least one tariff model. The early phase of the project focused on studies and external monitoring, which laid the foundation for the conceptual design of the tariff model.

Development of the tariff model

The development of the tariff model began with an analysis of existing tariff systems and identification of potential areas for improvement. Right from the start, a basic structure was formulated for how the load on the electricity grid would control pricing. The project identified the grid analysis company Plexigrid as a partner with similar visions regarding smart tariff models.

Data management and grid analysis

With support from the grid company Gotlands Elnät AB, an initiation process was carried out to make data from the selected experimental area on eastern Gotland available for analysis. Plexigrid developed a detailed analysis basis to assess the load in the electricity grid and thereby enable the calculation of the tariff's dynamic price signals. This work involved both technical preparations and continuous development.

Control and implementation

Heat pumps are automatically controlled via a customized application from Ngenic, which combines spot prices and the grid's dynamic price signals into a composite control signal in a mobile app. One price signal for electricity utilization and one for generation. Defrosting of larger freezers is also controlled automatically via Ngenic, while Gute Kyltjänst AB ensures correct control of the freezers. Battery storage and electric car charging are controlled manually or autonomously through Home Assistant, where Niska AB is responsible for installation and configuration. Other loads are manually controlled by the test pilots to balance costs and needs. All test pilots receive the price signal via Ngenic's mobile app.

Pilot area and test pilots

The project's test area on eastern Gotland includes subscribers under a specific distribution station. A selection of test pilots was equipped with control systems to be able to participate in the trial. These pilot users represent different types of electricity users, from small-scale agriculture to commercial operations.

Collaboration and knowledge dissemination

Energicentrum has been responsible for coordinating the collaboration between involved parties, with regular meetings with Plexigrid's project management to ensure progress and coordination. In addition, the project has actively shared insights and ideas with other grid companies and energy companies to promote a broader understanding and acceptance of the tariff model.

Introduction

Energy transition and grid challenges

To meet future energy needs, grids have so far been oversized to handle the most extreme peaks in the grids. However, as electrification continues, the need for balancing with flexibility increases, as it otherwise becomes increasingly difficult to maintain margins. Flexibility is required for the grid – to avoid transmission losses and avoid harmful loads. Flexibility is also required to lower the costs of the entire energy system, where the demand for cheap variable energy requires that subscribers can respond with demand at times when the supply of energy exceeds the need at the moment.

Focusing solely on expanding the grids is no longer a cost-effective or sustainable solution. Of course, the grid tariff that all grid companies have should also be used in the best way to eliminate unnecessary expansion. Only then should other solutions such as flexibility markets and conditional agreements be used (Energiforsk, 2024; SWECO, 2024).

Challenges with the current system

A major problem so far has been the increased need for grid reinforcement as a result of the expansion of solar photovoltaics in weak electricity grids. Since solar energy is generated both locally and regionally at the same time, incentives are required to ensure that flexibility can meet the demand for this energy when non-flexible energy demand decreases.

There are strong indications that the current incentives for managing electricity generation and utilization will not be sufficient in the future. Low or negative electricity prices not only impair the profitability of green variable energy, but they are also a huge waste of resources when generation of, for example, wind power is forced to shut down. The fact that negative prices in electricity trading are necessary in the first place is a sign that something is not right.

Overall, the emergence of negative prices can be explained by incorrect economic incentives, which lead to a lack of flexibility in the electricity system. However, the one-sided incentives that exist for flexibility risk damaging the electricity grids.

Since electricity prices fluctuate so much, active subscribers benefit from hourly contracts. This provides economic incentives for demand flexibility. For example, heat pumps and electric cars that automatically control the electricity trading price signals are becoming increasingly common, despite the fact that in order to maintain their viability, electricity grids need usage to be distributed evenly over time and not to the same hour. So even if electricity trading prices encourage the use of renewable energy, the one-sided incentive from electricity trading risks leading to local overloads when many people use electricity at the same time.

Need for new solutions

Despite the upcoming challenges, it is as if “we are running with half-full trains”, as a manager at Vattenfall describes it (Takács, 2023). Beyond the peaks, the electricity grid is therefore underutilized to a great extent. Underutilizing something as expensive as the electricity grid is a terrible waste of resources at a time when the whole world is about to change. Expensive both for the environment and for the wallet!

According to Sweco (2023), investments in the Swedish electricity grid of around SEK 900 billion are required by 2045, half of which is investment in local grids. The investments are required both to adapt the electricity grid to a significantly increased electricity consumption and to maintain the current level of service. Although Sweco's assessment is already based on the assumption that some flexibility in the electricity system will exist, there is likely great potential to further reduce the need for electricity grid expansion with smarter incentives for flexibility that affect all electricity grid subscribers.

The Swedish expert and regulatory authority Energy Market Inspectorate (Ei) believes that today's grid charges are also designed according to conditions that applied 10-20 years ago (Ei, 2022a), even though new regulations and tariffs are continuously being developed to help electricity grid companies work more efficiently. For example, all grid companies in Sweden must have introduced so-called *power tariffs* by 2027 at the latest.

These power tariffs have the potential to improve grid utilization – or to worsen it. During periods of anticipated high load on the grid, all subscribers in the local grid are expected to reduce their electricity utilization to avoid incurring a significant power fee. However, these high load periods must be determined based on the overall grid load, which increases the risk of impaired grid utilization in areas where no local high load situation exists. As a result, while the new legislation could lead to improved grid utilization, its effectiveness depends heavily on local grid dynamics and the criteria used to identify high load situations.

Regulatory challenges and proposals

The tariff project on Gotland focuses solely on grid charges and how these can help solve current and future load problems to reduce costs and increase the energy system's ability to use renewable energy. The project also sees that the existing regulations are sometimes not clear or sufficient - that further efforts are needed to get regulations to support more efficient use of the electricity grids.

Note! The project uses the same names that Ei uses for the different fee components, even if the costs that are distributed deviate from Ei's definitions. The hope is that this makes it easier to understand the project's proposed changes.

Allow location signals

The most important regulatory change that the project sees is needed is to make it legal to take location signals into account in all levels of grid networks. The Energy Market Inspectorate has already proposed such a legislative change several years ago (Tvingsjö, Carlsson, Kaplin, & Lundgren, 2020). Location signals enable strategic geographically differentiated price signals to be sent, as an incentive for subscribers to contribute to solving both local and more central load problems at the same time. The project wants to claim that it is also possible to send such signals without it having to entail increased costs for subscribers in weaker parts of the electricity grids. For those who choose flexibility, the opposite is true with the project's proposed tariff.

New distribution of costs

Here is a description of how the different fee types in the project's tariff differ from Ei's definition in terms of content, which costs are distributed.

The table below presents an overview of how the grid company's different cost categories according to Ei (2024) should be distributed in the different fee components, and briefly about what the regulations say about the distribution method.

Table 1. Overall picture of Ei's general advice on how a grid company's costs should be distributed.

	Cost categories	**Tariff components**	**Distribution methods**
1	Residual costs	Fixed fee	Subscribed power or equivalent
2	Short-term variable costs	Energy fee	Charge per kilowatt-hour- May be time-differentiated
3	Customer-specific costs	Customer-specific fee	Fixed amount per customer. Cost-reflective.
4	Forward-looking costs	Power fee	Charge on total grid load. To be time-differentiated.

Residual costs are other costs that the grid companies have in addition to customer-specific and cost-reflective costs, where cost-reflective costs can be divided into short-term variable and forward-looking costs (Ei, 2024). Residual costs essentially correspond to capital costs for the already built electricity grid. This latter definition is used by the project to enable an even finer division.

In the project, <u>residual costs</u> are divided into two categories:

1.1 Costs for the individually used parts of the grid
1.2 Costs for the shared parts of the grid

Fixed costs for other grids are included in category 1.2.

Short-term variable costs consist mainly of energy loss costs but also costs to other grids. The project sees the need to redefine parts of this category. However, for the time being, the starting point is still how it traditionally looks. <u>Short-term variable costs</u> are thus divided into three categories:

2.1 Controllable short-term variable costs
2.2.1 Non-controllable short-term variable costs in the individual grid
2.2.2 Non-controllable short-term variable costs in the shared grid

Short-term variable costs to other grids are included in category 2.1.

Forward-looking costs are investment costs that are planned for (proactive) or for which there is a risk that they may arise (reactive). <u>Forward-looking costs</u> are thus divided into two categories:

4.1 Reactive forward-looking costs
4.2 Proactive forward-looking costs

Power charges to other grids are included in category 4.2 for the time being.

In the project, the new cost categories are distributed among the various tariff components according to the table below. The project's distribution methods are described below, under the headings "*Footprint as a basis for residual fee components*" and in the more detailed description of the tariff design, under the heading "*The developed tariff model*".

Table 2. Overall picture of the project's allocation of the grid company's costs in the different cost categories.

	Cost categories	Tariff components
1.1 2.2.1	Individual used part of residual- Non-controllable short-term variable- in individual part	Fixed fee
2.1 4.1	Controllable short-term variable- Reactive forward-looking-	Energy fee
3	Customer-specific costs	Customer-specific fee
1.2 2.2.2 4.2	Residual- for shared part of the electricity grid Non-controllable short-term variable- in shared part Proactive forward-looking-	Power fee

Category 3, which constitutes customer-specific costs, is therefore left untouched according to the project's proposal.

Table 2 above provides an overview of the content of the following headings.

Costs charged for in the fixed fee

Category 1.1 above consists of costs associated with the electricity grid components that are used only by individual subscribers. The cost of the service cable in question is normally not affected by the behaviour of the subscribers, provided that the electricity contract is followed. This part of the residual costs is therefore best suited for a distribution that does not affect the behaviour of the subscribers at all.

The fixed fee also allocates costs for non-ideal energy losses, which are a non-controllable energy loss cost, which can be distributed between both the individual and the shared part of the electricity grid. This includes the part associated with the individually used part of the electricity grid (2.2.1). This cost is moved from the energy fee to the fixed fee.

Costs charged for in the energy fee

In addition to costs to other grids, an energy fee normally charges for all energy losses that occur in the electricity grid. The project sees that the latter leads to inefficient use of the electricity grid because parts of the energy losses are beyond the control of the subscribers to influence.

Two of three types of energy losses are considered in the project as non-controllable (2.2.1 and 2.2.2):

- Core losses, which occur regardless of the load in transformers. This category also includes other losses that are not dependent on the load. Included only in the shared part of the electricity grid (2.2.2).
- Non-ideal losses, which occur as a result of the electricity grid not being optimized for use. Included in both the individually used (2.2.1) and the shared part (2.2.2) of the electricity grid.

Although some non-ideal losses can be indirectly influenced by a subscriber, the root cause of such losses is not controllable by the subscriber. Costs for these “non-controllable” energy losses are therefore allocated with the project’s power fee and fixed fee.

Only controllable costs remain to be allocated with the energy fee:

- Costs for ideal energy losses 2.1, which are losses that occur even when the electricity grid is optimized. This component also includes energy costs to other grids.

- Reactive forward-looking costs, 4.1. This is a power component of the energy fee.

Both of these – but especially the last cost component (4.1) – mean that the energy fee rises exponentially for straining transfers at high load, since the risk of damage increases exponentially and thus the need for grid reinforcements.

Costs charged for in the power fee

Category 1.2 consists of costs for the part of the electricity grid where it actually matters how a subscriber follows the energy fee. The project proposes an allocation method based on the subscriber's footprint on the shared electricity grid. The allocation method is in turn based on the energy fee.

The power fee also allocates costs for non-ideal losses and costs for core losses (both of which are included in category 2.2.2), as well as proactive forward-looking costs 4.2. The latter are costs that arise as a result of the grid company's grid network expansion plan.

Footprint as a basis for residual fee components

It remains to be seen whether the valve provided in Chapter 3, Section 2, second paragraph of Ei's regulation EIFS 2022:1[1] on the design of grid tariffs is sufficient to provide support for the project's proposal for a distribution method for the residual costs (category 1.2) that are distributed in the project with the power fee. The difference from how these fixed costs should be distributed according to Ei is that the project takes a further step beyond the assessment of a subscriber's size that is made with subscribed power or similar. The project instead assesses the subscriber's so-called *footprint*.

To assess the footprint, the smart energy fee that the project has is required, where all of the subscriber's costs and grid benefit compensation are collected to get a relative picture of how helpful the subscriber is in solving grid network challenges.

The result of taking the footprint into account in this way in the power tariff is an additional incentive for subscribers to, for example, invest in electricity generation in a utilization-dominated area, provided that a grid benefit compensation from this over time provides a large part of the subscriber's total grid benefit compensation. It also provides an incentive to invest in flexible capabilities to contribute grid benefit according to the energy tariff when it is most important for the electricity grid. In a problem area, such grid benefit compensation can constitute a larger part of the subscriber's total grid benefit compensation.

An important context is that the project's energy tariff normally does not affect subscribers' behaviour almost at all because spot prices normally dominate, which is also related to the project's modification of the content of the energy tariff. Only when it is particularly important for the grid will the energy tariff be governing for subscribers because the price signals then follow the combination of controllable losses and reactive forward-looking costs, both of which increase exponentially with the load.

Another context is that the time- and location-specific price signals of the energy tariff are always directly reflected, where the price for straining energy, which is always dominant and which always

[1] "Despite what is stated in the first paragraph, the grid network concessionaire may apply a different distribution of the residual costs if the distribution can be assumed to lead to a more efficient use of the electricity grid network" Chapter 3, Section 2, second paragraph of Ei's regulation EIFS 2022:1 (Ei, 2022b).

constitutes a cost for subscribers, is always met with an equal amount of compensation for corrective energy.

The consequences of taking into account the subscriber footprint are that more people will want to acquire flexible capabilities to follow the energy tariff and participate in the spot price market. This in turn also strengthens the market for cheaper variable energy such as solar and wind power, reduces costs for both electricity generation and the electricity grid, and reduces the need for grid expansion.

Grid benefit compensation, not exclusively for producers

In the Swedish electricity system, grid benefit compensation is used to compensate producers for measured cost reductions at grid companies specifically as a result of electricity generation. The project believes that utilization can also contribute to balance in the electricity system, and therefore only wants to allocate grid benefit compensation to those who transmit corrective power.

The developed tariff model

This section describes in more detail how the tariff developed by the project is designed. Three of the four tariff components are described: the *energy fee*, the *power fee* and the *fixed fee*.

The project has therefore not engaged in the issue of how customer-specific costs should be distributed, as it is assumed that there is already a sufficient basis for this part.

Energy fee

According to Ei (2024), the energy fee shall charge for the marginal costs of transmitting electricity in the grid. The cost shall reflect the short-term variable costs. The energy fee may also be time-differentiated. Additional variable costs may be included if there is an increased cost for the grid company for the transmission of an additional kilowatt-hour of electricity.

Cost components in the energy fee

As described earlier, the following costs are charged in the energy fee:

- Influential short-term variable costs (see category 2.1 above).
- Reactive forward-looking costs (category 4.1).

The content of the latter category can be discussed, but the project believes that it is necessary for this cost to be both functional and ethically justifiable. So even if a subscriber negligently transmits the last kilowatt-hour that causes a transformer to break down, which can entail an extremely high cost - it is more reasonable that the grid company bears the ultimate responsibility and thus the risk including the costs that a breakdown may entail. If excessively high price signals are required, complementary solutions should instead be considered, such as flexibility trading, conditional contracts and grid network reinforcement.

These cost adjustments promote efficient grid utilization. When energy prices are normally lower, subscribers will first and foremost follow the variations in the spot price. Only when the load is high in the electricity grid will the energy fee be more clearly felt than the spot price.

Design of price signals

The price signals for the energy fee are calculated as a cost (+/-) per transferred kilowatt-hour. Straining transfers always entail a cost above SEK 0, while corrective transfers give a negative cost below SEK 0, i.e. a grid benefit compensation. The design therefore requires that straining transfers cover all costs – taking into account that corrective transfers are compensated in a functional way. The functional thing is that the compensation is always equal to the cost of straining transfers at the same time and place.

Although such compensation is not necessarily completely cost-reflective, the design is intended to promote more efficient use of the electricity grid. By having the signals for utilization and generation mirror each other in this way, incentives are created for subscribers to contribute to balance in the grid. Since the straining power direction always dominates, the energy fee always generates net income for the grid company. However, the more balance in the grid stations, the less income from the energy fee. This requires that all remaining energy costs can be transferred to the power fee and the fixed fee if necessary.

To achieve the secondary goal of cost coverage for ideal energy losses with the energy fee price signals, studies are required to adjust a cost-reflective loss curve for straining transfers based on a more or less general relationship relative to different conditions, for example voltage level. The goal is to provide effective price signals to each subscriber, which means that different categories of connection points can generate different price curves relative to the station load. For example, significantly less losses are generated at higher voltage levels, which is something that needs to be taken into account in order for the electricity grid to be used as efficiently as possible.

Artificial intelligence is used to predict station load

The price signals are based on the time-differentiated station load in the local grid station to which the subscribers are connected. The station load shows how much and in what power flow direction the transformer in the grid station is loaded. To predict these station loads, measurement data from grid stations and their transformers is used to train an AI engine. The AI engine is an advanced algorithm based on artificial intelligence, with the ability to learn and improve its forecasts.

The AI engine is trained with data on weather, changes in electricity use over time, spot prices and the price signals that have been generated previously. This is especially important during high load, when the price signals of the energy tariff affect the behaviour of subscribers and thus change the load. With each calculation, the prices are adjusted based on changes in load, which leads to new customer behaviours and new flows. This iterative process continues until the price changes between cycles become so small that the forecast stabilizes. It is then these price signals that apply for the day ahead.

Customer interface

Next-day price signals are published approximately three hours after the spot prices are released, meaning that subscribers have access to information for the next 24 hours around 4 p.m. the day ahead. Each grid station receives unique price signals, which theoretically could be generated every quarter of an hour, but the project uses 30-minute intervals to match power quality measurements and energy measurements taken every 10 and 15 minutes, respectively.

The station load, which is the basis for pricing, is a technical detail that is not normally displayed to subscribers. For those who want to control their loads manually, the price signals are displayed in an app, where they are combined with the spot price to provide a simple price for utilization and one for generation. However, automated control is most effective, as it reduces the need for manual adjustments. When the settings are properly adjusted, subscribers control their electricity usage to minimize costs, which at the same time benefits the stability of the electricity grid and the environment.

Technical description of the energy fee

The most basic component is the station load, which is determined by Formula 1 below. For example, the station load gives a positive value when the transformer's export (flow up in the grid network structure) is less than the transformer's import (flow down in the grid network structure).

Formula 1. Station load (x) is a measure of balance/imbalance in the transformer to which a subscriber is connected.

$$Station\ Load, x = \frac{import_{station} - export_{station}}{capacity_{station}}$$

In its original form, the station load is, as above, a value between -1 at the capacity ceiling for export, and +1 at the capacity ceiling for import in the local grid station. The value is then compared with the subscriber's electricity utilization (import, $E > 0$) and generation (export, $E < 0$) to determine whether the subscriber's transmission is in the dominant and burdening direction (E and x have the same sign) or in the corrective direction (E and x have different signs). When knowledge of which directions are burdening and corrective is assumed, it is more practical to refer to the load factor in absolute terms, which varies between 0 and 1.

Figure 1 below shows so-called loss equivalents per kilowatt-hour of straining transmission. The term loss equivalents is used here to represent both the magnitude of the ideal energy losses (category 2.1) at low station loads and the magnitude of the reactive forward-looking cost (category 4.1) loss equivalents at high station loads (in terms of the absolute of the station load value).

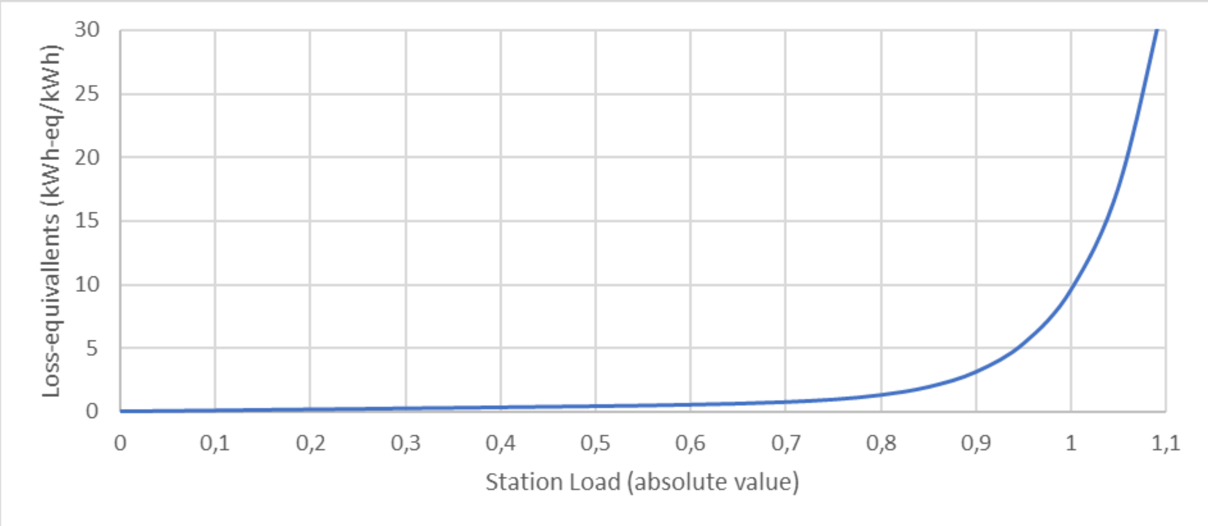

Figure 1. The curve in the diagram represents ideal energy losses (category 2.1) at low station loads and forward-looking costs (category 4.1) expressed as loss equivalents at high station loads.

To obtain the price signal for straining transfers, the curve also needs to be multiplied by the grid company's loss price (öre/kWh). The result is short-term and controllable marginal costs.

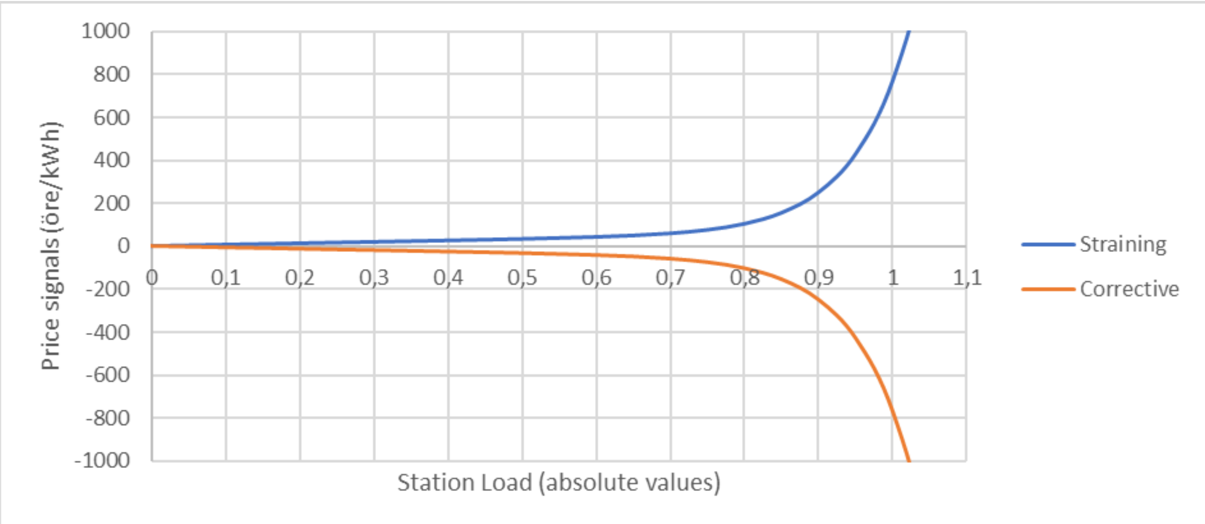

Figure 2. The diagram shows the prices for straining and corrective transfers, and how they are reflected across the x-axis at y = 0.

Overall optimization, including consideration of other grids

The project does not include more than a small grid area with approximately 1700 subscribers, which means that a larger grid analysis cannot be done in the project to optimize the grid based on a holistic picture. If no obstacles later prove to be in the way of the method below, the project sees a preliminary possible way forward to optimize the electricity grid using AI, including to reflect costs for overhead and other grids.

The method, in short, involves letting the previously described AI engine do what it already does, and analyse the power flows in each node in the electricity grid for the next day. The result of this – step 1 – is a “heat-map” based on station loads for the entire electricity grid. A new AI is trained in step 2 – to make set point changes to the station load in each node to resolve bottlenecks; convey costs from the overlying grid; and cost optimization. The first goal should be emphasized to eliminate risks of overloads, and then to reduce grid costs and, if possible, generate revenue from second or overlying grids; and to minimize costs for energy losses in the own grid. No part of the grid will thus be sacrificed in order to cost optimize the grid as a whole, as this would be a sub-optimization.

The change requires that the AI that handles the local analysis is also involved in the change and learns to handle the fact that its first result is to be modified. In step 3, the changes are therefore communicated back to the local AI engine that realizes the changes, which means that it is the new adjusted station load that forms the basis for the price signals based on how the new prices affect the power flows.

The result is a new heat map, and a new - or even several - cycles of modifications can be performed. The need for the number of cycles depends on how much resources the calculations require and what additional benefit it brings.

In normal cases, the spot price as a control signal will still be dominant for influencing behaviour, except when it is particularly urgent for the electricity grid to change the station load. Cost optimizations for the electricity grid in stage 2 should therefore not be at the expense of subscribers' ability to follow the spot price, as this would be a socio-economic sub-optimization.

Power fee

According to Ei (2024), the power fee should be an instrument to influence subscriber behaviour when necessary in order to avoid the need for expensive investments in the electricity grid if possible. According to Ei, the method should allocate forward-looking costs, which means that the allocation should be made on cost-reflective and objective grounds.

The project's power fee supplements the energy fee by charging for proactive forward-looking costs (category 4.2). It also takes over costs for the shared electricity grid (category 1.2) from the fixed fee, including associated "non-controllable" energy loss costs (category 2.2.2). This has also been described earlier in the report.

If expansive plans for expansion and reinforcement were completely absent, no "proactive" forward-looking costs would be required. However, the project's power fee would still fulfil an important function in providing all subscribers with cost-reflective economic incentives to continuously strive for balance in the electricity grid.

Four factors determine the size of the power charge, of which the first two determine the customer's footprint while the last two handle extreme cases and varying cost bases.

- Agreed connection power: Consists of Subscribed power or Fuse size. The choice means that subscribers should basically have full freedom to use the entire connection capacity that the grid company has invested in on behalf of the subscriber.
- Economic return in the energy charge: Through the detailed and valued information on how much a subscriber should pay or receive in grid benefit compensation for straining and corrective transfers through the energy charge, it is approximated how its behaviour affects the balance of the electricity grid over time.
- Minimum charge: Adjusted in relation to the agreed connection power.

- Adjustment for customer category: To take into account that certain customer groups either use parts of the electricity grid that have lower costs per transferred kilowatt-hour or have been disadvantaged by the fact that the electricity grid is not adapted to their needs.

The purpose of using the footprint as the allocation method for the power fee is that the footprint affects how much of the electricity grid is required to achieve a balance between generation and consumption. This also results in an incentive for subscribers – when they receive their monthly bill in their hand, or see it in their mobile app – to review whether they have the right equipment to, if possible, remedy the electricity grid even further.

Technical description of the power fee

Below is a more detailed description of each of the above points. The first two points are described under the same heading below.

The customer's footprint on the shared electricity grid

Formula 2 below is used to determine the subscriber's footprint (P_1) on the grid. The calculation is based on the subscriber's contracted connection power ($P_{Connection}$). The fee is then adjusted with respect to how the subscriber has acted in relation to the energy fee during the billing period. This is seen in Formula 2 where $I_{Energy\ fee}$ represents income and $C_{Energy\ fee}$ represents costs that a subscriber has through the energy fee during the billing period.

Formula 2. The result of the calculation below gives an initial power value (P_1) that represents the subscriber's footprint.

$$P_1 = P_{Connection}\left[1 - \frac{Sum\ (I_{Energy\ fee})}{Sum\ (I_{Energy\ fee}) + Sum\ (C_{Energy\ fee})}\right]$$

Since the contracted connection power marks the starting point for the power fee, it never constitutes an incentive for subscribers to reduce their power on the grid beyond this, which ensures that the grid can normally be fully utilized.

The valuation in part two of Formula 2 is based on the subscriber's summed income ($I_{Energy\ fee}$) and costs ($C_{Energy\ fee}$) in the energy fee. This provides an increased incentive for subscribers to acquire flexible capabilities, and to, for example, invest in generation in a utilization-dominated area or vice versa. Both flexibility and, for example, increased generation, as in the described case, contribute to a more balanced electricity grid, which reduces the need for imports or exports to/from more distant parts of the electricity grid – which is a **main argument** for these subscribers also paying a lower share of the costs for the shared electricity grid and the forward-looking costs.

The result of the distribution principle is also that the contracted connection power ($P_{Connection}$) alone forms the basis for the subscriber's footprint when the income from grid benefit compensations via the energy fee is missing. If, on the other hand, a subscriber has transferred corrective power, the footprint (P_1) is assessed to be lower.

Since the energy fee for straining transfers is normally very low, the generation and usage dynamics of the spot price and the grid area over time relative to the customer's capabilities will be the decisive factor in whether the footprint and thus the power fee will be lower. Whereas if corrective transfers are truly important for the electricity grid, there are increased opportunities for subscribers to recover the cost of investments in flexibility and, for example, battery storage.

Control for minimum fee

Assuming that a subscriber sees the value of being part of the electricity grid, the project wants the tariff to be designed to welcome everyone. With a minimum level, it is possible to create a prerequisite for this that also feels reasonable for the grid company and for other subscribers. This minimum size limit is related to the so-called *main argument* above, and can be philosophically associated with the fact that a subscriber is always dependent on a small part of the electricity grid. Its size can be compared to a micro grid, whose capacity is not non-existent but still significantly smaller than what would have been required for straining subscribers. However, the size should be linearly dependent on the subscriber's contracted connection power.

For cost-reflective reasons, it is conceivable that a minimum fee could also be deemed unnecessary. But if it is deemed necessary, it means that part of the power fee is assessed exactly as the fixed fee. This part of the power fee thus constitutes a fixed part of the power fee and corresponds approximately to a share m of the costs that are distributed.

Formula 3. The dimensioning power (P_1) has a minimum level relative to the contracted connection power. The formula's max function is based on choosing the highest value of what is in the brackets.

$$P_2 = Max\ (P_1; m \cdot P_{Connection})$$

The minimum level (m) together with the adjustment for customer category should, in the best case, result in the right incentive for the flexibility that is needed in the relevant part of the electricity grid.

Consideration of customer category

A simple adjustment mechanism (PF_{CC}) is used to adjust up or down the dimensioning power for the power fee. The mechanism allows for differences in the cost basis that are distributed with the power fee (PF_{Cost}) relative to different customer categories (CC). The adjustment results in the final dimensioning power (P_3).

Formula 4. Adjustment mechanism to compensate for the fact that different customer categories have different costs for the shared part of the electricity grid associated with their operations.

$$P_3 = P_2 \cdot PF_{CC}$$

It is up to the grid company to find the right adjustment values (PF_{CC}) for each customer category in accordance with applicable rules. These are saved and retrieved when used in a database.

On cost-reflective and objective grounds, the adjustment for customer category is made after the adjustment for the minimum level, so that the minimum level also becomes customer-specific. It is therefore always a profit for a subscriber to reach the minimum level, instead of a customer category adjustment lowering the level below the minimum level so that the minimum level instead becomes decisive.

Costs to be distributed with the power fee

The following three cost components shall be distributed with the power fee (see also Table 2 above):

1.2	Residual costs for shared part of the electricity grid
2.2.2	Non-controllable short-term variable costs in the shared part
4.2	Proactive forward-looking costs

Category 1.2 also includes power fees to other grids.

All these costs are summed up, which gives the cost to be distributed with the power fee (PF_{Cost}).

Final calculation of the power charge

The subscriber's power charge depends partly on how large the costs (PF_{Cost}) are to be distributed with the power charge, and partly on how large the subscriber's dimensioning power (P_3) is relative to the size of the sum of the other subscribers' dimensioning power ($Sum\ (P_3)$).

Formula 5. Distribution of the power charge costs takes place with respect to the individual subscriber's dimensioning power share relative to the summed dimensioning power of all subscribers.

$$PF_{fee} = \frac{P_3}{Sum\ (P_3)} \cdot PF_{Cost}$$

Fixed fee

According to Ei (2024), the fixed fee shall allocate all costs that are not customer-specific, forward-looking or short-term variable costs. This category of costs is called residual costs.

The minimum level of the power fee and the fixed fee described here constitute truly “fixed” fees in the project tariff. The project uses the subscriber’s connection power, which Ei also advocates, to allocate the cost of the individually used parts of the electricity grid (category 1.1). These parts are by definition not affected by how a subscriber uses the electricity grid, provided that they comply with their electricity contract.

As previously described, in practice, it is the costs of service cables to individual subscribers – which are not shared between different subscribers – that are included in the cost base together with non-controllable short-term variable costs in the individually used part of the electricity grid (2.2.1).

The distribution is based on the customer's contracted connection power, which can mean, for example, fuse size or subscribed power. Here too, the cost basis may be different for different customer categories.

Technical description of the fixed fee

Below is a simplified technical description.

Consideration of customer category

An adjustment mechanism (FF_{CC}) is used to adjust the fixed fee up or down. The mechanism allows for differences in the cost basis that are distributed with the fixed fee (FF_{Cost}) to be taken into account relative to different customer categories (CC). The adjustment results in the final dimensioning power (P_{FF}) for the fixed fee.

Formula 6. Adjustment mechanism to compensate for the fact that different customer categories have different costs for the individual parts of the electricity grid.

$$P_{FF} = P_{Connection} \cdot FF_{CC}$$

It is up to the grid company to find the correct adjustment values (FF_{CC}) for each customer category in accordance with applicable regulations. These are saved and retrieved when used in a database.

Costs to be allocated with the fixed fee

The following three cost components are to be allocated with the fixed fee (see also Table 2 above):

1.1	Individually used portion of residual costs
2.2.1	Non-controllable short-term variable costs in individually used portion

These costs are summed, which gives the cost to be allocated with the fixed fee (FF_{Cost}).

Final calculation of the fixed fee

The subscriber's fixed fee (FF_{fee}) depends partly on how large the costs (FF_{Cost}) are to be distributed with the fixed fee, and partly on how large the subscriber's dimensioning power (P_{FF}) is relative to the size of the sum of the other subscribers' dimensioning power ($Sum\ (P_{FF})$).

Formula 7. Distribution of the costs of the fixed fee takes place with respect to the individual subscriber's dimensioning power share relative to the corresponding summed dimensioning power of all subscribers.

$$FF_{fee} = \frac{P_{FF}}{Sum\ (P_{FF})} \cdot FF_{Cost}$$

Thus, all parts of the developed tariff model have been described.

Conclusions

The developed tariff carefully balances positive and negative incentives, with its capacity-based energy fee paving the way toward a more balanced grid. Achieving a balance between generation and utilization is always the ultimate goal, though stronger incentives for balance are only applied during periods of high load. Subscribers' footprints are measured both by how they respond to the energy fee's signals and by the size of their power connection. This footprint is then used to determine their share of the costs for the shared grid, directly influencing the largest component of their grid fees. As a result, the project's tariff does not restrict energy use unless there is a clear need to do so.

In this way, the project's electricity grid tariff complements flexibility incentives driven by the electricity trade market. The result is a significantly more efficient energy system that supports decentralized, variable energy production and utilization, fostering an energy system that is more decentralized and economically, socially, and environmentally sustainable.

Possibilities with dynamic grid tariffs

The project shows that it is entirely possible to use dynamic capacity-based electricity grid tariffs from a technical point of view. The result is also expected to contribute to efficient grid utilization. A contributing reason for this is that the project's grid tariff does not affect subscribers unnecessarily, while there are strong incentives to act for flexibility when it is really needed.

Differences from traditional models

The designed grid tariff differs significantly from how traditional grid tariffs are designed. The project's tariff is based on artificial intelligence learning what the station load for the coming day will look like. Based on this, time- and location-specific price signals are calculated, which provides incentives to solve real challenges in a cost-reflective manner.

Social benefits and fairness

From a social context, it is shown that all subscribers are given an opportunity to participate in maintaining balance in the grid. Expanded opportunities are also given to be part of the energy transition, while costs are expected to be distributed fairly. Even though the model is complex, it is no more difficult than following the spot price. The project advocates automation as the only possible way to balance the electricity grid. With these conditions, subscribers will need to be even less involved in managing their energy needs in the future.

Need for regulatory adjustments

Based on the results, the project sees reason to review the regulations so that, among other things, location signals will be allowed in local and regional grids. Otherwise, Ei's regulation for the design of electricity grid tariffs is very well thought out and good. This is also basically the reason why the project's grid tariff basically follows the regulations. It remains to be seen whether the project receives support in the image that the footprint as an allocation method is approved for the allocation of residual costs.

Expected effects of the model

- Continued opportunity for subscribers to participate in the spot price market.
- Existing and future flexibility can also be used to balance the electricity grid.
- Reduced need for electricity grid expansion, which strengthens electrification.
- Increased demand for green renewable energy.

- Lower economic and resource costs through efficiency improvements.

Possible challenges

A certain level of digitalization and metering is required to make it possible to use the designed electricity grid tariff. One challenge is that it takes a certain amount of time to initiate new grid areas. The project naturally hopes that the entire electricity grid uses cost-reflective and time- and location-specific price signals, even if this transition will take time.

Since the price signals vary dynamically, higher demands are placed on subscribers. Trying to control manually may be possible for individual subscribers, but for the broad mass, automated flexibility is required. This additional requirement for automation and technical conditions will create gaps between different consumer groups, which means a need for extra efforts from society.

The increased digitalization can mean increased vulnerability. When using a smart grid tariff in critical situations, it is therefore necessary to have a plan B in case something goes wrong. For example, an AI can design forecasts that extend even further into the future. If this also fails, a traditional grid tariff can be used. A third solution is to use the fact that only a relatively short power line separates the transformer from the subscriber. In cases where the usual price signal fails, the transformer balance would then be transmitted directly to avoid excessive imbalances and risks of damage.

More likely, this will be with increased dynamics in the future. Could quarter metering be reduced to 5 minutes or even less? It would also be possible to give each customer completely unique price signals. However, the project does not see a need for this. The spatial distribution that the project uses should be well balanced to provide the right control signals. However, longer forecasts can allow the control of flexibility to be optimized in a better way.

Recommendations and next steps

The project already combines the spot price with its price signals. The next step is to also include trading in flexibility. Furthermore – if grid companies have been allowed to control subscribers to manage electricity quality – new signals could be included directly in the tariff control signals.

The first part of the project will be completed at the end of January 2025, shortly after this report has been published. The second part of the project, Tariff 2.0, will then begin. The tariff will then be rigorously tested on the test pilot companies that have been equipped, and with the system that has been calibrated.

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