A Capacity Based Tariff

Hand-out made for Almedalsveckan 2024

Gotland tariff project, 2023-2025
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Magnus and Carl next to the distribution station in Östergarn, Gotland

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Content

1. Fixed fee components

In this section, annual rated power (Swedish: *värderad årseffekt*) and capacity based annual power (Swedish: *kapacitetsreflektiv årseffekt*) will be presented. Only the latter (II.) will be tested live in Östergarnslandet, Gotland.

I. Annual Rated Power

This is the older proposal coming out of the TariffGotland project, but where the annuality has been added to make sure the most dimensioning situations of the year are reflected in the fixed fee. This fee is also capacity based.

This component will not be tested directly against the test pilots. However, the concept may be theoretically evaluated at a later stage.

In short, the idea with annual rated power is to (1) rate all transfers according to their impact on the grid in a geographical and timely manner. This results in higher ratings for customers in weaker grids (who generally have higher load factors). Thus, for a fair distribution of fixed costs, the first rating needs to be combined with a second (2) rebate rating, which is linked to the average load (X_N) in the node to which the customer is connected.

Combining the two rating methods and to arrive in a cost-reflective and fair distribution, could become a difficult task.

Definitions:

- d_L, the limit value for dimensioning load (here 0.75). The grid is within dimensioning loads when $|x_N| \geq d_L$.
- x_N, the load in the node (observe, small x): -1 at maximum production, and +1 at maximum consumption.
- h_{DL}, the adjustment parameter for the rating 1 function to adjust the boundary condition $f_1\,(x_C = -d_L) = h_{DL}$. I.e. the rating 1 value at the limit for dimensioning load for corrective transfers.
- $X_{N,Y}$, the annual average load based on absolute values of x_N
- *E*, the customer's net transferred energy (consumption minus production) over a measuring period: With *E < 0*, there is net production, while with *E > 0*, there is net consumption.
- S_Y is the number of smart meter measuring periods for year Y
- t is the length of a single measuring period
- L_{adj} is an adjustment parameter used in the rating 2 function. The value 1 is used here.
- m_R is the maximum rebate value used in the rating 2 function. The value 0.6 is used here.

Rating 1 – Step by step

When a new month has passed, the following calculations are made.

The first steps are to find the rated power P_R value for each quarter-minute (or half-hour) for the new month, select a new set of maximum rated power measurements (e.g. 12) for the new yearly range, and then calculate the average maximum rated power P_1 from these.

1. Find the customer specific load factor , x_C for each measured period

   If $E = 0$, then $x_C = +|x_N|$

   Else, $x_C = x_N \cdot \frac{E}{|E|}$

2. Find the rating 1 function value for each measured period

$$f_1\,(x_C) = \frac{(1-h_{DL})}{2d_L}x_C + \frac{1+h_{DL}}{2}$$

The linear function is based on the following boundary conditions

$$f_1\,(x_C = +d_L) = 1$$

$$f_1\,(x_C = -d_L) = h_{DL}$$

The rating 1 function looks like in figure 1 below, where $h_{DL} = 0$.

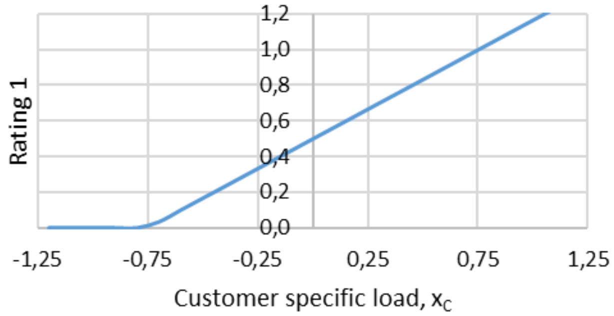

Figure 1. The rating 1 function, f_1 when $h_{DL} = 0$.

3. Find the rated power, P_R for each measured period

$$P_R = \frac{|E|}{t} \cdot f_1\,(x_C)$$

4. Find the average maximum annual rated power, P_1 for the new yearly range. Here we choose to select 12 maximum ratings. The size of the selection will have large impact for connections used seldom and for flexible users who then will have fewer degrees of freedom with a smaller selection size.

$Selection_{Max}$ = Maximum 12 transfers from P_R-column within the new yearly range

P_1 = Average ($Selection_{Max}$)

Rating 2 – Step by step

Next after the P_1 value has been calculated, the result is rebated via the rating 2 function in order to restore an otherwise unfair cost distribution between customers in weaker and stronger grids.

5. Find the new annual average load factor, $X_{N,Y}$

$$X_{N,Y} = \frac{1}{S_Y}\sum_Y |x_N|$$

Where S_Y is the number of measuring periods for the new annual range.

6. Find the rating 2 function value

$$f_2\,(X_{N,Y}) = L_{adj} \cdot \frac{h_{DL}-1}{2d_L} \cdot X_{N,Y} + 1$$

Where L_{adj} is an adjustment parameter.

The following boundary conditions has been used,

$$f_2(0) = 1$$
$$f'_2(X_{N,Y}) = -f'_1(x_C)$$

The rating 2 function looks like in figure 2 below, given that $h_{DL} = 0$ in the rating 1 function and where $L_{adj} = 1$.

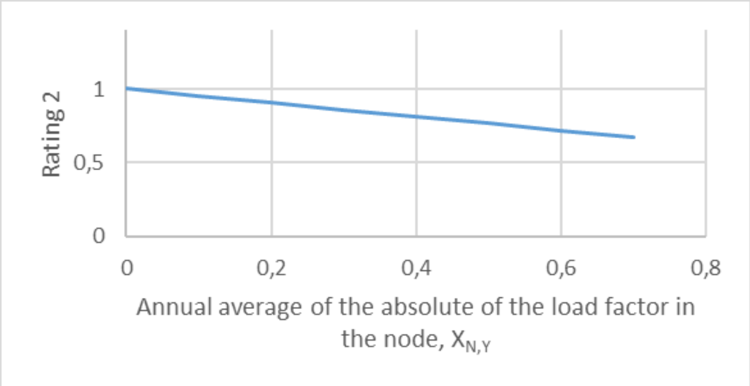

Figure 2. Rating 2 function. The slope can be adjusted in comparison with the negative of the slope in the rating 1 function via L_{adj} (set to 1).

7. Find the final rated and rebated annual power value, P_2

$$P_2 = P_1 \cdot f_2(X_{N,Y})$$

This value (P_2) can be used as a single basis to distribute residual costs, or in a combination with another fee (most basic would be to use a fuse fee or a subscription fee) if this fee is smaller than what would be motivated as a cost-reflective minimum charge. However, to reach zero cost with this method is practically impossible. Facilities who use the grid during fewer than 12 measuring periods during a year will have a reduced fixed cost.

For a more developed complementary solution, see how the minimum-fee question is solved for the next conceptual fixed fee method.

II. Capacity Based Annual Power

In short, the capacity based annual power fee is based on the average value in kilowatts (or kWh/h), of the size of the transmissions that constitute the highest 5 percent made during any of the 5% most dimensioning quarter minutes (or half hours) of the year, for the node to which the customer is connected.

A minimum level for the fee is necessary to ensure a fair distribution of costs and to reflect minimum costs for the grid. A quota is therefore calculated and compared with a determined minimum value to make sure all customers will contribute with a fair share of the fixed fee.

In this way, the fee will (1) reflect that imbalances in the electricity grid mean that larger parts of the electricity grid will be used, and (2) that however flexible you are, there are still some parts of the grid which are necessary and which comes with a minimum cost.

Definitions

- x_N, the load in the node (observe, small x): -1 at maximum production, and +1 at maximum consumption.
- *E*, the customer's net transferred energy (consumption minus production) over a measuring period: With $E < 0$, there is net production, else there is net consumption.
- t is the length of a single measuring period
- P_L, the customer power load: With $P_L < 0$, the transfer is corrective. Else it is a straining transfer.
- P_S, annual average selected straining power
- P_{Max}, annual average maximum power, including a percentage (here 0,25%) of all transfers of the year, both corrective and straining power
- Q_C and Q_{min} are quotas to ensure a fair and cost-reflective minimum fixed fee, where Q_C is the customer based quota and Q_{min} is the minimum quota (here 0,4) determined by the DSO
- FF, the customers capacity based fixed fee

Calculate annual average straining power, P_S

1. Select 5% of the quarter minutes of the year when the <u>local</u> grid (node) has the highest load level (x_N). Of a year's approximately 35,063 quarter minutes (or 17,532 half-hours), approximately 1,753 quarter minutes (877 half-hours) should be chosen. Each new month means that the last month is added, and that the oldest month falls away from the data.

   Selection_N = Query in all annual node x_N results for $\text{Max}_{5\%}$ ($|x_N|$)

2. Of these quarter minutes (half hours), only the 5 percent of measurements are again selected at the customer's site, where the customer has transferred the most straining energy. Of 5% of 5% of all the quarter minutes of the year (half hours), about 88 (44 half hours) remain in the sample.

   a. Find the customer power load (P_L) for each measured period

   $$P_L = \frac{E}{t} \cdot \frac{x_N}{|x_N|}$$

   If $P_L \geq 0$ then the transfer is straining, else it is a corrective transfer.

   b. Select the 5% highest P_L values within *Selection$_N$*

   $$Selection_L = Max_{5\%}(P_L \ within \ Selection_N)$$

A smaller *Selection*$_L$ size results in a lower degree of freedom for customers to influence the fee. Here the size is chosen to be 5% which correspond to approximately 88 quarter-minutes or 44 half-hours of the year.

3. Calculate the annual average straining power (P_S), in kW or kWh/h.

$$P_S = Average(Selection_L)$$

Calculate average maximum power, P_{Max}

4. Of all quarter minutes (half hours) of the year, select the 0.25% (i.e. the same selection size as above) highest power transfers at the customer's site, where the customer has transferred the most energy, regardless if it is corrective or straining power. From 0.25% of all the quarter minutes of the year (half hours), about 88 (44 half hours) remain in the selection.

   c. Find the customer power (*P*) for each measured period

$$P = \frac{|E|}{t}$$

   d. Select the 0.25% highest *P*-values of the year

5. The average of the above selection yields P_{Max}

Determine the customers fixed fee

6. Calculate the customer based quota

$$Q_C = \frac{P_S}{P_{Max}}$$

7. Select fixed fee

   a. If $Q_C \geq Q_{min}$, then use $P_{FF} = P_S$ as a basis for the fixed fee

   b. Else if $Q_C < Q_{min}$, then use $P_{FF} = P_{Max} \times Q_{min}$ as a basis for the fixed fee

8. The customer's capacity based annual power fee is calculated.

   The customers' monthly updated fixed fee (FF),

$$FF = P_{FF} \cdot \frac{Total\ residual\ costs\ (group)}{Sum_{Group}\ (P_{FF})}$$

The capacity based annual power fee should be complemented with an extended grid benefit (in Swedish: *utökad nätnytta*) for corrective transfers in the energy fee in order to push enthusiastic users to invest in flexibility and reduce for its neighbours the only costs which are more expensive in weaker grids – the energy fee costs.

2. Capacity based energy fee with extended grid benefit compensation

The proposed capacity based energy fee *without* an extended grid benefit compensation (Swedish: *nätnyttoersättning*) would (also) compensate for corrective transfers, but only when the load level in the closest node is dimensional, i.e. $|x_N| > d_L$. With the extended grid benefit compensation, there will be additional/earlier incentives to act flexibly and remedy problems on the electricity grid during periods of higher loads. The purpose is to provide an exclusively positive chance for customers in weaker electricity grids to both lower their own costs and to let them collectively invest in a more balanced, secure and robust local electricity grid. This will help to lower all user's costs.

The current test pilot can only analyse the middle and low voltage grid on Östergarnslandet, Gotland. The day ahead forecast for the load level (and price signal) is therefore limited in comparison with the optimum situation where the load level would reflect all parts and congestion issues in the wider grid.

Formulas for corrective and straining transfers

The weekly average of the absolute load level in a node ($X_{N,W}$) determines in short term how well the power grid copes with straining loads. The weaker an electricity grid, the higher the extended grid benefit compensation will be. This weekly average load level in the node is a moving average representing either a period from 6 days back in time, and including the day ahead forecasted load levels $|x_N|$ – or a period 7 days back in time (without the forecasted load levels). If including the day ahead forecast in the weekly average, calculations of the load level forecast may be too complex and computer power intensive.

*Formula 1. The average weekly load level in the node makes sure that a complete set of weekly changes are represented in the extended grid benefit compensation. Choosing a weekly average, sets W (below) to 7*24*2, if the measurement period is 30 minutes.*

$$X_{N,W} = \frac{1}{W}\sum_{i=1}^{W}|x_N|$$

The variable x_N is calculated by the AI-system and represents the actual load in the node, which is negative if the dominant load is because of production (-1 is the capacity roof). Else if the load level is positive, consumption is the dominant load (+1 is the capacity roof).

When signals from a wider area are included to take into account all relevant congestion issues in the grid, an adjusted load level will be used for the price signal.

The weekly average load level in the node ($X_{N,W}$) calculated using Formula 1, is used in Formula 2 to set the extended grid benefit compensation level.

Formula 2. The formula for corrective transfers with extended grid benefit compensation "as needed". Parameters a, c, d, d_L and k can be adjusted for cost-benefit reflectiveness. The calibration parameter k can be increased to generally increase the extended grid benefit compensation.

$$f_A(x_N, X_{N,W}) = -a\left[e^{b(|x_N|+c)} - \left(1 - \frac{|x_N|}{d_L}\right)e^{bc}\right] + d \cdot \left(1 - |x_N| \cdot X_{N,W} \cdot e^{kX_{N,W}}\right)$$

Note that parameter d is fixed in the formula for straining transfers (Formula 4 below), where it adjusts the base level of the resulting price curve. But in the formula for corrective transfers (Formula 2 above), the "base level" has a more complex dependence to allow for an extended grid benefit compensation.

Formula 3. The parameter b in formula 2 has the following dependence on the other parameters in order for the grid benefit compensation $f_A(x_N, X_{N,W})$ to be applied exactly at the limit for dimensioning load (d_L). This dependence is used for tuning the curves even though the given presumption (i.e. the first sentence in this paragraph) will only be valid when $X_{N,W} = 0$.

$$b = \frac{ln\left(\frac{d}{a}\right)}{d_L + c}$$

It is also possible to use Formula 3 directly in Formula 2.

In order for the formulas for corrective and straining transfers to meet exactly when $x_N = 0$ and for them to be exactly mirrored (which they are only when $X_{N,W} = 0$), the previous formula for corrective power is supplemented with the expression $-\left(1 - \frac{|x_N|}{d_b}\right) e^{bc}$ according to formula 4 below.

Formula 4. Formula for straining power. This curve goes upwards with increased load levels.

$$f_B(x_N) = a\left[e^{b(|x_N|+c)} - \left(1 - \frac{|x_N|}{d_L}\right) e^{bc}\right] + d$$

Visualization

With the parameter values below, the curves shown in Figure 1 and 2 are obtained. The figures show straining transfers $f_B(x_N)$ and corrective transfers $f_A(x_N, X_{N,W})$, where the latter is shown as the weekly average for the node's load level X_N is varied between three values.

$$\begin{cases} a = 0{,}2 \\ c = 0{,}1 \\ d = 25 \\ d_L = 0.75 \\ \rightarrow b = 5.680 \\ k = 2 \\ X_{N,W} = 0, 0.4, and\ 0.6 \end{cases}$$

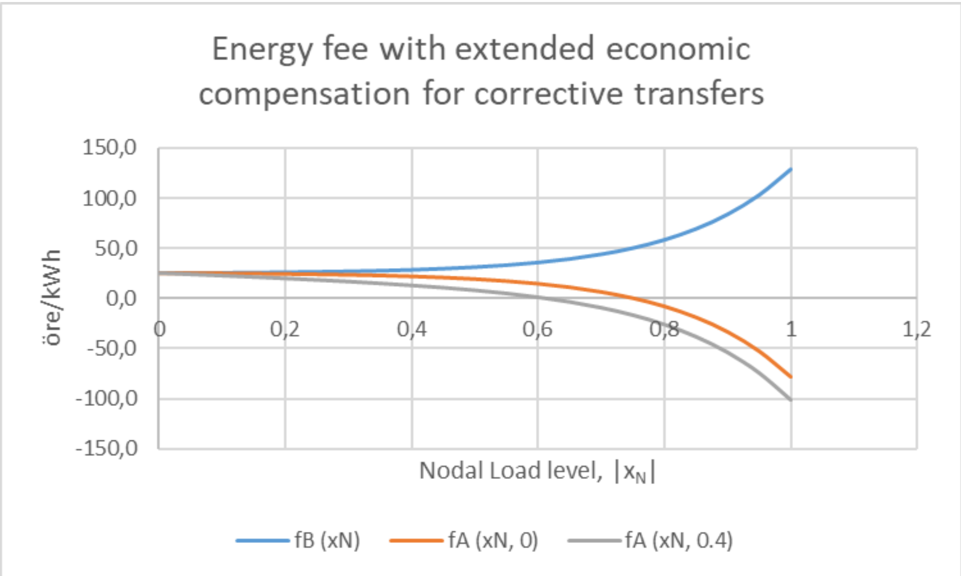

Figure 3. As the weekly average load level in the node ($X_{N,W}$) rises, the cost/compensation curve for corrective (Swedish: Avhjälpande) transfers becomes increasingly advantageous for flexible customers.

Figure 1 shows that customers in a node with an average load level ratio of 0.4 (grey line) receive a more advantageous – extended – grid benefit compensation compared to a node with an average load level of 0 (orange line). The straining (Swedish: *Belastande*) transfer curve (f_B) is not affected by the weekly average load level.

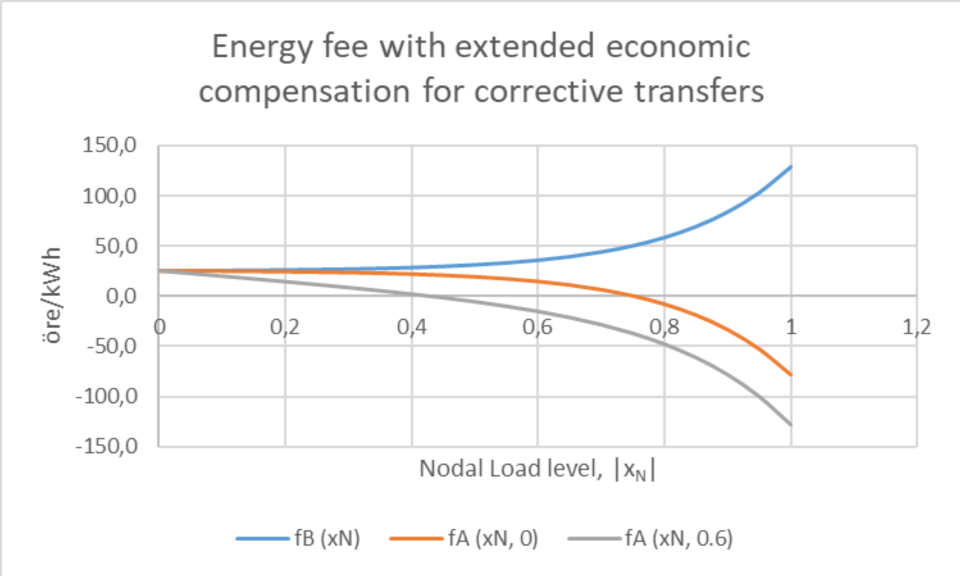

Figure 4. In comparison with figure 1, the weekly average load level is increased to 0.6, which gives an even more advantageous extended grid benefit compensation for flexible customers. In order for the change with respect to this weekly average to be desirable, the calibration parameter k is used (see formula 2).

As the average load level decreases, the extended grid benefit compensation decreases. However, as the need for flexibility resources in the local grid decreases, they can instead join flexibility markets to satisfy needs on the more central parts of the grid.