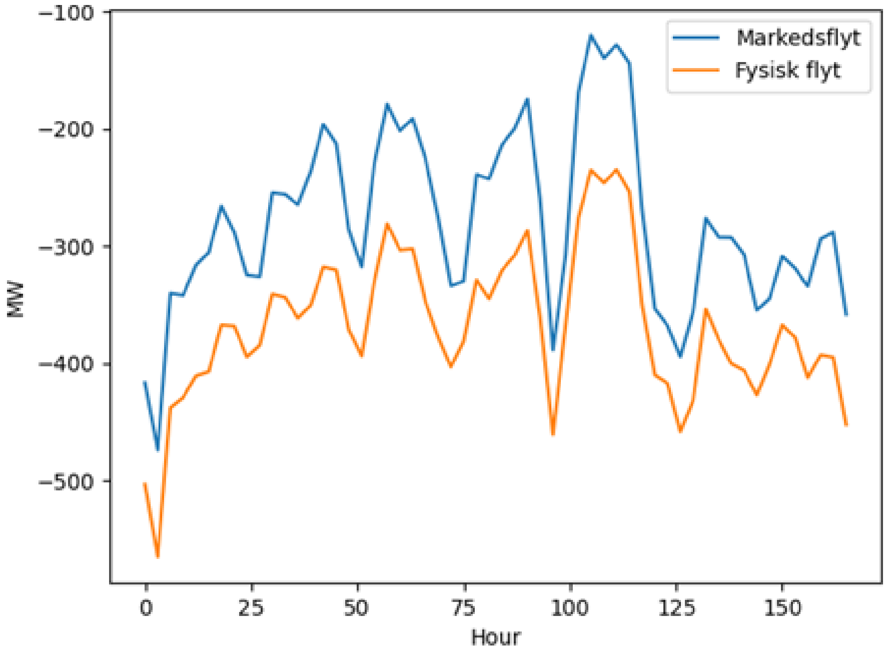

Report

Analysis of flow-based parameters in IPN Vannfly

Project results

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Report No:

2024:00072 - Unrestricted

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KEYWORDS
Flow-Based Market Coupling
Remaining Available Margin
Power Transfer Distribution Factor

VERSION
1.1

DATE
2023-12-11

AUTHOR(S)
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CLIENT(S)
IPN Vannfly

CLIENT'S REFERENCE

PROJECT NO.
502002632

NO. OF PAGES
16

SUMMARY
This report is written as part of the project IPN Vannfly. The goal is to analyze what data is necessary to perform good market analysis in the FBMC capacity calculation methodology. The topic of this report is the formation of the parameters defining the flow-based constraints, and two ways of including flow-based grid constraints in a market model.

The difference between using a detailed grid description and using exogenous grid constraints is the core challenge of adapting to FBMC. The market actors in the Nordic region do not have access to a detailed grid description. Instead, it is expected that they will use exogenous grid constraints published by the TSOs, which are created using a detailed grid description.

The FBMC methodology is better for predicting physical flow than the NTC methodology, but it is using an aggregated area approach, which requires linearizing the constraints around a predicted base case. This works well in practice, since the predicted base case is usually quite accurate, but the validity of the constraints for different market situations, and as input to market models, is uncertain.

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REPORT NO.
2024:00072

ISBN
978-82-14-07145-0

CLASSIFICATION
Unrestricted

CLASSIFICATION THIS PAGE
Unrestricted

Document history

VERSION	DATE	VERSION DESCRIPTION
1.0	2023-08-21	Draft for checking
1.1	2023-12-11	Final version

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1 Introduction

This report is written as a part of the project IPN Vannfly[1]. It describes the analyses of the main parameters in flow-based market coupling: Power Transfer Distribution Factors and Remaining Available Margin.

The background for the project is the introduction of Flow-Based Market Coupling (FBMC) as the new capacity calculation methodology (CCM) in the Nordic region. FBMC will improve utilization of the grid by better representing the physical flow of power in the grid, but it will also make long-term market analysis more complicated. The goal of IPN Vannfly is to understand what type of information market participants need, in order to perform good market analysis within the new CCM.

The NTC approach limits the direct trade between each pair of bordering areas, while the grid constraints in FBMC limit the flow on each Critical Network Element (CNE) in the grid. The grid constraints in FBMC are defined by two parameters: Power Transfer Distribution Factors (PTDFs) and Remaining Available Margin (RAM). PTDFs describes how the flow from each area is distributed on the CNEs in the grid. RAM is the capacity on the CNEs.

Both PTDFs and RAM are dependent on the grid topology on a nodal level. Since market participants as of today do not have access to a full detailed grid description for the whole Nordic system, they rely on the flow-based domain parameters that are published by the Nordic TSOs. However, to perform long-term market analysis, actors need to forecast these parameters beyond the time-horizon and level of detail provided by the TSOs. It is important to have a thorough understanding of these parameters and what affects them. The aim is to address this knowledge gap based on the analyses described in this report.

This document is structured as follows: First, in section 2, we look at RAM variations in a grid with a stable topology, and the effect of area-PTDFs on RAM. Next, in section 3, we discuss the importance of good generation shift keys (GSK) and compare different GSKs in a fundamental market model. Finally, in section 4, we report how grid constraints from a detailed grid model can be used as input to a model with exogenous grid constraints.

[1] NFR 309413

2 Variability of RAM

2.1 Detailed grid vs. exogenous constraints in FanSi

The fundamental power market model FanSi was used for the analyses in the project [1]. There are two ways to include flow-based grid constraints in FanSi: 1) with a detailed grid description, or 2) by supplying exogenous constraints on flow directly, cf. Figure 1 and Figure 2. The main difference is that when using a detailed grid description, the PTDFs and RAM on each CNE is calculated for each time step by taking into account the system dispatch and a detailed DC-power flow. A consequence of performing this calculation / adjustment is that RAM on each CNE will vary from timestep to timestep due to change in system dispatch. Additionally, when using a GSK strategy that considers expected production and/or load, the PTDF matrix will also be constantly changing.

On the other hand, when using exogenous grid constraints, it is not possible to take system dispatch into account. It is possible to define different constraints for each timestep. However, then it is difficult to justify why the constraints are changing, since the market solutions are not known in advance.

Figure 1 and Figure 2 show flowcharts of how flow-based grid constraints are considered in the power market model FanSi for the detailed grid model and the exogenous grid model respectively. Beside the different implementation, a different set of input data is required for both alternatives.

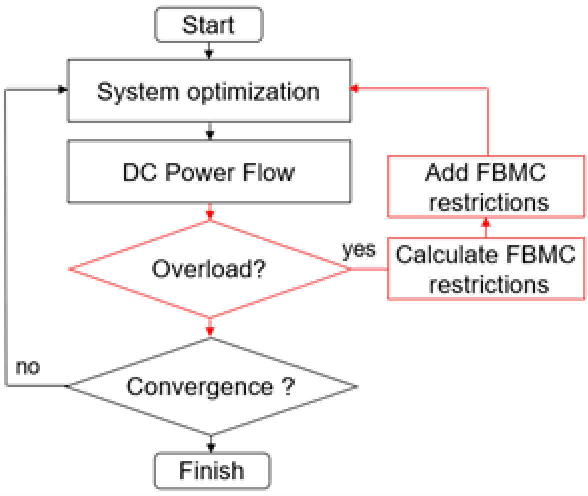

Figure 1 Flowchart grid constraints with detailed grid description

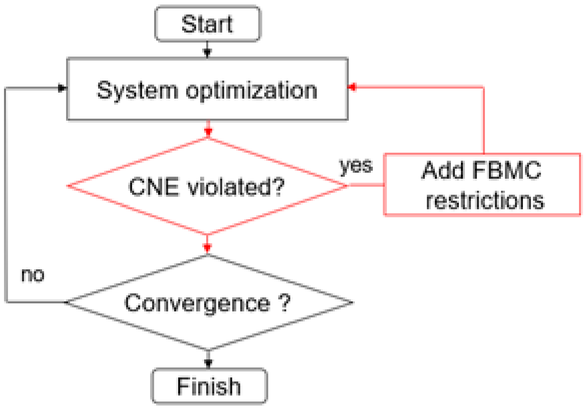

Figure 2 Flowchart exogenous grid constraints

2.2 Physical flow and Market flow

Within FBMC the flow on a network element is calculated from the PTDF matrix and the net positions in the synchronous area. The flow calculated on an element will usually be different depending on whether one is using nodal PTDFs and nodal net positions, or if one is using area PTDFs and area net positions. The flow calculated with nodal PTDFs is shown in equation (1) and will be referred to as the physical flow in the following. In equation (3) area PTDFs are used, and the resulting flow is referred to as market flow. In both equations, A is the set of all areas in the synchronous area, and N_a is the set of all nodes in area a.

The computation of nodal and area PTDFs, as used in (1) and (3) is further described in [2].

$$Flow_l^{nodal} = \sum_{a \epsilon A} \sum_{n \epsilon N_a} NP_n * PTDF_{n,l} \tag{1}$$

$$NP_a = \sum_{n \epsilon N_a} NP_n \tag{2}$$

$$Flow_l^{area} = \sum_{a \epsilon A} NP_a * PTDF_{a,l} \tag{3}$$

Figure 3 illustrates the physical and market flow for a single week on a line between the model areas Sver-NN2 (SE2) and Sver-Midt (SE3). Figure 4 shows the same for the line between Vestmidt (NO5) and Norgemidt (NO3). The figures show a difference between the physical and the market flow, especially on the interconnection between NO5 and NO3. The deviation in flow is due the linearization done in FBMC.

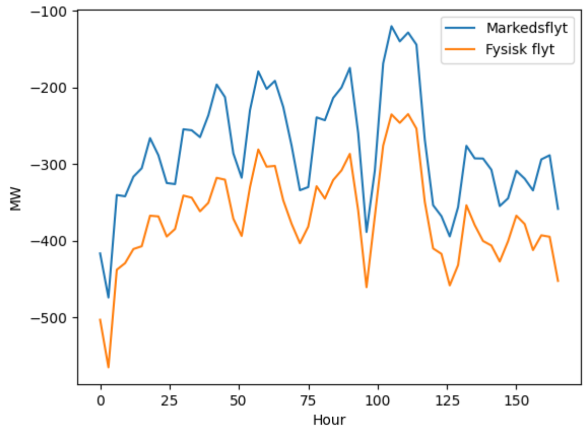

Figure 3 Comparison physical flow and market flow on the line from Vestmidt to Norgemidt

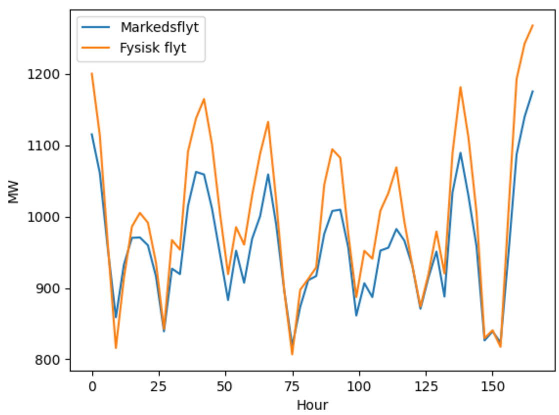

Figure 4 Comparison physical flow and market flow on the line from Sver-NN2 to Sver-Midt

2.3 Flow deviation

Figure 5 shows the relationship between flow, net position and RAM in the FBMC methodology [2]. By setting the Final Adjustment Vanlue (FAV), and Flow Reliability Margin (FRM) to zero and using DC Load Flow instead of AC load flow, we can calculate RAM by equation (4). This equation is used in the model with detailed grid description. This means that Fref' is equal to the difference between F^{nodal} and F^{area}. For the rest of the report this difference will be refered to as 'flow deviation'. Since RAM is directly dependent on the flow deviation, it is important to understand what causes the flow deviation.

$$RAM = F_{max,l} - F'_{ref} \; = F_{max,l} - \left(F_l^{nodal} - F_l^{area}\right) = F_{max,l} - Flow\ deviation \tag{4}$$

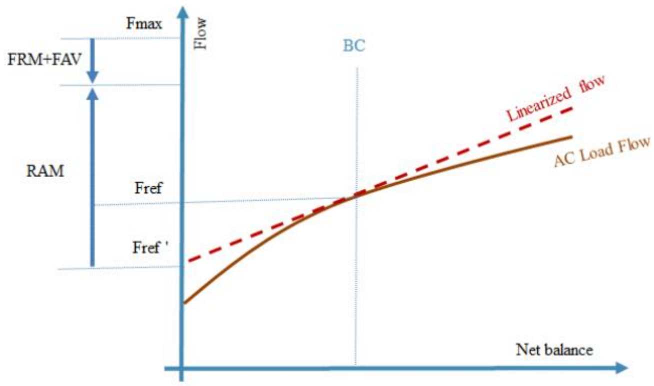

Figure 5 Relation between flow, net position, and RAM, BC is the flow in the base case [2]

2.4 Finding a good area PTDF

It is possible to find the contribution to the flow from each area on a line by omitting the outer summation in equations 1 and 3. The difference between the contributions to physical flow and market flow, gives the contribution to flow deviation. Figure 6 shows the contributions from each area on the line from Vestmidt (NO5) to area Norgemidt (NO3). In this case the largest contribution to flow deviation stems from Norgemidt (in gray), while the contributions from the other areas are much smaller.

The contribution to the flow deviation for an area indicates how well the area PTDF represents the nodal PTDFs in the area. The area PTDF is a weighted average of the nodal PTDFs, based on the GSK. Hence, if all nodal PTDFs in an area were equal, the area PTDF would be the same. Then the area PTDF would represent the nodal PTDFs exactly and the flow deviation from that area will be zero. On the other hand, if there is a large span in the nodal PTDFs, it is difficult to choose/calculate a representative area PTDF. Thus, the flow deviation might be significant. Mostly, the largest variations of the nodal PTDFs are found in the areas located geographically near to the lines, which also means that contributions to flow deviation will be larger for nearby areas.

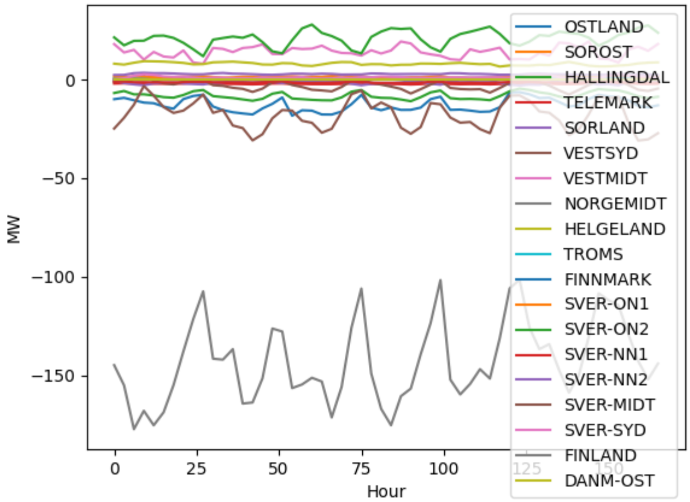

Figure 6 Contribution to flow deviation on the line from Vestmidt to Norgemidt by area

The flow deviation from an area depends on which area PTDF is chosen for that area. Figure 7 shows the nodal PTDFs for all the nodes in SE3 on the area border between the model areas SVER-NN2 (SE2) and SVER-MIDT (SE3). Within the same area, the nodal PTDFs range from -0.02 to 0.49. Any area PTDF in that range could be considered reasonable. The chosen area PTDF depends on the selected Generation Shift Key (GSK). A GSK is an aggregation scheme that determines how each nodal PTDF is weighted within each area to arrive at the area PTDF. Many different weighting strategies are possible. The simplest is usually referred to as a flat GSK, where the area PTDF is calculated as the average of all the nodal PTDFs. Other GSKs usually have the objective to weigh nodal PTDFs based on how large the net position in the node is expected to be, or by how variable the net position in a node is. This gives an indication of how much the node can affect the flow on the network element.

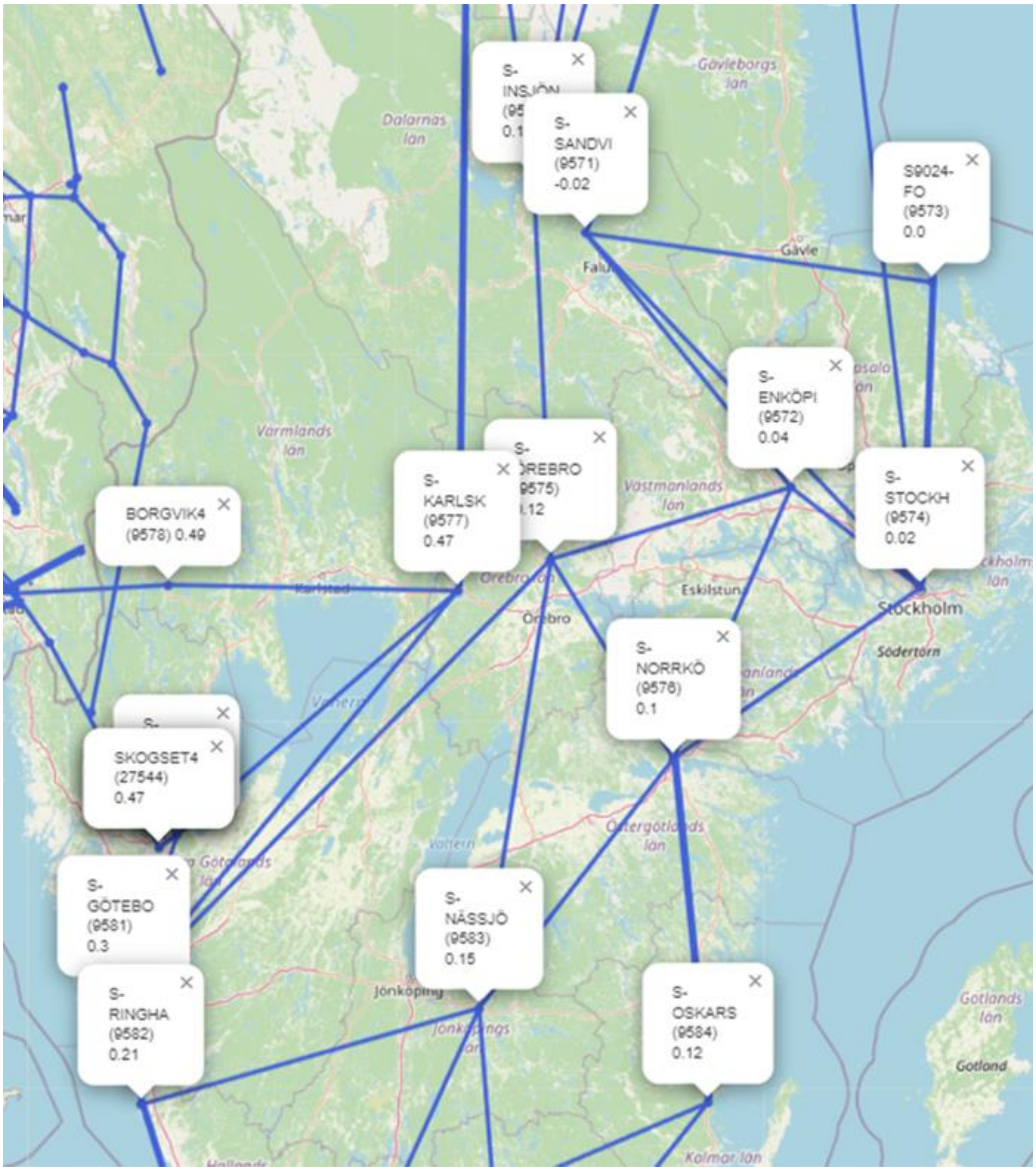

Figure 7 Nodal PTDFs in Sver-Midt for the line between Sver-NN2 and Sver-Midt

Error! Reference source not found. shows the flow deviation from Sver-Midt on the line between areas Sver-NN2 and Sver-Midt for a single week, with a range of different area PTDFs. Looking at the figure, it is not obvious that any of the area PTDFs are a better fit than the others. In OSTLAND, the nodal PTDFs are more equal and therefore easier to determine the best area PTDF, shown in **Error! Reference source not found.**. An area PTDF of 0.52 will give a flow deviation that is both close to zero and has low variability.

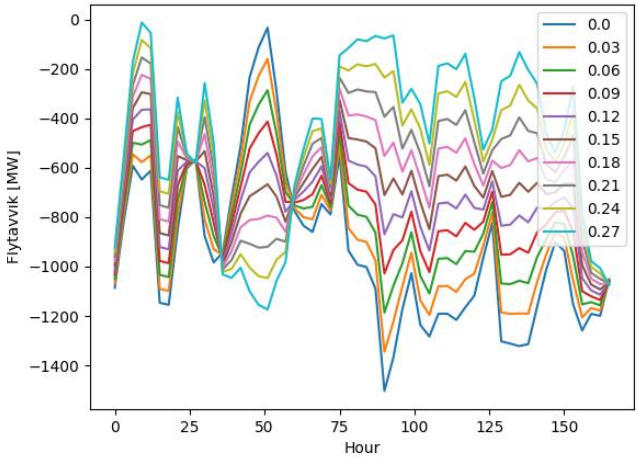

Figure 8 Contribution to flow deviation on the line from Sver-NN2 to Sver-Midt for area PTDFs in Sver-Midt from 0 to 0.27

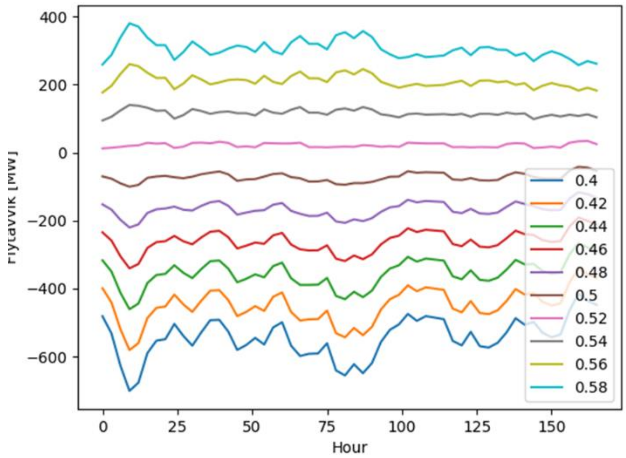

Figure 9 Contribution to flow deviation on the line from Sver-NN2 to Sver-midt for area PTDFs in Ostland from 0.4 to 0.58

The contributions to flow deviation from an area can be divided further to examine the impact of individual nodes in an area. The contribution from a single node is given in equation 5. It is determined by two factors: the net position of the bus, and the difference between the nodal PTDF and the area PTDF.

$$Flow\ deviation\ for\ node = (PTDF_n - PTDF_a) * NP_n \quad (5)$$

Nodes with a higher net position will have a bigger impact on the flow deviation. Especially nodes with high variations of net position can potentially be the cause of large variations in RAM. For this reason, it could be a good idea to weight some of the nodes in an area more heavily when selecting the area PTDF. In Figure 11 the net positions of all the nodes in Norgemidt for the for the first week is plotted. A few of them have very large net positions and will have a high impact on the contribution to the flow deviation from the area.

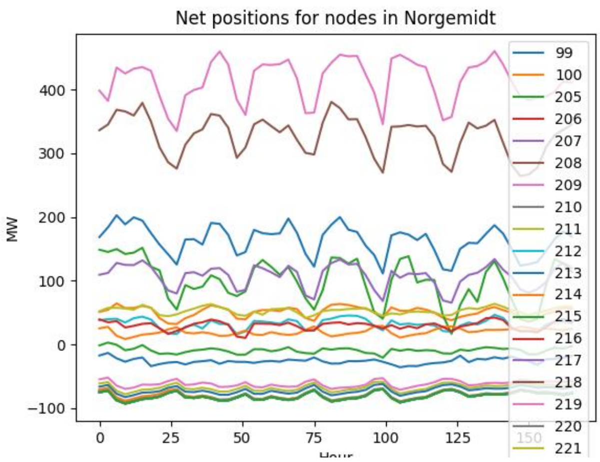

Figure 10 Net positions for nodes in Norgemidt

Dividing the existing price areas into smaller areas or separating out large power plants and loads could give better area PTDFs. This would create more accurate price signals by considering grid constraints on a finer resolution and reduce the variability of RAM. The final resolution would be a nodal description of the system. Within the Nordic FBMC methodology, HVDC cables with their implicit high point-load are planned to use nodal PTDFs.

3 What is a good GSK?

An interesting question regarding area PTDFs (and in turn GSKs) is what criteria they should be evaluated on. Area PTDFs should represent the nodal PTDFs in their respective areas. However, in cases where there is a wide range of nodal PTDFs, this is challenging. While the criterion could be to minimize the flow-deviation, this is not necessary since RAM is calculated with an offset to account for this difference. Other criteria could be to reduce the variation of flow deviation, and therefore also RAM, as much as possible. For a market participant this would be convenient, as it would be easier to know which RAM values to use as input to the power system models. Thus, the level of uncertainty in the input data would be reduced. But, from the perspective of the system operator (TSO), the variation of RAM is not an issue. Instead, the system operator cares about getting the predicted flow of a given GSK strategy as correct as possible, accounting for possible differences between their predicted market solution and the possible market solutions that could be realized at market clearing. To understand this difference, we need to look a bit closer at the process of operational FBMC.

3.1 In system operation

During system operation there can be a significant difference between the Base Case (BC), which is the forecasted market solution two days in advance, and the actual Market Solution (MS), which is cleared day-ahead. The forecasted Base Case is used along with a grid model and a GSK to calculate RAM on each critical network element. This results in the flow-based domain which is given to the market. The relationship between Base Case, realized Market Solution and PTDF is illustrated in Figure 11. Based on different GSK strategies, there exist different types of PTDF methods, such as average (black line) and marginal PTDF (red line). This also results in a different set RAM as described in equations (5) and (6).

$$RAM_{avg} = F_{max,l} - F'_{ref_{avg}} \tag{5}$$

$$RAM_{marg} = F_{max,l} - F'_{ref_{marg}} \tag{6}$$

If the Base Case is accurate, i.e., forecasting the Market Solution precisely, any type of PTDF will give the same flow since RAM will change to correct for the different PTDFs. If the realized Market Solution is different from the Base Case the resulting flow will also be different. The resulting flow can be found in the intersection of the Market Solutions MS1 and MS2 and the PTDFs.

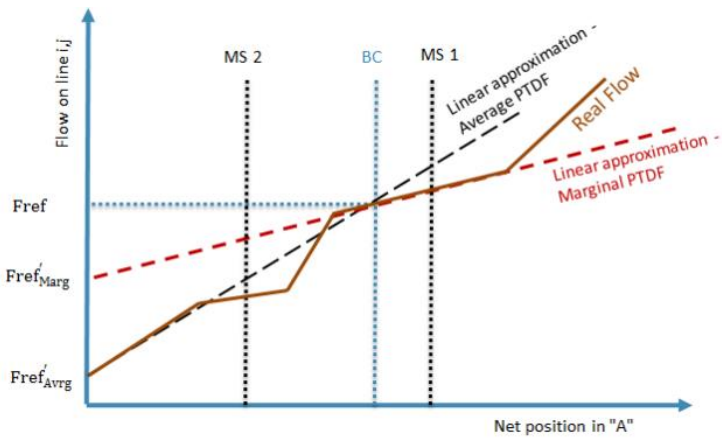

Figure 11 Possible relation between flow on a line as a function of the position [2]

A difference between the base case and the market solution means that the calculated RAM value is either too high or too low. How big the difference is, depends on the PTDFs, which in turn is decided by the selected GSK. For the TSOs the choice of GSK is often a tradeoff between accuracy and robustness. A 'marginal GSK strategy' might be the best fit if the base case is accurate, while a 'flat GSK strategy' may work better if the market solution is far off base case [2].

The linearization around the base case also explains why there can still be overloads in the FBMC methodology, even though none of the constraints are violated. Since the linear approximations of the flow might not be equal to the market solution, the actual flow might be higher than the flow in the Base Case. If there is an overload, the TSOs can handle the problem by counter trading, like they are doing in the current capacity calculation methodology. The system operator can also choose to increase the flow-reliability margin, effectively lowering RAM, to create a buffer against potential overloads in the market solution.

The difference between what the TSOs are doing and what happens in Samnett/FanSi is that in the latter the Market Solution is equal to the Base Case. This means that the RAM value will be set correctly according to the PTDFs and the maximal flow on each grid element, such that no CNEs are overloaded. The result is that there is effectively no difference in the model results for different GSKs.

3.2 Comparison of GSK-strategies in a fundamental market model

When using a detailed grid model in the market model, a GSK is applied to aggregate the nodal PTDFs to area PTDFs. Given that the topology of the grid does not change, the nodal PTDFs will remain constant. The area PTDFs, however, can change depending on the market solution and the GSK. To examine the impact of the GSK in the market model we have compared the results of simulations with five different GSKs, as shown in Table 1.

Table 1 Compared GSKs

GSK	Description
0	Flat
1	Abs (Net export)
2	Abs (Production)
3	Abs (Load)
4	Abs (Production) + Abs (Load)

Some of the results for the comparison are shown in Figure 13 and Figure 14. Socio-economic welfare, prices, and reservoir-handling is almost identical for all GSK strategies. The reason is that even though the area PTDFs are different, RAM will be varying to correct for the difference between physical flow and market flow. The result being that the choice of GSK has no impact on the effective flow-based capacity domain in our model setup. Another way of saying it is that Base Case and Market Solution are identical when using the market model and this causes all GSKs to yield equivalent grid constraints.

Regardless, the choice of GSK is not irrelevant, as it determines how the flow-based domain is represented. This can be important if the output from the detailed grid model is used as an input to an exogenous model, as will likely be the case for the market participants in the Nordic region[2]. The difference between RAM-values for the different GSKs is shown for one line in Figure 15.

[2] The flow-based domain including PTDFs and RAM on CNEs will be exogenously provided through a web platform.

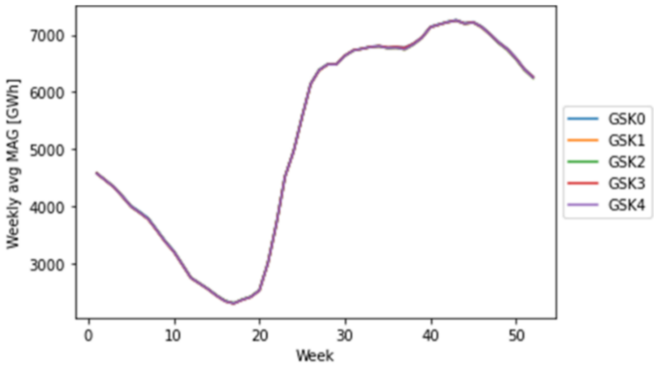

Figure 13 Reservoir level in Hallingdal over a year

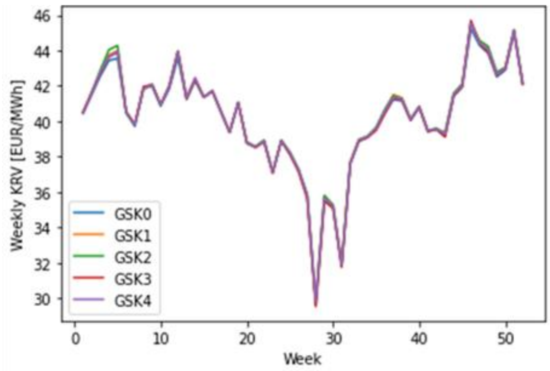

Figure 12 Weekly average price in Hallingdal

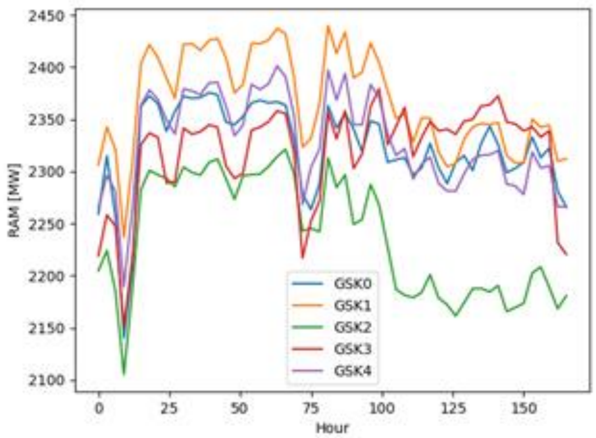

Figure 14 RAM on the line from Ostland to Sorost for multiple GSKs

4 Exogenous grid constraints

4.1 Using grid constraints from detailed grid

Due to the lack of access to a detailed grid model, most market participants in the Nordic region will most likely have to use a model with exogenously defined grid constraints. Therefore, we study the difference in results when using exogenous grid constraints based on a detailed grid description and the detailed grid description itself.

The grid parameters needed as input to the model are RAM and PTDFs for each CNE in the system. Since the constraints need to be defined in advance, and therefore cannot adjust for the market situations that arise, it is convenient to use the same constraints for all timesteps when using an exogenous model. The PTDF matrix from the detailed grid model can be used directly, if a GSK with unchanging PTDFs is used, such as a flat GSK. RAM would normally be varying to constantly adjust for the difference between market flow and physical flow. We did not find obvious patterns in the variations on a weekly or seasonal level, though this might be possible with more effort. Hence, predicting RAM in advance is challenging. This parameter is taken as constant across all time steps in our following analysis. We will, however, compare different selections of RAM and assess the impacts on model results.

Figure 16 shows the RAM values, normalized around the mean, occurring on each of the lines bordering the model area Ostland. It shows that the RAM on some of the lines varies by several hundred MWs within the span of a single week.

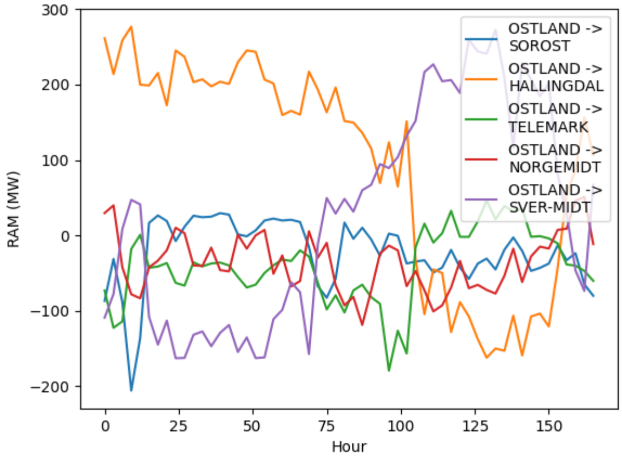

Figure 15 RAM on lines bordering Ostland

4.2 Comparison minimum, maximum and median RAM with exogenous constraints

For our analysis it is necessary to choose one RAM on each CNE. To understand how different selections of RAM-values affect the results, we compare the results of the four cases in Table 2. The PTDFs from the first case are used as exogenous PTDFs in the other cases. The RAM values in the cases with exogenous PTDFs are chosen to be the maximum, minimum and median of the observed RAM values in the reference case. The “min ram” and “max ram” cases can be thought of as representing a heavily constrained and a heavily relaxed grid.

Table 2 Cases for comparison to assess impact of RAM

Case name	Description
GSK0	Detailed grid with flat GSK
Max ram	Exogenous PTDFs, maximum RAM
Min ram	Exogenous PTDFs, minimum RAM
Median ram	Exogenous PTDFs, median RAM

When using a model with exogenous flow-based constraints it is impossible to know whether the market solutions would cause overloads in the full grid model. Therefore, when comparing the results of the exogenous model with the detailed model, the objective is to get equal results. Alternatively, the objective is to find lower and higher bounds on prices, which is the case for long-term price forecasting. Comparison of price in the model area Ostland for each of the cases is shown in Figure 17.

Figure 18 shows the same prices, but here the price in the reference case is subtracted from all the curves to highlight the differences. The latter figure shows that for Ostland, minimum RAM gives an upper bound on price, maximum RAM gives a lower bound on price and median RAM gives the overall best match. This result will not generalize to other areas. Relaxed grid constraints will lead to reduced price differences between the areas. Ostland usually has a net import of power, and therefore normally has a higher price than neighboring areas. Thus, relaxing the grid constraints for Ostland leads to lower prices, while for an exporting area it might lead to higher prices. For areas that import or export depending on the market situation, the direction of the price change will also be dependent on the market situation, this is shown in Figure 18 for a model area in southern Norway.

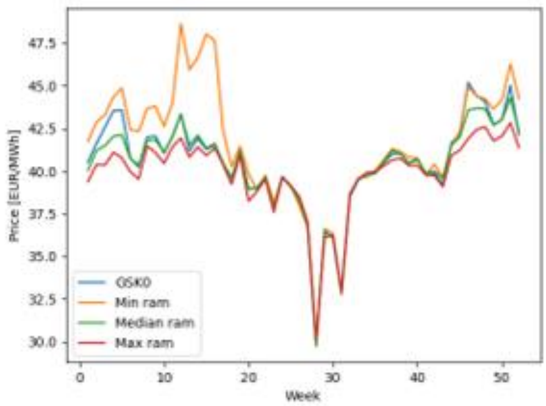

Figure 16 Price in Ostland

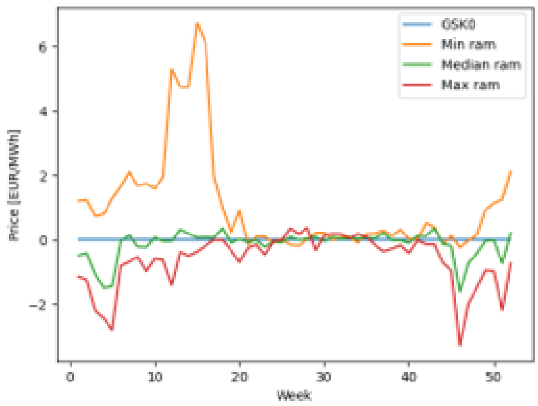

Figure 17 Price in Ostland, normalized around reference.

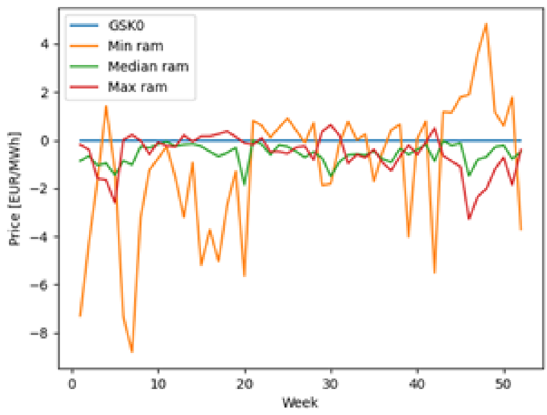

Figure 18 Price in Sorland, normalized around reference.

4.3 Correlation of RAM

Variations in RAM on certain grid components are highly correlated. The reason for the varying RAM is due to the deviation between the physical flow and the market flow. However, both the detailed and aggregated PTDF-matrices are still internally consistent. That means an increase of the net position in an area is going to result in an equal increase of flow out of the area, distributed across all the lines bordering the area. The only thing different for physical flow and market flow will be how the flow is distributed among the lines. Because of this, if market flow gives an overestimation of the flow on one line out of an area, the sum of the flow on the remaining lines will be correspondingly underestimated.

The correlation of flow deviations translates directly into correlation of RAM. Negatively correlated lines will never have their minimum RAM values at the same time. On the contrary, it is likely that when one line is at a minimum, some of the correlated lines will be at a maximum and vice versa. In Figure 20 the lines from Ostland to Telemark and the lines from Ostland to Hallingdal are correlated. Even though the "Min ram" and "Max ram" cases can be useful, they are also unrealistic. The median ram case is better at preserving realistic relations between the lines. Another way to achieve realistic relations between the lines would be to use a snapshot of the RAM-values in one hour. In Figure 19, the full matrix of correlation coefficients is given showing the correlations between RAM on each pair of lines.

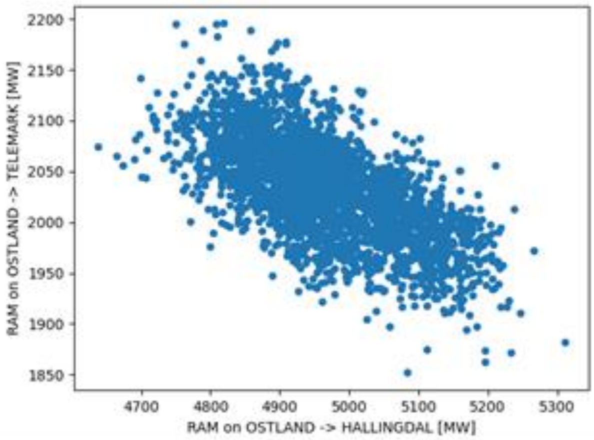

Figure 19 Correlation of RAM on the line from Ostland to Hallingdal with the line from Ostland to Telemark

Lines	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	1.00	-0.21	0.03	0.25	-0.53	-0.65	0.97	-0.21	-0.19	-0.12	0.82	0.78	0.45	0.33	0.54	0.20	0.19	-0.00	0.20	0.15	0.07	0.23	-0.62	0.62	-0.61	-0.02
2	-0.21	1.00	-0.65	-0.24	-0.40	0.11	-0.20	1.00	-0.22	-0.31	-0.31	-0.56	0.67	0.33	0.37	0.33	-0.06	0.00	0.33	0.13	0.20	0.10	-0.30	0.31	-0.26	0.00
3	0.03	-0.65	1.00	0.04	0.13	0.28	-0.07	-0.65	0.42	0.62	0.16	0.64	-0.19	-0.05	-0.15	-0.05	0.01	-0.03	-0.05	-0.04	-0.01	-0.03	0.10	-0.09	0.07	-0.00
4	0.25	-0.24	0.04	1.00	-0.57	-0.19	0.25	-0.24	-0.07	0.00	0.20	0.22	-0.09	0.43	0.54	0.28	0.22	0.01	0.28	0.42	-0.12	0.52	-0.42	0.44	-0.36	-0.00
5	-0.53	-0.40	0.13	-0.57	1.00	0.25	-0.49	-0.40	0.18	0.09	-0.37	-0.33	-0.77	-0.76	-0.95	-0.59	-0.19	0.01	-0.59	-0.47	-0.15	-0.54	0.86	-0.90	0.79	0.01
6	-0.65	0.11	0.28	-0.19	0.25	1.00	-0.82	0.11	0.17	0.54	-0.69	-0.32	-0.16	-0.12	-0.28	-0.05	-0.12	-0.01	-0.05	-0.10	0.05	-0.16	0.25	-0.25	0.23	0.02
7	0.97	-0.20	-0.07	0.25	-0.49	-0.82	1.00	-0.20	-0.20	-0.27	0.85	0.70	0.39	0.28	0.50	0.17	0.18	0.00	0.17	0.14	0.03	0.23	-0.55	0.55	-0.54	-0.02
8	-0.21	1.00	-0.65	-0.24	-0.40	0.11	-0.20	1.00	-0.22	-0.31	-0.31	-0.56	0.67	0.33	0.37	0.33	-0.06	0.00	0.33	0.13	0.20	0.10	-0.30	0.31	-0.26	0.00
9	-0.19	-0.22	0.42	-0.07	0.18	0.17	-0.20	-0.22	1.00	-0.34	0.35	0.12	-0.16	-0.14	-0.16	-0.10	-0.04	-0.03	-0.10	-0.07	-0.04	-0.09	0.18	-0.18	0.17	0.00
10	-0.12	-0.31	0.62	0.00	0.09	0.54	-0.27	-0.31	-0.34	1.00	-0.45	0.29	-0.10	0.01	-0.12	0.02	-0.01	-0.01	0.02	-0.02	0.04	-0.02	0.05	-0.05	0.03	0.00
11	0.82	-0.31	0.16	0.20	-0.37	-0.69	0.85	-0.31	0.35	-0.45	1.00	0.73	0.29	0.20	0.39	0.10	0.15	-0.01	0.10	0.10	0.01	0.17	-0.43	0.42	-0.42	-0.02
12	0.78	-0.56	0.64	0.22	-0.33	-0.32	0.70	-0.56	0.12	0.29	0.73	1.00	0.23	0.22	0.33	0.13	0.15	-0.02	0.13	0.09	0.04	0.16	-0.42	0.41	-0.43	-0.02
13	0.45	0.67	-0.19	-0.09	-0.77	-0.16	0.39	0.67	-0.16	-0.10	0.29	0.23	1.00	0.59	0.73	0.50	0.06	-0.02	0.50	0.24	0.28	0.26	-0.72	0.74	-0.68	-0.01
14	0.33	0.33	-0.05	0.43	-0.76	-0.12	0.28	0.33	-0.14	0.01	0.20	0.22	0.59	1.00	0.51	0.88	0.04	0.00	0.88	0.44	0.47	0.44	-0.54	0.62	-0.52	-0.02
15	0.54	0.37	-0.15	0.54	-0.95	-0.28	0.50	0.37	-0.16	-0.12	0.39	0.33	0.73	0.51	1.00	0.34	0.23	-0.01	0.34	0.40	-0.03	0.50	-0.88	0.88	-0.79	-0.01
16	0.20	0.33	-0.05	0.28	-0.59	-0.05	0.17	0.33	-0.10	0.02	0.10	0.13	0.50	0.88	0.34	1.00	-0.45	-0.01	1.00	0.48	0.56	0.24	-0.35	0.43	-0.34	-0.01
17	0.19	-0.06	0.01	0.22	-0.19	-0.12	0.18	-0.06	-0.04	-0.01	0.15	0.15	0.06	0.04	0.23	-0.45	1.00	0.03	-0.45	-0.18	-0.29	0.33	-0.27	0.26	-0.27	-0.01
18	-0.00	0.00	-0.03	0.01	0.01	-0.01	0.00	0.00	-0.03	-0.01	-0.01	-0.02	-0.02	0.00	-0.01	-0.01	0.03	1.00	-0.01	-0.04	0.02	-0.02	0.01	-0.01	0.01	0.02
19	0.20	0.33	-0.05	0.28	-0.59	-0.05	0.17	0.33	-0.10	0.02	0.10	0.13	0.50	0.88	0.34	1.00	-0.45	-0.01	1.00	0.48	0.56	0.24	-0.35	0.43	-0.34	-0.01
20	0.15	0.13	-0.04	0.42	-0.47	-0.10	0.14	0.13	-0.07	-0.02	0.10	0.09	0.24	0.44	0.40	0.48	-0.18	-0.04	0.48	1.00	-0.46	0.87	-0.29	0.32	-0.23	0.02
21	0.07	0.20	-0.01	-0.12	-0.15	0.05	0.03	0.20	-0.04	0.04	0.01	0.04	0.28	0.47	-0.03	0.56	-0.29	0.02	0.56	-0.46	1.00	-0.59	-0.09	0.14	-0.12	-0.02
22	0.23	0.10	-0.03	0.52	-0.54	-0.16	0.23	0.10	-0.09	-0.02	0.17	0.16	0.26	0.44	0.50	0.24	0.33	-0.02	0.24	0.87	-0.59	1.00	-0.41	0.44	-0.36	0.01
23	-0.62	-0.30	0.10	-0.42	0.86	0.25	-0.55	-0.30	0.18	0.05	-0.43	-0.42	-0.72	-0.54	-0.88	-0.35	-0.27	0.01	-0.35	-0.29	-0.09	-0.41	1.00	-0.99	0.99	0.03
24	0.62	0.31	-0.09	0.44	-0.90	-0.25	0.55	0.31	-0.18	-0.05	0.42	0.41	0.74	0.62	0.88	0.43	0.26	-0.01	0.43	0.32	0.14	0.44	-0.99	1.00	-0.98	-0.03
25	-0.61	-0.26	0.07	-0.36	0.79	0.23	-0.54	-0.26	0.17	0.03	-0.42	-0.43	-0.68	-0.52	-0.79	-0.34	-0.27	0.01	-0.34	-0.23	-0.12	-0.36	0.99	-0.98	1.00	0.03
26	-0.02	0.00	-0.00	-0.00	0.01	0.02	-0.02	0.00	0.00	0.00	-0.02	-0.02	-0.01	-0.02	-0.01	-0.01	-0.01	0.02	-0.01	0.02	-0.02	0.01	0.03	-0.03	0.03	1.00

Figure 20 Correlation coefficients between each pair of lines in the synchronous area

5 Conclusion

Due to large amounts of hydropower with its multi-year reservoirs, the planning and forecasting horizon for Nordic market participants is rather long. With the introduction of FBMC in the Nordics, market participants face the challenge of accounting for the flow-based domain a long time in advance. Because of lack of access to a detailed grid description, it is necessary to make production plans and price forecasting based on the exogenously defined grid constraints published by the Nordic TSOs.

To improve the understanding of these grid constraints we look deeper into the flow-based parameters and discuss ways to consider flow-based grid constraints in a fundamental market model. The main challenge for market participants is that the grid constraints in FBMC are linearized around a forecasted Base Case. Since the planning horizon is long and includes different system and market situations, any given published flow-based domain is unlikely to be valid for the entire period. Additionally, the assumptions that goes into the Base Case is not necessarily known.

To ease the task of taking FBMC into account for market participants the TSOs should consider the following when designing the data publication for long term flow-based domains:

- A robust GSK, that is not dependent on the market situation, should be used for all areas, so that the PTDFs remain constant.
- For a given grid topology the flow-based domain for several hours should be published, so that the market participants can estimate of how RAM is likely to be varying for different market situations.

As both market participants and TSOs gain experience with the new capacity calculation methodology some structural changes might increase the predictability of the flow-based domain:

- Increase the number of price areas so that the nodes in an area are better matched.
- Give the largest power plants and loads nodal PTDFs, in a similar manner as HVDC cables. This will reduce variability and make RAM more predictable.

Using exogenously defined grid constraints give similar results to a model with detailed grid description, but it would be preferable for market participants to use a detailed grid description. In the cases we have compared, the underlying market assumptions are identical to the reference case. More deviations and forecast errors could decrease the validity of the exogenous grid constraints. In addition, to analyse cases where the grid topology changes, it seems necessary to use a detailed grid description. Examples of this would be to find the effects of outages on lines, or to account for future grid improvements.

6 References

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