Oscar Jacobsen

The Nordic Transparency Model for Analysis

Improving Modelling and Analysis of the Nordic Electrical Power System Operations through Open Transparency Data

Master's thesis in Energy and the Environment
Supervisor: Kjetil Uhlen
Co-supervisor: Daniel Baltensperger
October 2021

Master's thesis

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Abstract

The Nordic Electrical Power System, as any other power system, is becoming increasingly more complex. Simultaneously, as complex topology and requirements for safe operations is in focus, its modelling methods and validation of analysis results in open research models are static, often overly simplified representation on both the systems operational responses and topology. As the Nordic power system is dynamic, it's topology and operational data is dynamic and always altering the systems representation and behaviour for analysis. Increased focus on data accuracy in dynamic modelling, maintenance and analysis, allows for real dynamic systems to be accurately modelled.

The goal of this work is to *discover*, *access* and *implement* important dynamic transparent data on the Nordic power systems topology and operations into dynamic system modelling for accurate system representation and analysis. Transparency data was discovered through restrictive research focused on the key market participant within the Nordic, accessed though built applications, and implemented into a Python scientific platform, obtaining dynamic data access and active modelling.

High value, maintained transparent data exist for use in both modelling of the Nordic operational behaviours, but also its present and complex topologies. Through platforms found on Transmission System Operators-, ENTSO-E- and country government sites, somewhat *hidden* transparent data has been discovered and in this work made accessible. Built applications providing dynamic access in Python to the transparent data sources and the large resulting dataset extracts from discovery and work is made open and available at this projects repository. Utilizing the built applications and high value transparent data, first principles high accuracy modelling and analysis of the Nordic Electrical Power System is made possible.

Sammendrag

Det nordiske elektriske kraftsystemet er som alle andre kraftsystemer i konstant utvikling, med økende kompleksitet. Samtidig som systemets topologier og krav til driftsikkerhet er dynamiske og økende, er dagens metoder for modellering og analyse i åpne forskningsmodeller statiske, ofte overforenklede representatsjoner av både systemets topologier og drifter. Ved økt fokus på data nøyaktighet i dynamisk modellering, vedlikehold og analyse, muligjøres nøyaktige model-representasjoner av det komplekse nordiske kraftsystemets driftssituasjoner og endrende topologier.

Målet med dette arbeider er å *oppdage*, *tilgjengeligjøre* og *implementere* faktiske dynamisk transparente data angående det nordiske kraftsystemets topologier og drifter for bruk i nøyaktig systemmodellering. Transparente kilder og data ble oppdaget gjennom restriktive søk siktet mot nøkkelaktører i drifting av det nordiske systemet, tilgjengeliggjort gjennom arbeidets utviklede applikasjoner, og implementert i en Python-basert modelleringsplatform for aktiv tilgang til de transparente dataene og programmeringsverktøy for bruk i modellering.

Høy kvalitets, opprettholdte transparente datakilder finnes for bruk i både åpen modellering av det nordiske kraftsystemets drifter, og faktiske komplekse topologier. Gjennom platformer driftet av de nordiske systemoperatørene, ENTSO-E og statlige platformer, er det oppdaget transparent data, til dels noe *skjult*, som i dette arbeidet er tilgjengeligjort for modellering og aktiv model vedlikehold. Utviklede applikasjoner for dynamisk tilgang til de opprettholdte transparente datakildene og uthentinger av komplekse system-dataset er tilgjengeligjort i dette prosjektets digitale mappe. Ved å utnytte de utviklede applikasjonene og tilgangen til høykvalitets transparente data, er høykvalitets modellering og analyse bygget på de fundamentale systemdataene i det nordiske kraftnettet gjort mulig.

Preface

This thesis work is the authors final delivery as part of a two-year Master of in Energy and Environmental Engineering, at the Norwegian University of Science and Technology, NTNU Trondheim Norway. Prior author experiences include a Bachelor of Science degree in Electrical Power Engineering at the Western University of Applied Sciences, HVL Bergen Norway.

This projects initial objectives were set to investigate possible improvements on System Protection Schemes in operations within the Nordic Electrical Power System. As system protection schemes are the baseline of defence against instability and blackouts in the increasingly more complex power system, solid modelling of the power systems topology and real behaviours was felt needed.

Feeling a lack of confident on the validity and modelling complexity in present static representations being handed around for use in analysis of the Nordic power systems, lead this project and this researcher down the *rabbit hole*, seeking to improve on how the Nordic power systems data is acquired and utilized in dynamic modelling.

This thesis work in turn became the investigation into transparency. Allocating available, actively maintained open data sources on the Nordic topology and operations for modelling. Resulting in key important transparency sources being identified, being linked to the modelling scientific Python platform and initiated in modelling of the Nordic Transparency Model.

I would like to thank my supervisors Prof. Kjetil Uhlen and Ph.D-candidate Daniel Baltensperger for being available throughout my work, even though the authors endeavours is not often easily tamed in his quest towards envisioned goals. The author is looking forward to keeping track on this projects further results and add contributions on future improvements to Nordic power system modelling and analysis through this projects repository, and future works.

Problem Description

In an ideal situation, models used for electrical power systems analysis is able to accurately describe its modelling systems topology and provide real systems behavioural responses as results, for any given case study situation. Accurate models of real operational power systems, as the Nordic Electrical Power System, hence is always up to date on topology changes and its real systems case operational situations.

In reality, open research analysis models on the Nordic power system are often reused static oversimplified representation, being manually maintained towards changes to its electrical networks and operational base-case situations. Leading to varying quality in modelling and analysis results, and the cause for this works **hypothesis**:

> *Utilizing the trend in data transparency, it is possible to greatly improve on modelling complexity, accuracy and quality of results in an open researching analysis model of the Nordic Electrical Power System.*

Reused static Nordic models in open research, consequently often assuming, or slightly better, attempting to manually ensure its continuous validity, gives cause to poor results and possible faulty researchers conclusions on the Nordic systems case responses.

Following this works hypothesis and aim towards improving on present Nordic open research models complexity, validity and quality of results, this works **research questions** is set:

- What available transparent data *exist*, utilizable in an improved Nordic analysis model?
- How may the available transparent data be *implemented* in order to actively ensure high model accuracy, validity and continuous usability in complex analysis?
- Using transparency, what are the *benefits* gained in open-research modelling and analysis of the Nordic Electrical Power System?

In combination, this works final **problem statement** is made:

> ***There are benefits to be made on improving the Nordic Electrical Power System Analysis modelling and results, possibly reached through transparency.***

Concluding on the proposed problem statement is done through restrictive research, accurate data implementation and result analysis in an proposed Nordic Transparency Model.

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Chapter 1

Introduction

1.1 Background

In order to gain solid results in electrical power system analysis, two key elements is needed:

- A model, accurately representing the real world systems topology and reproduction its behaviours in analysis, and;
- Knowledge of what behaviours to expect as its operational base-case results.

Concerning analysis on the Nordic Electrical Power System (Nordic), important model representations being used for open research and educational purposes related to operational and dynamic analysis, are static variants of the *Nordic-44 (N44) test network model*, where existing variants and features as of recently, is being shortly summarised and presented in [1]. Creating base-case N44 model variants, matched to historical operating data gathered from the Nordic and European main power market contributor, NordPool, is performable using the *Nordic44-Nordpool*-toolkit [2]. Still, no automated process exist ensuring the N44 topology representation to be validated against the present real Nordic topology in operations. As so, the N44 Nordic model in its formats, is seen in several cases to give different unmatched responses as results, showcasing the case models possible inaccurate topology or operational state modelling.

In various works, different methods is being utilized in order to create highly accurate topology model representations of real world electrical power systems. As created from available *OpenStreetMap(OSM)*-data in the *SciGRID-project*[3], ”blind-estimations” from analysing operational data in various works [4],[5], and from published maps, as the *unofficial ENTSO-E interactive map extract*, performed in the *GridKit-project* [6], and improved in the *PyPSA-Eur*-project [7].

In no other works objectives, has the focus been identified towards utilizing the increased industry data transparency in improving modelling and analysis results on the Nordic power system, or any other system.

1.2 Objective

The objective of this work is to investigate on electrical industry transparency, and its usability in improving the Nordic Electrical Power Systems representation in a dynamically maintained, high quality, validated model for improved Nordic power system analysis.

1.3 Scope

The scope of this work is to firstly discover the existing available transparency data utilizable in a model for improved Nordic power system analysis. Secondly, creating a strong linkage between the model and the transparent sources, ensuring the models dynamic maintenance and high validity, Lastly, to analyse the transparent modelling data and in combination create key features of the Nordic Transparency Model for use in accurate system representation and analysis.

1.4 Methodology

The methodology used in this work is quantitative, set on reaching this works objective through high quality data *discovery*, *collection* and *analysis*.

1.5 Outline

The general paper outline of this work is as listed:

Chapter 2, reviews on relevant theory and methodologies.
Chapter 3, describes the process overview and methods for work.
Chapter 4, present results.
Chapter 5, provide discussions.
Chapter 6, concludes on works results in conclusion and present proposal for further work.

Chapter 2

Theory

In this chapter, theory important to modelling of the Nordic Electrical Power System on available transparent data is reviewed, following **the general outline:**

Section 2.1:	Presents theory on, and the methodologies used in operations of the Nordic Electrical Power System.
Section 2.2:	Presents key theories on modelling Electrical Power Systems for Analysis.

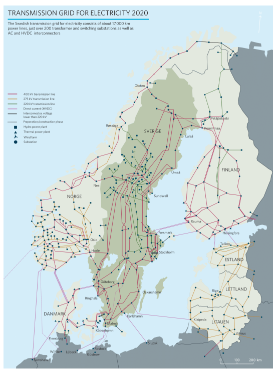
In case of additional understanding on presented aspects is sought, key sources on Nordic Operations [8], Power Systems [9] and Graph Modelling [10] theory is provided.

2.1 The Nordic Electrical Power System Operations

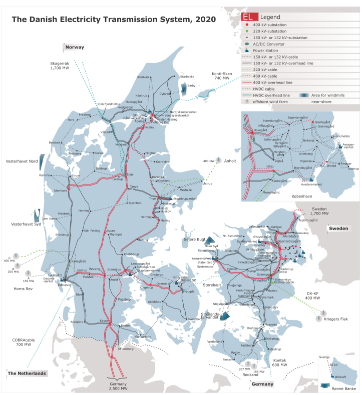
The Nordic Electrical Power System (Nordic) is comprised of the country subsystems in the Nordic Synchronous Area (NSA), comprised of; Norway, Finland, Sweden(including Kraftnät Åland) and Eastern Denmark, together with the closely DC-connected asynchronous subsystem in Western Denmark. Responsible for the Nordic power systems efficiency and security in operations, are each subsystems Transmission Systems Operators (TSOs), being; Statnett, Fingrid, Svenska Kraftnät(SvK) and Energinet. Ensuring the bare minimum for acceptable subsystem operations by complying with the systems Network Codes as Eu regulatory guidelines [11], provided by the common Nordic membering organisation, the European Network of Transmission System Operators for Electricity (ENTSO-E), facilitating the transparent cooperation between the European TSOs.

Following available transparent system data and operational regulations originating from all of the above mentioned organisations; Statnett, Svenska Kraftnät, Fingrid, Energinet and ENTSO-E, as is to be presented below, behaviour and operations of the Nordic power systems, as shown in its official static maps in Figure 4.3, is made describable, and hence it's features accurately included in a model.

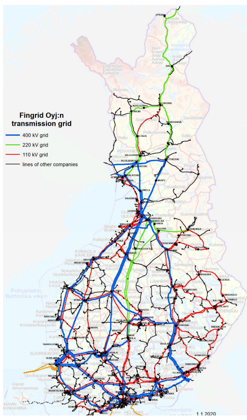
(a) Entsoe Nordic Map 2019 [12]



(b) Svenska Kraftnät Map 2020 [13]



(c) Energinet Map 2020 [14]



(d) Fingrid Map 2020 [15]

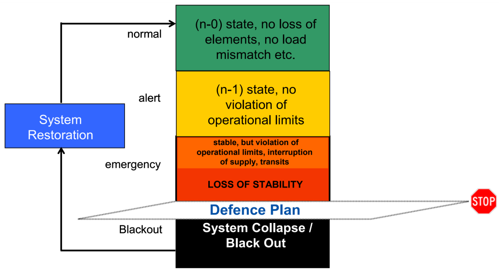
Figure 2.1: Nordic Electrical Power System Maps

2.1.1 Nordic Operational Security Requirements

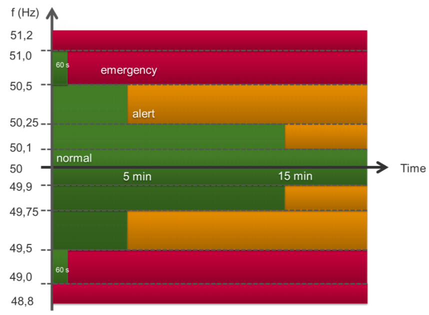
Safeguarding the operational security, frequency quality and efficient use of interconnected systems resources, each subsystem TSO is needed to operate their network according to the Operational Security Requirements, set in the Network Code and Regulation (EU) 2017/1485 on transmission system operations, in general describing the acceptable operating boundaries for: *frequency-, voltage-, thermal-, short-circuit current- and dynamic stability-limits.*

At any instance, relating the systems operational conditions to the operational security requirements, the Nordic systems operating state is made classifiable into five states, described in Figure 2.2a. With classifications being made on current and possible operational contingency outcomes related to containment of the systems state variables, voltage and frequency, not reaching unstable states, with the possibility for systems operational collapse in blackout state.

As thermal-, short-circuit current- and dynamic stability-limits at their fundamentals provide operational restrictions ensuring safety of operations related to the same systems state variables, the Nordic system is operating at a normal system state, in any case where the voltage and frequency is ensured to be within their operational security requirements.
Being $0.90\ pu < V < 1.05\ pu$ in case of Nordic voltage and Nordic frequency, generalised to $49.9\ Hz < f < 51\ Hz$, and in its relation to time as shown in Figure 2.2b.



(a) Nordic System States [16]



(b) Nordic Frequency Limits [17]

Figure 2.2: Nordic System States and Frequency Security Limits

Being operated on the minimum of *n-1 contingency criteria*, stating the requirement in operations of Nordic operating state not to reach its blackout state in any case of one single contingency occurrence on the largest dimensioning unit connected in operation. In 2022, the largest active dimensioning unit in Nordic operations is the Olkiluoto generation plant at 1600MW, but since a possible trip of generation activates 300MW load shedding in a System Protection Scheme(SPS)[18], its dimensions is efficiently reduced, making the Oskarshamn 3 generator at 1450MW the present, and future HVDC-units the Nordic operational security dimensioning elements.

2.1.2 Nordic Operations

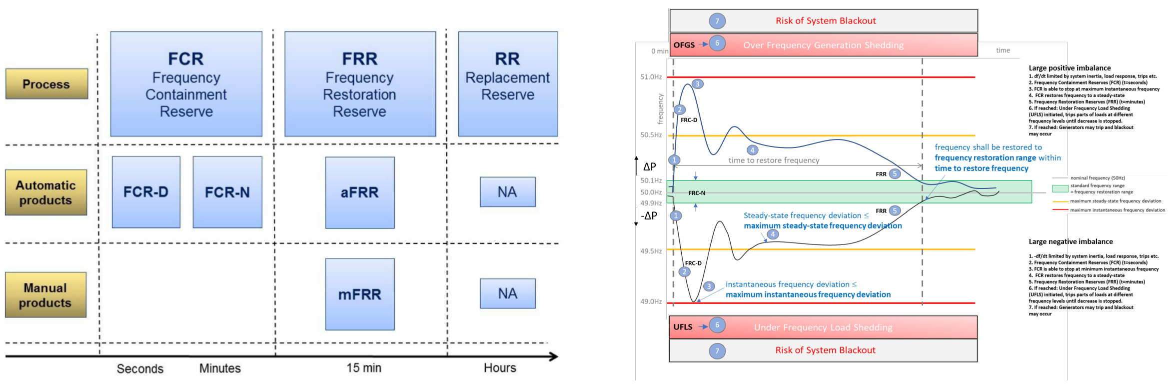
As for any electrical power system, the main objectives in Nordic operations is to do *power: -generation, -transmission and -demand supply*, as efficiently as possible, while still maintaining the operational requirements set forth in Section 2.1.1. Using the defined objectives as main modelling units, the combined Nordic operations for modelling is made possible to be described. Specifying data quality on each unit is made in the Network Code EU Regulation 543/2013 on data transparency, commonly referred to as the ”Transparency Regulation”.

2.1.2.1 Nordic Generation

At any instance within a confined Nordic observed subsystem area, there are generation units being either *decommissioned/offline* or *commissioned/online*. In addition to the commissioned units main contribution on either injecting, or possibly extracting power into operations, all commissioned and some decommissioned units provide additional contributions in form of *balancing reserves*, shown in timed operations in Figure 2.3a, tasked on ensuring operational power balance, closely linked to frequency stability. Serving as the fast frequency balancing reserves are the commissioned, and also possibly fast controllable power electronic units, adding inertia to the operations *inertia* based on; *capacity, type and units controls*. Commissioning of decommissioned units may provide added balancing contributions at a later stage, as medium timed frequency restorative-, and slower replacement reserves.

As presented, in addition to the the static operating contribution being simply the *total net sum of generations* within the confined area, modelling for dynamic operations and possible contingency event responses, shown in its time course in Figure 2.3b, requires the added knowledge on Nordic inertia in available reserves, units types and operational controls.

Actual transparent area generation data is computed as the average of all measured instantaneous net generation output on each market time unit, being one hour. Missing measuring data on other area generation units are estimated and included.



(a) Balancing Reserves [17]

(b) Frequency Response, reproduced from [18]

Figure 2.3: Nordic Balancing Reserves and Frequency Response

2.1.2.2 Nordic Transmission

Not reviewing on the emerging technologies in controllable transmission power flow electronic devices, such as High Voltage Direct Current(HVDC)- and Flexible Alternating Current Transmission System(FACTS)-devices, the Nordic transmission related to initial modelling of its operations, is seen as a static uncontrollable element. Related to the generation units contribution to static operations within a confined observed area, the contributions from transmission into operations equals *the area net sum of power import, and export*. Although often not directly controllable, other operational measures are performed as controlling energy cost in different Market Bidding Areas(MBA), in order to stimulating the resulting power flows on transmissions to be within their confined Net Transfer Capacities(NTC), set from the operational security requirements.

Data made transparently available on actual area exchanges, are computed as the netted average measured values.

2.1.2.3 Nordic Demand

Knowing two of the three contributors to operations, at any time of instance in a confined Nordic observed area, the last contributor as a areas demand, become the *total areas net sum of generation and transmission*. Due to lack of quality in measurements on power demanding market consumers as *load*, and power demanding transmission consumption as *loss*, both are included and combined in the computed area *Actual Total Load.*

The available transparent data on actual total area demand is computed on hourly average values, from the sum of all other contributors to area powers, as set in the relation:
Actual Total Load = Net Generation - Exports + Imports - Absorbed Energy.

2.2 Modelling the Nordic Power System

Following graph theory, the Nordic Electrical Power System may be modelled using graph basic elements of nodes and links, with node attributes of the systems state variables as *voltage* and *frequency*, and link attributes of other systems natural elements as *resistance* and *reactance*, determining the interactions between two nodes, connected each at an end of the link. It's use in power systems modelling is vast, and used in modelling of various subsystems as; *overall topology, subsystem grid elements and operational states.*

The operational state and response of a power system subsystems modelled as a graph, is overall made describable by its inner network topology of all nodes and links, and their energy exchanges and interactions with other systems/graphs elements, illustrated in Figure 2.4, describing the graphs/systems steady state preservation of energy.

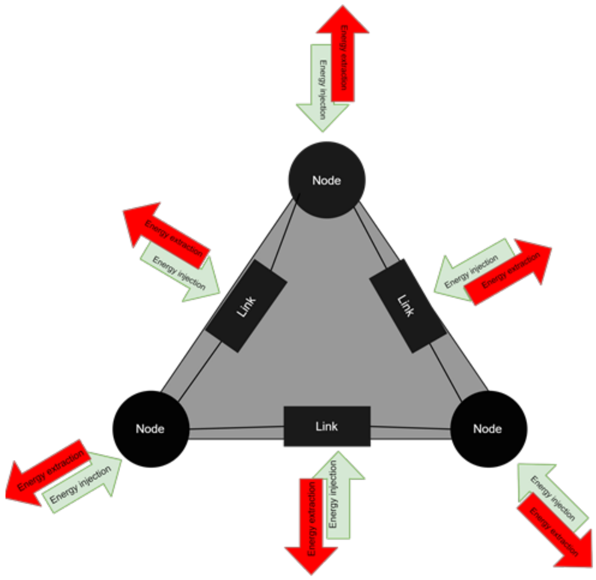


Figure 2.4: Graph Energy Model

2.2.1 Modelling Nordic Topology

As the Nordic Power Systems is a widespread, large physical system, modelling on all nodes and links to be included within the overall Nordic *graph network topology*, greatly revolves around *Geographic Information System(GIS)*-data modelling. Modelling the Nordic links on observed transmission lines, and nodes from centers of multiple transmissions endpoints, the Nordic overall topology is revealed, with its identifiable sub-topologies as explained in Figure 2.5.

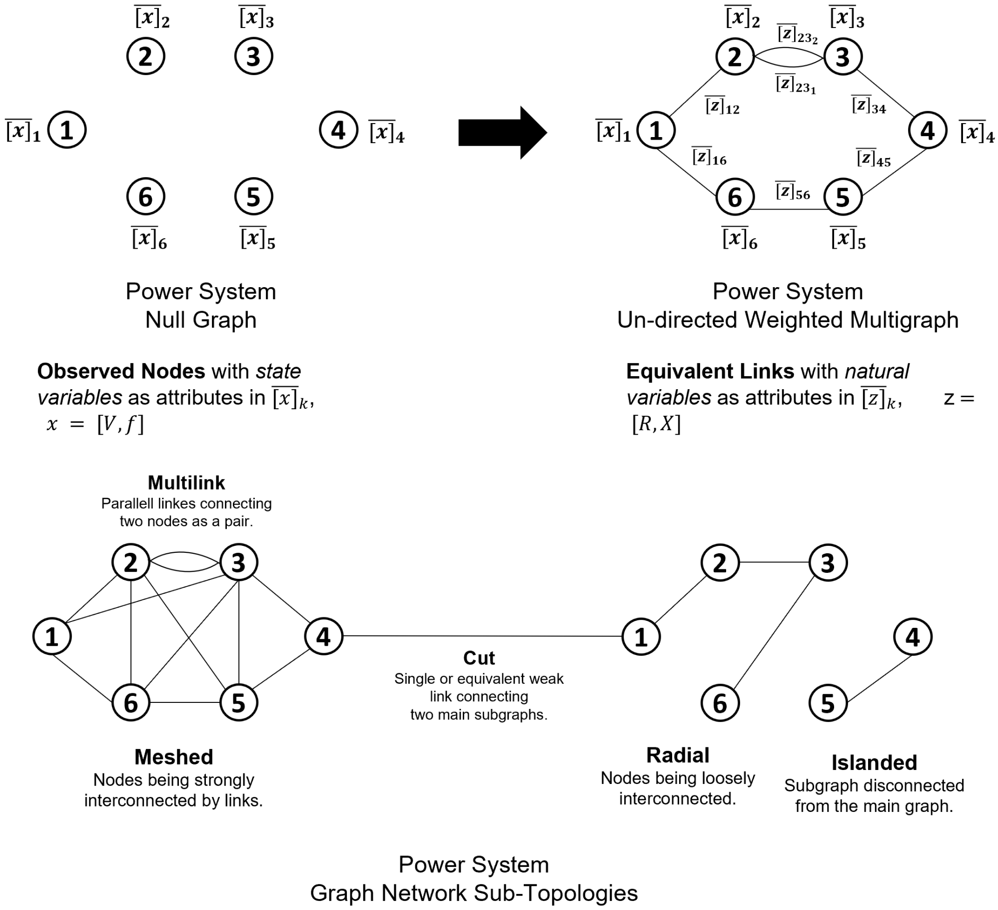


Figure 2.5: Power System Topology as Graph

Provided the Nordic graphs topologies, network altering techniques as known from standard electrical circuit theory may be used to *complicate*; *add nodes and split links*, or *simplify*; *exclude nodes and merge links* within Nordic subnetworks. In doing so, the Nordic networks topologies is efficiently altered into any suitable shape, while still maintaining the overall identifiable Nordic topology attributes from its exact GIS-data source.

2.2.2 Modelling Nordic Operations

As the Nordic operations is focused on power *in; generation, transmission and load demand*, thus is modelling of its operations as a graph equally focused. From the nature of *power flows*, and *Kirchoffs law of currents*, the total sum of power being *injected as generation* or *extracted as load* on each node is is equal to the sum of power flows on links connected to the node, as described in the *Power Flow Equations*, 2.1-2.2.

`Power Flow Equations:`

$$P_i = \sum_{j=1}^{N} \mid V_i \mid\mid V_j \mid \left(\frac{R_{ij}}{R_{ij}^2 + X_{ij}^2} \cos(\delta_i - \delta_j) + \frac{X_{ij}}{R_{ij}^2 + X_{ij}^2} \sin(\delta_i - \delta_j)\right) \tag{2.1}$$

$$Q_i = \sum_{j=1}^{N} \mid V_i \mid\mid V_j \mid \left(\frac{R_{ij}}{R_{ij}^2 + X_{ij}^2} \sin(\delta_i - \delta_j) - \frac{X_{ij}}{R_{ij}^2 + X_{ij}^2} \cos(\delta_i - \delta_j)\right) \tag{2.2}$$

In addition to powers being injected or extracted at nodes as generation and load, powers is also being *extracted* as *resistive and inductive losses* and *injected* as *capacitive reactive powers* and to some extent *resistive external powers from heat/radiations* on the transmission lines as links. In its simplest model representation of bulk resistance and inductance in series, the simplified active and reactive power losses on transmission links is as stated in Equation 2.3

`Simplified Transmission Links Power Losses:`

$$P_{resistive} = P_{flow}^2 R \;\; [p.u.] \qquad\qquad Q_{inductive} = P_{flow}^2 X \;\; [p.u.] \tag{2.3}$$

Following the principles of *preservation of energy*, the Nordic system is in rested steady state when all power; *injections*, and *extractions* in sum equals zero, as stated in Equations 2.4-2.5.

`Preservation of Energy at Steady State:`

$$\sum_{i=1,j=1}^{n,l} P_{i,j} = \sum_{i=1}^{nodes} (P_{generation} - P_{load}) + \sum_{j=1}^{links} (P_{externals} - P_{resistive}) = 0 \tag{2.4}$$

$$\sum_{i=1,j=1}^{n,l} Q_{i,j} = \sum_{i=1}^{nodes} (Q_{generation} - Q_{load}) + \sum_{j=1}^{links} (Q_{capacitive} - Q_{inductive}) = 0 \tag{2.5}$$

Through iterative solving of the Nordic Power Flow Equations, taking into account the preservation of energy with operational powers in generation, loss and loads, with boundary conditions set on the operational requirements in 2.1.1 enables the Nordic Transparency Models steady state, base-case operations to be accurately modelled.

Chapter 3

Method

In this chapter, methods for reaching this works objectives is explained, following **the general outline:**

Section 3.1:	Presents methodology for data selection and processing.
Section 3.2:	Presents methodology for work process design.
Section 3.3:	Evaluates on use of methodology.

The methodology chosen for this work, is in all matter of its definition, quantitative. Modelling data is *discovered* through restrictive literature research, *collected* using this works built API applications and *analysed* in the rich and featured Python programming and researching environment.

3.1 Data and Environment

Following this works objectives, data selection is set to be restrictive. Aiming to create a high quality model representation of the Nordic Electrical Power System, only sources directly, or strongly connected to the Nordic power system operations is chosen. Once usable data is found, and high quality data identified, it is collected directly from its source using this works built client modules. As the data sources is key main market participant within the Nordic, and collection of data is performed directly from its source into this works Python modelling environment in a streamlined process, high quality data and management is achieved.

3.2 Process Design

Reaching this works goals, the working process is initiated in extensive literature research. High quality data is searched for on all available open channels, linked to the Nordic key market participants; TSOs, governments and ENTSO-E. Searching for references to dynamic transparency sources in open official documents, and online sites. As no initial knowledge or list of existing available transparent data sources within the Nordic power system is known to exist, the process of literature research was performed mostly on *blind research* and *acquired leads*, aimed at identifying all available Nordic transparency data sources.

Following the identification of high quality transparency sources in research, work is put on acquiring data access and applications for its continuous availability and service in the dynamically maintained model. Using existing services when available, and creating new application if needed. As the main reasoning of the transparency models creation is improved data quality for modelling and result validation, creating strong linkages at this stage in access and collections is though critical to this models high data transparency quality.

Once access and strong linkage to the identified available transparency sources is obtained, analysis on the transparent data and modelling of the Nordic Transparency Model begin. At this stage, all modelling results and analysis is strongly rooted in transparency, actual Nordic operational system state and actual topology.

3.3 Methods of Work

Given that the methodology used in this work is *restrictive* and *data-accuracy* focused by design, obtained final objective results may be in the same manner, restrictive or even possibly lacking if non or little transparent sources is obtained in this works initial steps. In turn, managing to create strong linkage to high quality transparent sources, modelling and dynamic maintenance of the Nordic Transparency Model, equally ensures high quality in results.

Chapter 4

Result

In this chapter, results from this projects work is presented, following **the general outline:**

Section 4.1: Presents results from literature study on major transparency data sources and results from work done at accessing, linking and implementing the transparency data sources to the modelling platform.

Section 4.2: Presents key features of the obtained Nordic Transparency Model and other featured preliminary model results.

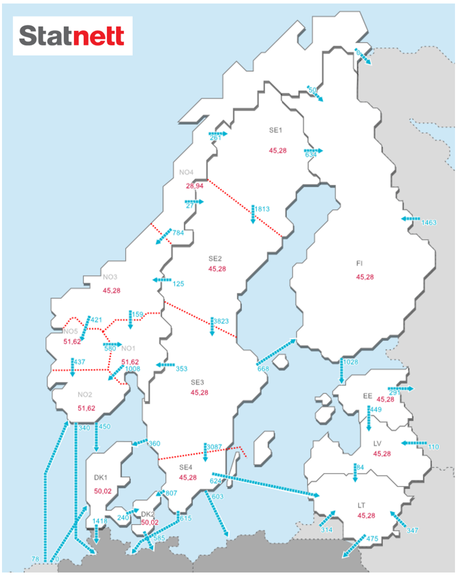
Due to the impracticality's of including, accessing and interpreting this works large datasets and created client modules lines of code as appendix, all results, created modules and linked content to this work is made available at this projects open repository. In addition, as most of the transparent data being utilized in this work is made accessible through free licensing and open platforms, free licensing for reuse is also appended all datasets resulting from this work.

Seeking to make the constructed model data and analysis results easily available, interactive displays of the model links to contents in the project repository data are both presented at this projects web page site found on https://ocrj.github.io/Nordic-T/, linking to source data locations in its main repository.

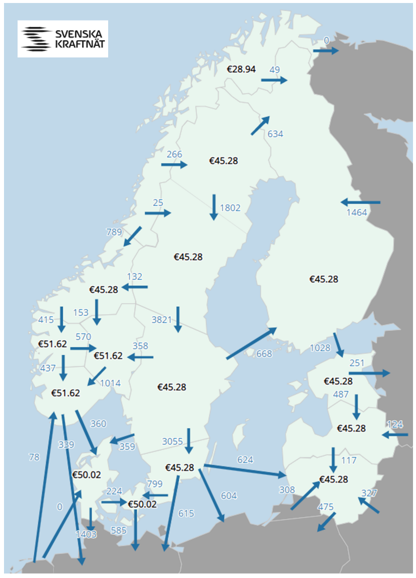
4.1 The Transparent Nordic Data Sources

4.1.1 Nordic System State Data

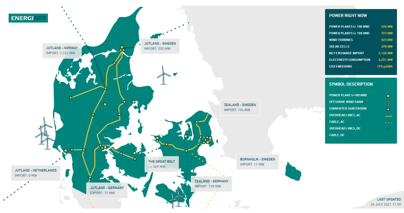
Transparency data on the Nordic power system operations is made accessible in various formats, of varying quality on various platforms. Figure 4.3 shows each TSOs hosted transparent data displays.



(a) Statnett,
State of the System Map [19]



(b) SvK,
Flow of Electricity Map [13]



(c) Energinet,
Energy System Right Now Map [14]

(d) Fingrid,
State of the Power System Map [15]

Figure 4.1: Nordic Systems States Maps

4.1.1.1 Fingrid Open Data

The Fingrid Open Data-platform is a major provider of Nordic operational system state data. On their platform, Fingrid Oyj encourages it's platforms users to experiment and publish their own creations as both free and commercial products, in accordance with the Creative Commons Attribution 4.0 International -licensing and terms of use.

Although the datasets is made available through the platforms REST API service, is is not made accessibly on the python scientific platform, as no open client module for working with the platform exist. In order to gain dynamic access to the datasets, great efforts has been put into creating a pythonic client module located in this project repository's *fingridopendata.py* module. Following this work, the client module is made freely available as a python package, available for use to all given their own personal api-key, gained from free registration on the platform. All the 136 system state datasets on the platform is accessible thorough use of this works client module, datasets as listed in 4.1.

Available FingridApi Datasets							
	Name	**VariableId**	**Formats**		**Name**	**VariableId**	**Formats**
1	Other power transactions, down-regulation	213	csv, json	69	Intraday transmission capacity EE-FI	110	csv, json
2	Other power transactions, up-regulation	214	csv, json	70	Wind power generation forecast - updated once a day	246	csv, json
3	Fast Frequency Reserve FFR, procurement forecast	278	csv, json	71	Day-ahead transmission capacity FI-EE – official	115	csv, json
4	Fast Frequency Reserve FFR, procured volume	276	csv, json	72	Total production capacity used in the solar power forecast	267	csv, json
5	Fast Frequency Reserve FFR, received bids	275	csv, json	73	Wind power generation forecast - updated hourly	245	csv, json
6	Fast Frequency Reserve FFR, price	277	csv, json	74	Electricity consumption forecast - next 24 hours	165	csv, json
7	Kinetic energy of the Nordic power system - real time data	260	csv, json	75	Electricity consumption in Finland	124	csv, json
8	Cross-border transmission fee, import from Russia	85	csv, json	76	Bilateral trade between FI-RUS	68	csv, json
9	Cross-border transmission fee, export to Russia	86	csv, json	77	Condensing power production - real time data	189	csv, json, app
10	Imbalance power between Finland and Sweden	176	csv, json	78	Intraday transmission capacity EE-FI – real time data	111	csv, json
11	Emission factor of electricity production in Finland - real time data	266	csv, json	79	Ordered down-regulations from Balancing energy market in Finland	33	csv, json
12	Emission factor for electricity consumed in Finland - real time data	265	csv, json	80	Electricity consumption in Finland - real time data	193	csv, json
13	Power system state - real time data	209	csv, json	81	Temperature in Jyväskylä - real time data	182	csv, json, app
14	Net import/export of electricity - real time data	194	csv, json, app	82	Cogeneration of district heating - real time data	201	csv, json, app
15	Transmission between Sweden and Åland - real time data	90	csv, json, app	83	Special regulation, up-regulation	119	csv, json
16	Transmission between Finland and Central Sweden - real time data	89	csv, json, app	84	Temperature in Helsinki - real time data	178	csv, json, app
17	Transmission between Finland and Norway - real time data	187	csv, json, app	85	Electricity production in Finland - real time data	192	csv, json, app
18	Transmission between Finland and Northern Sweden - real time data	87	csv, json, app	86	Automatic Frequency Restoration Reserve, price, up	52	csv, json
19	Transmission between Finland and Russia - real time data	195	csv, json, app	87	Automatic Frequency Restoration Reserve, price, down	51	csv, json
20	Transmission between Finland and Estonia - real time data	180	csv, json, app	88	Time deviation - real time data	206	csv, json, app
21	Balancing Capacity Market bids	270	csv, json	89	Stock exchange trade FI-RUS-FI	69	csv, json
22	Balancing Capacity Market results	261	csv, json	90	Electricity production prediction - updated hourly	241	csv, json
23	Frequency - historical data	nan	zip	91	Automatic Frequency Restoration Reserve, capacity, up	1	csv, json
24	Frequency - real time data	177	csv, json, app	92	Transmission of electricity between Finland and Northern Sweden - measured hourly data	60	csv, json
25	Frequency containment reserve for disturbances, procured volumes in hourly market	82	csv, json	93	Temperature in Oulu - real time data	196	csv, json, app
26	Frequency containment reserve for disturbances, received bids in hourly market	286	csv, json	94	Total production capacity used in the wind power forecast	268	csv, json
27	Frequency containment reserves for disturbances, hourly market prices	81	csv, json	95	Temperature in Rovaniemi - real time data	185	csv, json, app
28	Peak load power - real time data	183	csv, json, app	96	Stock exchange capacity FI-RUS	102	csv, json
29	Industrial cogeneration - real time data	202	csv, json, app	97	Transmission of electricity between Finland and Russia - measured hourly data	58	csv, json
30	Hour change regulation, down-regulation	239	csv, json	98	Electricity production prediction - premilinary	242	csv, json
31	Hour change regulation, up-regulation	240	csv, json	99	Automatic Frequency Restoration Reserve, activated, down	53	csv, json
32	The sales price of production imbalance electricity	93	csv, json	100	The price of comsumption imbalance electricity	92	csv, json
33	Surplus/deficit, cumulative - real time data	186	csv, json, app	101	Electricity production in Finland	74	csv, json
34	Wind power production - real time data	181	csv, json, app	102	Commercial transmission of electricity between FI-EE	140	csv, json
35	Wind power generation - hourly data	75	csv, json, app	103	Transmission of electricity between Finland and Norway - measured hourly data	57	csv, json
36	Hydro power production - real time data	191	csv, json, app	104	Special regulation, down-regulation	118	csv, json
37	Nuclear power production - real time data	188	csv, json, app	105	Electricity production, reserve power plants and small-scale production - real time data	205	csv, json, app
38	Day-ahead transmission capacity SE1-FI – planned	142	csv, json	106	Frequency Containment Reserve for Normal operation, hourly market bids	285	csv, json
39	Intraday transmission capacity FI - SE1	44	csv, json	107	Frequency Containment Reserve for Normal operation, activated	123	csv, json
40	Day-ahead transmission capacity FI-SE1 – planned	143	csv, json	108	Bilateral trade capacity FI-RUS	101	csv, json
41	Intraday transmission capacity SE1-FI	38	csv, json	109	Transmission of electricity between Finland and Åland - measured hourly data	280	csv, json
42	The sum of the down-regualtion bids in the Balancing energy market	105	csv, json	110	Activated down-regulation power	252	csv, json
43	The sum of the up-regulation bids in the balancing energy market	243	csv, json	111	Ordered up-regulations from Balancing energy market in Finland	34	csv, json
44	Day-ahead transmission capacity FI-SE3 – official	27	csv, json	112	Stock exchange capacity RUS-FI	67	csv, json
45	Transmission capacity RUS-FI	63	csv, json	113	Day-ahead transmission capacity FI-SE3 – planned	145	csv, json
46	The buying price of production imbalance electricity	96	csv, json	114	Solar power generation forecast - updated once a day	247	csv, json
47	Intraday transmission capacity FI-EE – real time data	114	csv, json	115	Frequency Containment Reserve for Normal operation, hourly market volumes	80	csv, json
48	Commercial transmission of electricity between FI-SE3	32	csv, json	116	Bilateral trade capacity RUS-FI	65	csv, json
49	Bilateral trade capacity RUS-FI, unused	64	csv, json	117	Congestion income between FI-SE3	71	csv, json
50	Intraday transmission capacity FI-SE3	45	csv, json	118	Activated up-regulation power	253	csv, json
51	Day-ahead transmission capacity SE1-FI – official	24	csv, json	119	Day-ahead transmission capacity SE3-FI – planned	144	csv, json
52	Automatic Frequency Restoration Reserve, capacity, down	2	csv, json	120	Solar power generation forecast - updated hourly	248	csv, json
53	Automatic Frequency Restoration Reserve, activated, up	54	csv, json	121	Frequency Containment Reserve for Normal operation, hourly market prices	79	csv, json
54	Intraday transmission capacity SE3-FI	39	csv, json	122	Frequency containment reserves for disturbances, nordic trade	289	csv, json
55	Electricity consumption forecast - updated hourly	166	csv, json	123	Price of the last activated up-regulation bid - real time data	22	csv, json
56	Electricity production, surplus/deficit - real time data	198	csv, json, app	124	Congestion income between FI-EE	48	csv, json
57	Bilateral trade capacity FI-RUS, unused	49	csv, json	125	Intraday transmission capacity RUS-FI	66	csv, json
58	Transmission of electricity between Finland and Central Sweden - measured hourly data	61	csv, json	126	Down-regulation bids, price of the last activated - real time data	251	csv, json
59	Commercial transmission of electricity between FI-SE1	31	csv, json	127	Down-regulation price in the Balancing energy market	106	csv, json
60	Intraday transmission capacity FI-EE	113	csv, json	128	Congestion income between FI-SE1	70	csv, json
61	Intraday transmission capacity FI-RUS	50	csv, json	129	Planned weekly capacity from north to south	28	csv, json
62	Measured transmission of electricity in Finland from north to south	30	csv, json	130	Day-ahead transmission capacity FI-SE1 – official	26	csv, json
63	Day-ahead transmission capacity EE-FI – official	112	csv, json	131	Day-ahead transmission capacity SE3-FI – official	25	csv, json
64	Planned transmission capacity RUS-FI	127	csv, json	132	Frequency Containment Reserve for Normal operation, foreign trade	287	csv, json
65	Planned transmission capacity FI-RUS	41	csv, json	133	Up-regulating price in the Balancing energy market	244	csv, json
66	Transmission of electricity between Finland and Estonia - measured hourly data	55	csv, json	134	Balancing Capacity Market price	262	csv, json
67	Transmission capacity FI-RUS	103	csv, json	135	Frequency containment reserves for disturbances, reserve plans in the yearly market	290	csv, json
68	Planned weekly capacity from south to north	29	csv, json	136	Frequency Containment Reserve for Normal operation, yearly market plans	288	csv, json

Table 4.1: Available Fingrid Open Datasets, summarized from source [20].

4.1.1.2 Statnett RestApi

As the data being displayed on the Norwegian TSOs *state of the system* map display, similar transparent datasets being used in the map service is also made transparently available through Statnett's RestApi platform [21]. This services available transparent datasets, primarily being Norwegian power flows, production, consumption and frequency, is included into this work through the created client module contained in the statnettrestapi.py module.

4.1.1.3 Energinet Datahub

Another provider of transparent system state data within the Nordic system is the Danish TSO. Serving its state data on Energinets Energy Data Service [22], consisting of 51 available datasets concerning the Danish transmission system state operations. The platforms API service is made accessible on most platform using the standards found in *ckan*-caller specification. As most datasets related to the full Nordic system is covered on the Fingrid platform, a client module to include this platform into the model has not been created at this instance.

4.1.1.4 SvK Elmarknadshubb

Similarly to the other Nordic TSOs, SvK is working towards publishing transparent data on their open data platform; *Elmarknadshubben* [23]. Unfortunately to this projects work, as of September 22. 2020, due to Swedish legislation's, the project is postponed and not yet made available to be implemented into the Nordic Transparency Model at this time.

4.1.1.5 Entso-E Transparency Platform

Being the common platform for all Nordic subsystems, the ENTSO-E transparency platform as the single most important source for transparency state data within the Nordic power system is accessible through use of personal api-key, provided on free registration. Confined in this project repository's large *entsoetransparency.py* file, the full content on the platform has been made strongly linked to the Python scientific platform for use in this project, and other works as a soon to be published open library client. In order to ensure correct service static values for use in a constantly changing ENTSO-E electrical system, efforts has been made to create a web-scraper service, ensuring the client service parameters is up to date. In the platforms use of terms, ENTSO-E embrace all services working to ensure transparency in data within the electrical markets.

Available datasets and examples of this clients easy pythonic use is shown in Figure 4.2.

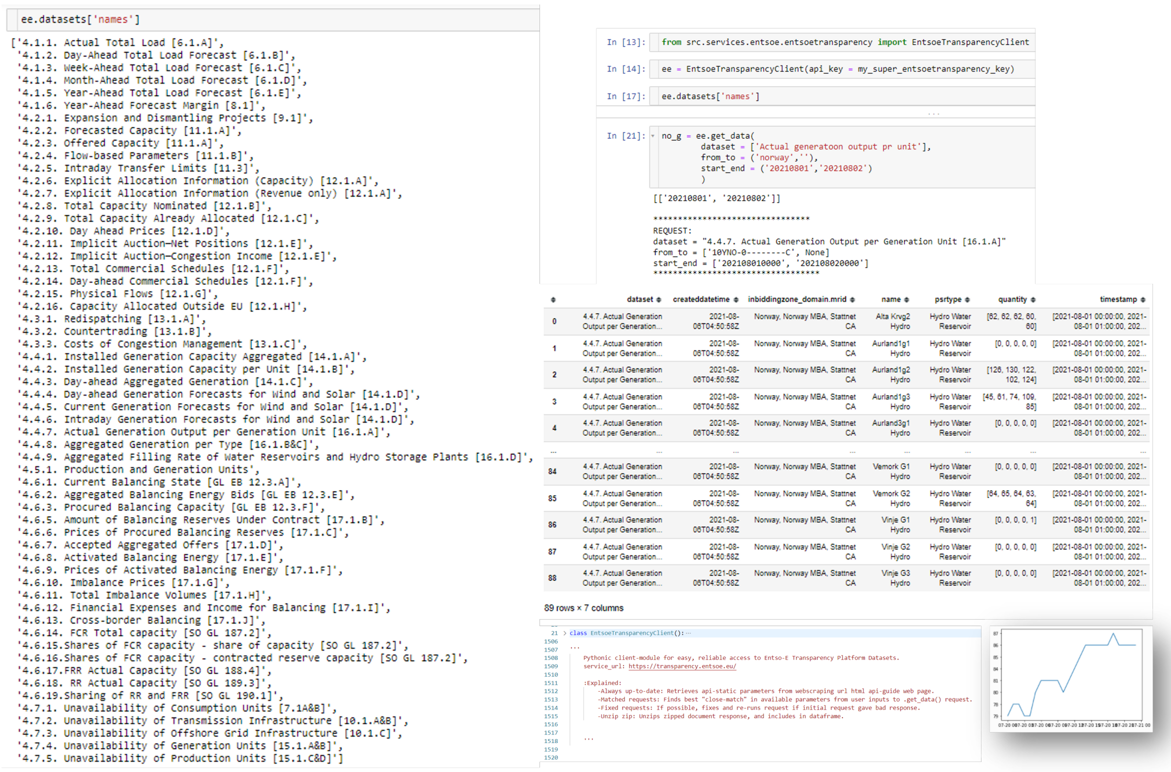
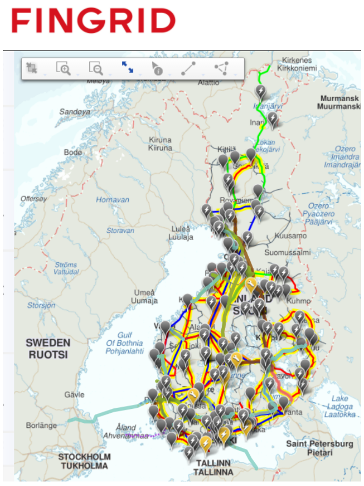


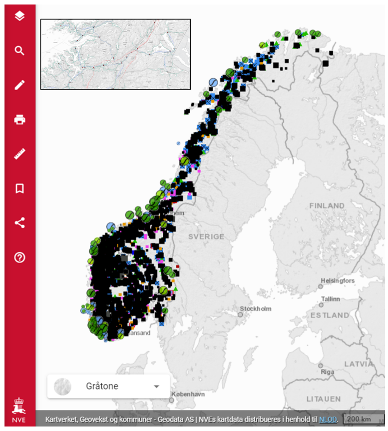
Figure 4.2: Entsoe Transparency Client Preview

4.1.2 Nordic Network Data

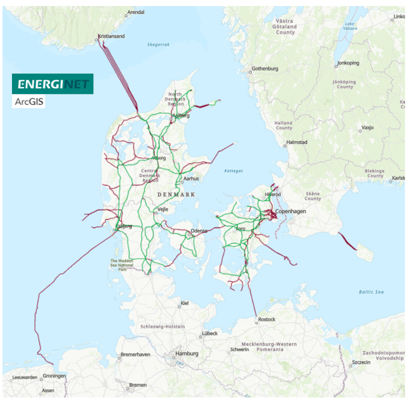
Transparent data on the Nordic networks was initially restricted to static information found in published reports, and on the official static maps as show in Figure 2.1. Still, working towards this works objectives on finding strong transparent dynamic sources on the Nordic networks, finally closing in at the end of this works, strong transparent data sources on the Nordic networks was found, as shown in summary in Figure 4.3.



(a) Fingrid,
Navici Map [24]



(b) Statnett,
NVE Map [25]



(c) Energinet,
arcGIS Map [26]

(d) SvK,
Lantmäteriet Map [27]

Figure 4.3: Nordic Networks Maps

4.1.2.1 Finland, Fingrid

Fingrid Navici Map Client

Hosted on the Fingrid Navici Map platform, is a actively maintained network representation of the Finnish electrical power system. As the platform contain no service for easy access and download of the data, investigative research and work gave results in the creation of a easy to use client, *fingridnavici.py* module, providing updated access to the map open WMS service, hence the official updated Finnish networks data. Showcasing its available datasets and ease of use in Figure 4.7. Adding to the updated network data, this service also provides updated operational states linked to transmission downtime and active and planned projects.

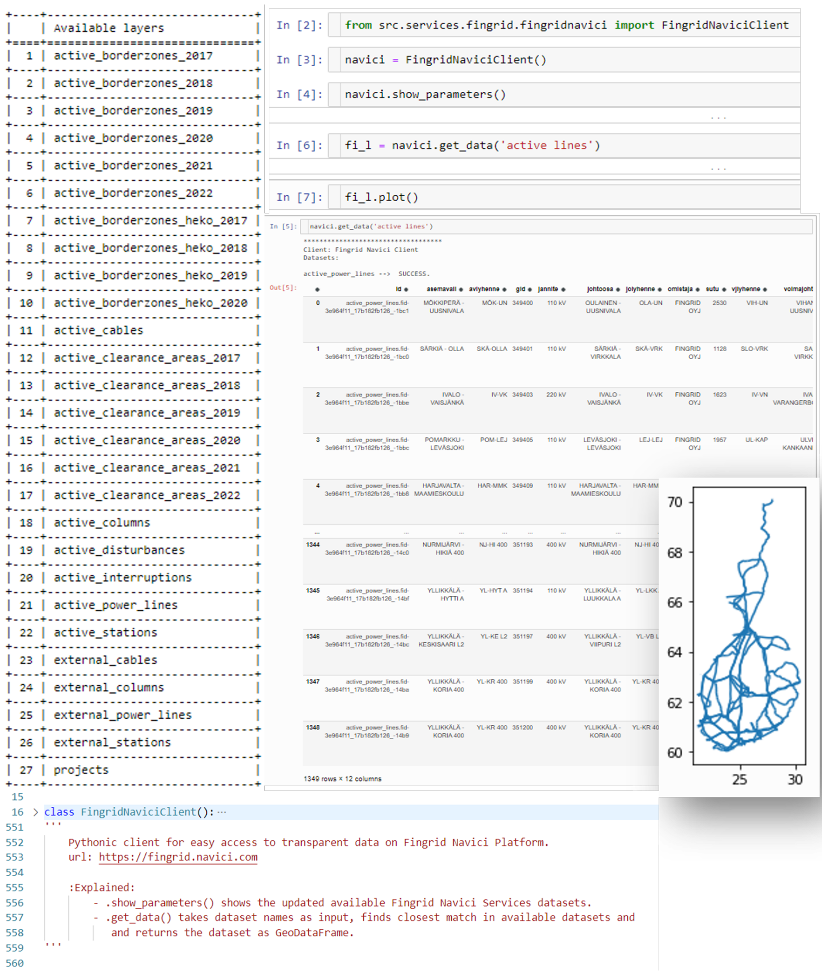


Figure 4.4: Fingrid Navici Client Preview

In addition to the network being hosted on the navici platform, Fingrid actively published a list on all of its systems power plant units with registered capacities above 1MW, found through search on ”Voimalaitosrekisteri” on the regulatory Energy Autority platform [28].

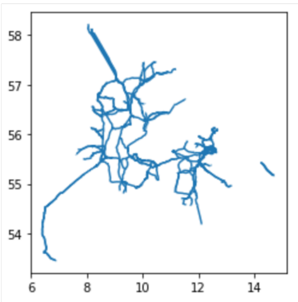
4.1.2.2 Denmark, Energinet

Energinet ArcGIS REST

A detailed geopsacial model representation of the Danish power system, hosted by Energinet has been discovered on the Energinet ArcGISs platform [26]. Linking this sub-network to the model is the created *energinetgis.py*-module, with datasets and module use as shown in Figure 4.5.

```python

class EnerginetGisClient():

    def __init__(self):
        pass

    def get_lines(self): ...

    def get_stations(self): ...
```

```
In [10]: from src.services.energinet.energinetgis import EnerginetGisClient

In [11]: eg = EnerginetGisClient()

In [12]: dk_l = eg.get_lines()

In [13]: dk_l.plot()
```



	OBJECTID	Byggenavn	Spaending	Shape_Length	DGD_TIMESTAMP	geometry	Type
0	1	HL1281 Stasevang-Teglstrupgård	132.0	18384.942954	1628182849309	LINESTRING (12.47105 55.88883, 12.47100 55.888...	lin
1	2	Landerupgård-Odense Øst	400.0	614.899696	1628182849309	LINESTRING (10.49741 55.36208, 10.50103 55.363...	lin
2	3	Læsø Vest-Læsø Øst	250.0	17412.326214	1628182849309	LINESTRING (10.90349 57.25243, 10.90687 57.252...	lin
3	4	Magstrup-Landerupgård	400.0	6850.018782	1628182849309	LINESTRING (9.44825 55.45952, 9.44675 55.46258...	lin
4	5	Magstrup-Landerupgård	400.0	22647.977768	1628182849309	LINESTRING (9.36263 55.27800, 9.36310 55.28050...	lin
...	...	...	...	...	...	...	.
6201	5835	(AFV) HK15026 Klim Fjordholme-St. Klim Fjordholme	150	88.975571	1628182845044	LINESTRING (9.14432 57.05818, 9.14432 57.05818...	cabl
6202	5836	(AFV) HK15026 Klim Fjordholme-St. Klim Fjordholme	150	89.313607	1628182845044	LINESTRING (9.14430 57.05813, 9.14429 57.05813...	cabl
6203	5837	Blåbjerg-Endrup	150	0.512220	1628182845044	LINESTRING (8.70503 55.53217, 8.70504 55.53217)	cabl
6204	5838	Blåbjerg-Endrup	150	55764.570722	1628182845044	LINESTRING (8.21378 55.75247, 8.21381 55.75249...	cabl
6205	5839	HK15034 Fraugde Vest-Fraugde	150	1694.313279	1628182845044	MULTILINESTRING ((10.48449 55.36404, 10.48449 ...	cabl

6206 rows × 7 columns

Figure 4.5: Energinet GIS Client Preview

In addition to the Danish grid geospacial data, Energinet published their official simulations Common Grid Model, providing static data on the TSOs official systems representation, without its geospacial representation. [29].

4.1.2.3 Norway, Statnett

NVE ArcGIS REST

The Norwegian Water Resources and Energy Directorate (NVE), as part of the Norwegian Ministry of Petroleum and Energy, is responsible for managing the Norwegian water and energy resources, as its national power supplies. NVE believes in open dialog and provides their open datasets as services on their ArcGIS REST Service Platform [25].

NVE provides open data on topology of the Norwegian Electrical Power Systems Transmission, Hydro- and Wind ressources. Norwegian topology data is extracted from its official database, NetBas. Although metadata states last revision was made in 2011, the dataset is assumed still maintained at some extend as data timestamps as recent as 2020 is being observed. Linking this dataset to the python science platform, and this model is the created *nvegis.py*-module, with available datasets and use as shown in Figure 4.6.

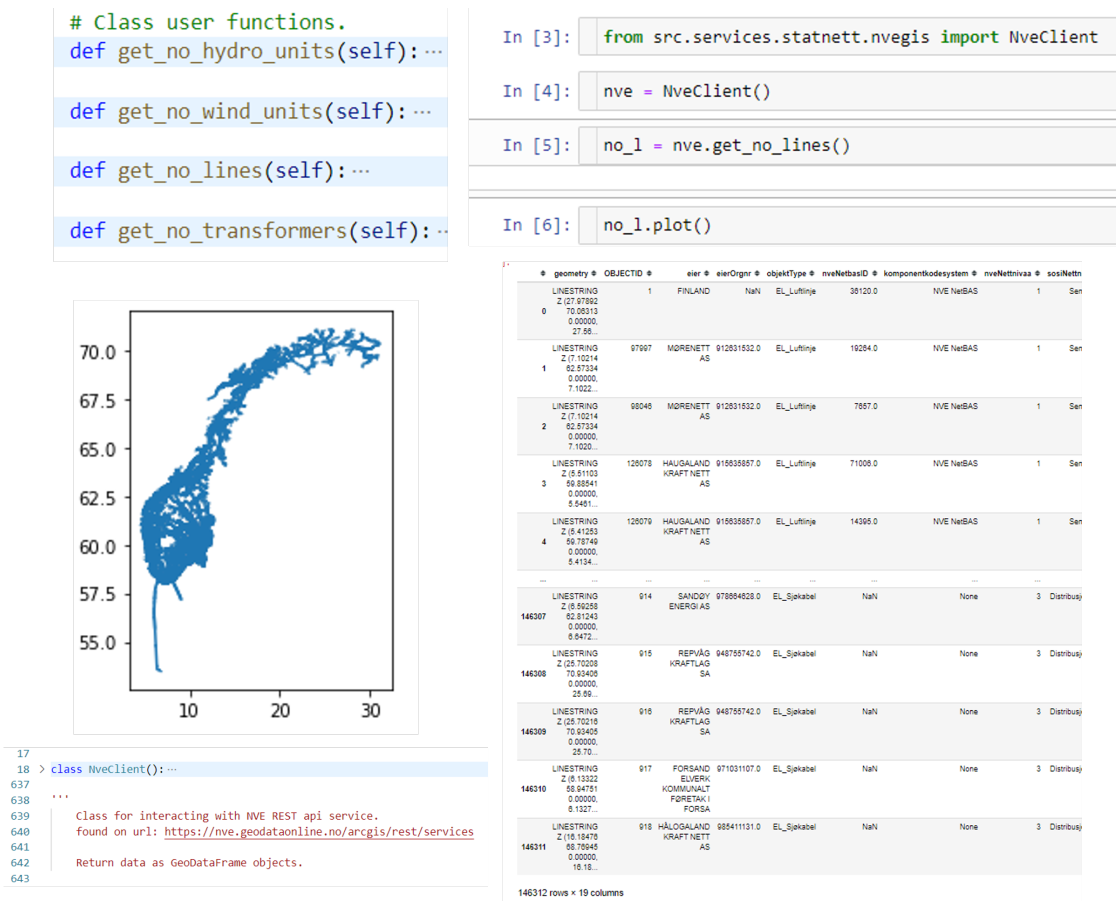


Figure 4.6: NVE ArcGIS Client Preview

In addition to the detailed geospacial data published by NVE, Statnett hosts their own ArcGIS model, being actively maintained on [30]. Unfortunately, access to these datasets are restricted and less detailed than the datasets obtained from the NVE platform.

4.1.2.4 Sweden, SvK

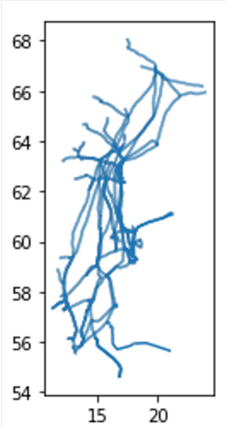
Lantmäteriet Geodata

The Lantmäteriet Autority, as part of the Swedish Financial Supervision Government Agency, is objected to keep mappings on various parts of operations in relevance to the Swedish country operations. As part of this mapping objective, is mapped Swedish Electrical Power System made available as part of it's dataset services [27].

The actively maintained published data is accessed and linked to the projects model using the created *svklantmateriet.py*.

	datasets
0	STATIONER
1	STATIONSOMRÅDEN
2	SVK_LEDNINGAR
3	SVK_STOLPAR

```
In [9]:  from src.services.svk.lantmaterietgeodata import LantmaterietClient
In [10]: lmg = LantmaterietClient()
In [11]: svk_n = lmg.get_svk_net()
         ...
In [24]: svk_l = svk_n['SVK_LEDNINGAR']
In [27]: svk_l.plot()
```



	geometry	FÖRLÄGGN_	SPÄNNING
0	MULTILINESTRING ((16.77991 63.63289, 16.78098 ...	Luftledning	220
1	MULTILINESTRING ((15.68248 64.05959, 15.68305 ...	Luftledning	220
2	MULTILINESTRING ((14.81359 64.35767, 14.81388 ...	Luftledning	220
3	MULTILINESTRING ((14.17325 64.50146, 14.17348 ...	Luftledning	220
4	MULTILINESTRING ((14.14689 64.55679, 14.14703 ...	Luftledning	220
...	...	...	...
442	MULTILINESTRING ((18.13688 60.40313, 18.13839 ...	Luftledning	500
443	MULTILINESTRING ((18.16265 60.41210, 18.16477 ...	Kabel i vatten	500
444	LINESTRING (18.13679 60.40321, 18.13678 60.403...	Kabel i mark	500
445	MULTILINESTRING ((18.13437 60.40397, 18.13451 ...	Luftledning	0
446	MULTILINESTRING ((12.32114 58.30072, 12.32209 ...	Luftledning	130

447 rows × 3 columns

```

class LantmaterietClient():
    '''
    Client for easy access to updated transparent data on Svk lines, stations.
    urls: https://gis-services.metria.se/svkfeed/svk_topfeed.xml, https://gis-services.metria.se/svkfeed/svk_subfeed.xml

    '''

    def __init__(self):···

    def get_svk_net(self, crs='EPSG:4326'):···

```

Figure 4.7: SvK Lantmateriet Client Preview

4.2 The Nordic Transparency Model

As extensive work was put into finding, gaining access, and creating the modelling sources strong dynamic data linkages to the python scientific platform and to this model, preliminary works and results analysis of the resulting transparent data and works in modelling creation is included in this section.

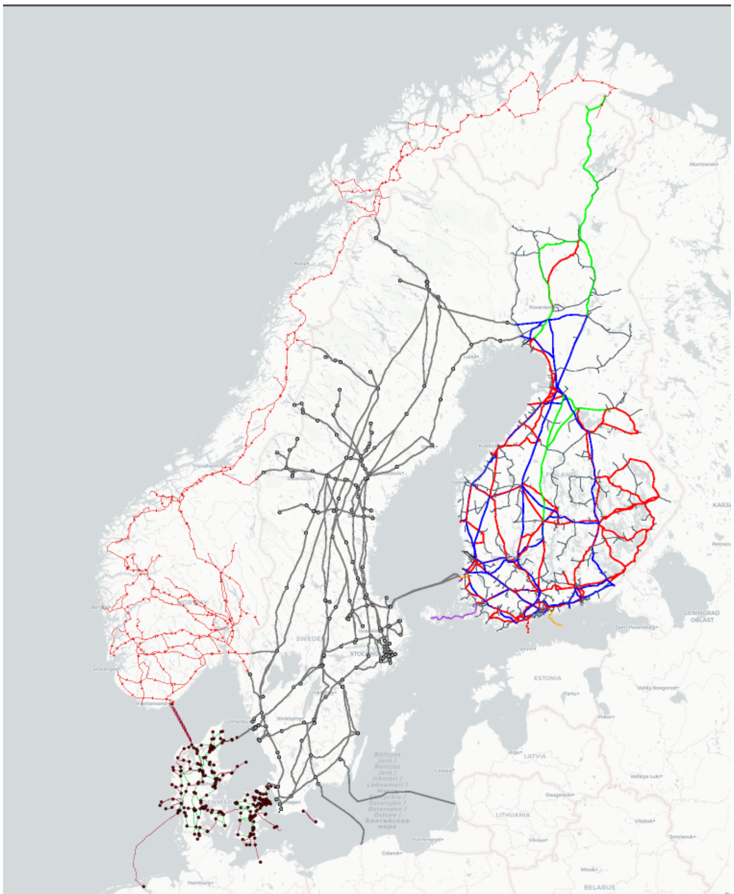
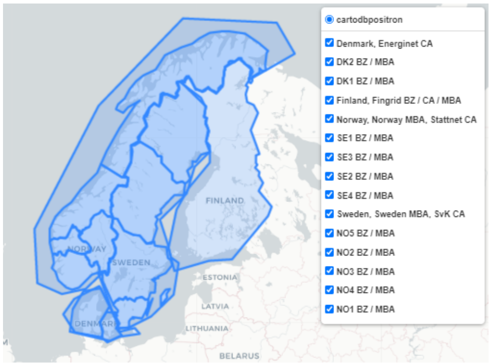


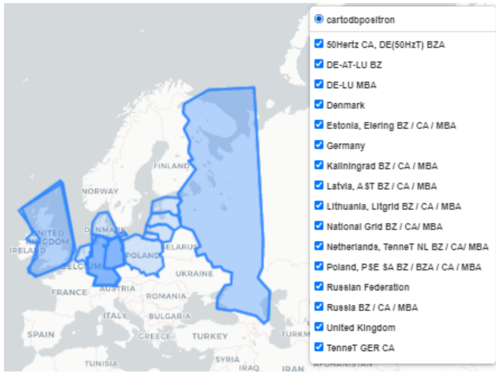
Figure 4.8: The Nordic Transparency Raw Source Topology

4.2.1 Subsystem Areas

In order to link the models geospacial network data to the subsystems operational states data, geospacial subsystem area geometries has been created, following the subsystem confinements given in the recent ENTSO-E bidding zone review [31], with equal area and naming conventions as used in the Nordic main source on operational states, ENTSO-E transparency platform. In order to model both internal Nordic system states, and it's interactions with neighbouring subsystems, all internal as listed in Table 4.2 and neighbouring subsystems has been modelled as areas, shown in Figure 4.9.



(a) Nordic Subsystems



(b) Neighbouring Subsystems

Figure 4.9: Nordic and Neighbouring Subsystems

<table>
<tr><th colspan="3">The Nordic System State Model Areas</th></tr>
<tr><th>Control Areas (CA)</th><th>Market Bidding Areas (MBA)</th><th>Bidding Zones (BZ)</th></tr>
<tr><td rowspan="2">Denmark, Energinet CA</td><td>DK1 BZ / MBA</td><td>DK1 BZ / MBA</td></tr>
<tr><td>DK2 BZ / MBA</td><td>DK2 BZ / MBA</td></tr>
<tr><td>Finland, Fingrid BZ / CA / MBA</td><td>Finland, Fingrid BZ / CA / MBA</td><td>Finland, Fingrid BZ / CA / MBA</td></tr>
<tr><td rowspan="6">Norway, Norway MBA, Stattnet CA</td><td>Norway, Norway MBA, Stattnet CA</td><td></td></tr>
<tr><td>NO1 BZ / MBA</td><td>NO1 BZ / MBA</td></tr>
<tr><td>NO2 BZ / MBA</td><td>NO2 BZ / MBA</td></tr>
<tr><td>NO3 BZ / MBA</td><td>NO3 BZ / MBA</td></tr>
<tr><td>NO4 BZ / MBA</td><td>NO4 BZ / MBA</td></tr>
<tr><td>NO5 BZ / MBA</td><td>NO5 BZ / MBA</td></tr>
<tr><td rowspan="5">Sweden, Sweden MBA, SvK CA</td><td>Sweden, Sweden MBA, SvK CA</td><td></td></tr>
<tr><td>SE1 BZ / MBA</td><td>SE1 BZ / MBA</td></tr>
<tr><td>SE2 BZ / MBA</td><td>SE2 BZ / MBA</td></tr>
<tr><td>SE3 BZ / MBA</td><td>SE3 BZ / MBA</td></tr>
<tr><td>SE4 BZ / MBA</td><td>SE4 BZ / MBA</td></tr>
</table>

Table 4.2: Nordic-T Subsystem Areas, adopted from [32]

4.2.2 Exchanges

Utilizing the created models subsystem areas, and the pythonic nature of the created *entsoe-transparency.py* client module, the Nordic operational state exchanges is made discoverable at any instance through *blind search*. Requesting data on physical flows, using the Nordic areas and a time-period as input, the client module request physical flow data between all the input areas, against all available service areas. Determining physical flows from blind search, combined with the web-scraper maintenance of the client module, added or removed physical model exchanges is automatically included in the models dynamic state modelling as they are included in the transparency platforms service. Hence, modelling of the physical flows state is ensured true up on modeling of all previous, present, and future interconnections and exchanges.

Figure 4.10 shows the models exchange state results from blind search on the date 1. January 2021.

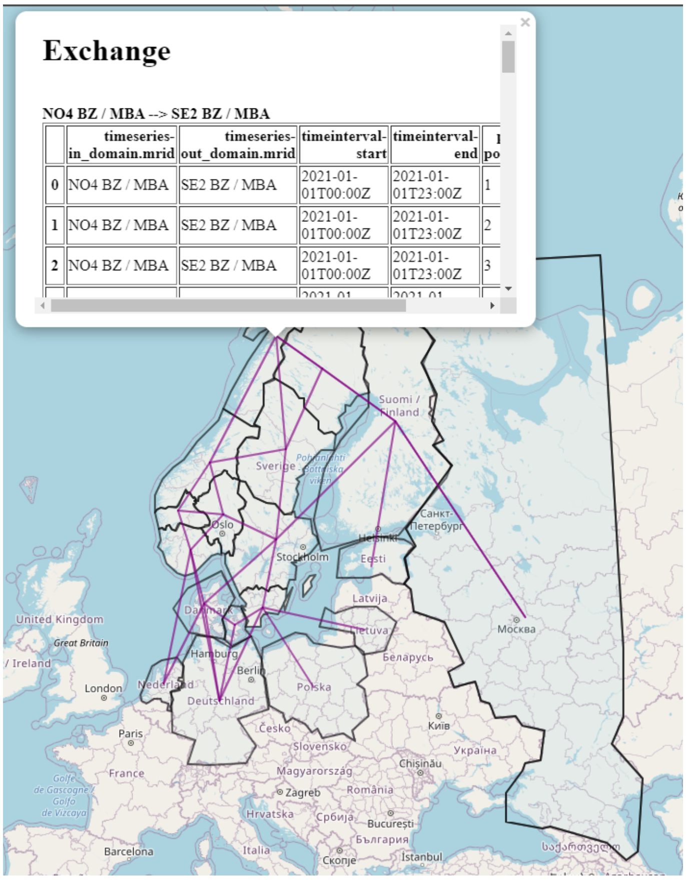
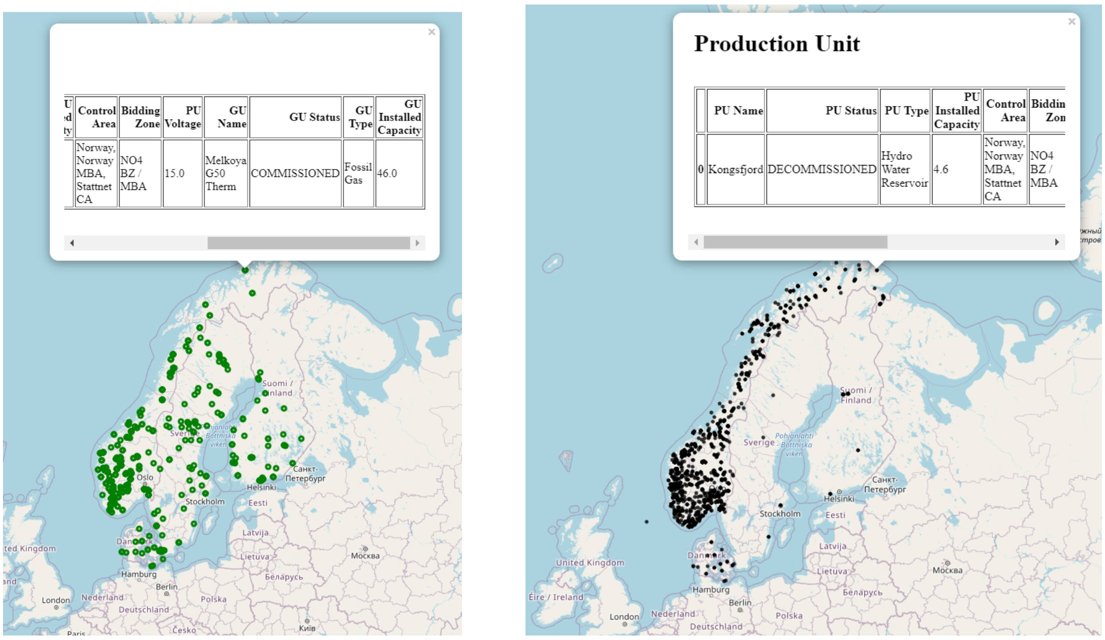


Figure 4.10: Nordic Exchanges

4.2.3 Generations

Requesting data on subsystem generations return all subsystems commissioned production units above 100MW, and their hourly measured or presumed generations. From name and location searches made against major open world generators datasets [33], Again utilizing the created model areas, faulty geospacial data from the database search was excluded, and missing locations manually added from internet search, primarily data found on the generation plants official cites.

As results, all registered Nordic generation units on the transparency platform is provided their geospacial locations as shown in Figure 4.11, giving a detailed description of the subsystem generation states. The Nordic mix of subsystems generations types, easily accesses using the entsoetransparency-client is listed in Table 4.3.



(a) Commissioned units

(b) Decommissioned units

Figure 4.11: Nordic Generations

Installed Capacity per Production Type [MW]																
		Production Type														
Year	**Area**	Fossil Peat	Nuclear	Fossil Hard coal	Wind Onshore	Hydro Run-of-river and poundage	Hydro Water Reservoir	Wind Offshore	Other renewable	Solar	Waste	Fossil Gas	Fossil Oil	Other	Biomass	**Total Grand Capacity**
2021	DK1 BZ / MBA	-	-	1943	3725	7	-	1277	117	878	211	1049	211	-	695	10113
	DK2 BZ / MBA	-	-	1471	756	0	-	423	25	422	173	605	799	-	1177	5851
	Denmark, Energinet CA	**-**	**-**	**3414**	**4481**	**7**	**-**	**1700**	**142**	**1300**	**384**	**1654**	**1010**	**-**	**1872**	**15964**
2021	**Finland, Fingrid BZ / CA / MBA**	**1135**	**2794**	**1682**	**2422**	**3153**	**-**	**-**	**273**	**7**	**163**	**1849**	**1089**	**436**	**1860**	**16863**
2020	NO1 BZ / MBA	-	-	-	166	999	1937	-	-	-	-	0	-	0	-	33044
	NO2 BZ / MBA	-	-	-	1145	147	10690	-	-	-	-	5	-	0	-	11987
	NO3 BZ / MBA	-	-	-	1090	2	3452	-	-	-	-	0	-	0	-	4544
	NO4 BZ / MBA	-	-	-	668	1	4753	-	-	-	-	270	-	0	-	5692
	NO5 BZ / MBA	-	-	-	0	0	7353	-	-	-	-	367	-	0	-	7720
	Norway, Norway MBA, Stattnet CA	**-**	**-**	**-**	**3069**	**1149**	**28185**	**-**	**-**	**-**	**-**	**642**	**-**	**0**	**-**	**33045**
2021	SE1 BZ / MBA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SE2 BZ / MBA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SE3 BZ / MBA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SE4 BZ / MBA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sweden, Sweden MBA, SvK CA	**-**	**6871**	**-**	**10017**	**-**	**16334**	-	-	**-**	**-**	**-**	**-**	**7977**	**-**	**41199**
	Nordic	**1135**	**9665**	**5096**	**19989**	**4309**	**44519**	**1700**	**415**	**1307**	**547**	**4145**	**2099**	**8413**	**3732**	**107071**

Table 4.3: Nordic Installed Generations State Summary, through client from [32]

4.2.4 Networks

Statements found on the subsystem TSOs web pages provide official descriptions on the Nordic subsystems transmissions, stating 14 600 km lines and 120 substations in Finland, 15 000 km lines and 160 transformers in Sweden, 11 000 km lines and 150 substations in Norway and 7000 km lines in Denmark. As discovery of many of the high quality, actively maintained, dynamically accessible transparent data sources came at a late stage in this work, and given the efforts made to gain access to the transparent data linking them to this model, only preliminary filtering and analysis is made available at this time. From its preliminary analysis, its transparent data in total consists of 24 000 km lines in Finland, 53 000 km in Sweden, 90 000km in Norway and 7 000 km in Denmark. Data procured for Finland, Sweden and Norway is seen to be highly detailed, including parallel lines and additional line lengths from external connections.

From its transparent sources, important to link attributes in a graph model, all datasets lines has attributes on line types and operating voltages. Combined with line lengths being computed from its geospacial attribute, there exist great possibilities in further studies on further creation of this high detailed models base network of weighted links and nodes. The combined subsystems transparency, networks raw networks collection from sources is shown at this sections beginning in Figure 4.8. Filtered and combined, the full network and its operational voltage levels is shown in 4.12.

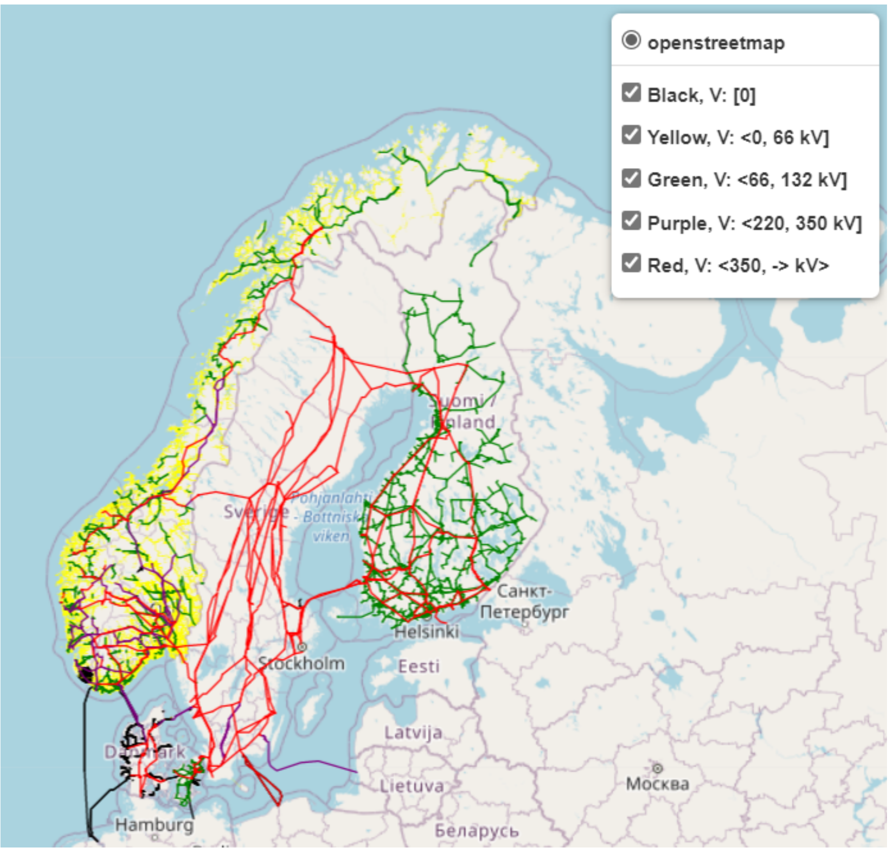


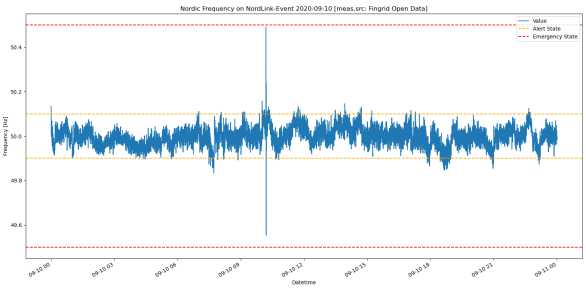
Figure 4.12: Nordic Transparency Network Voltage-Levels

4.2.5 Transparent State Observations

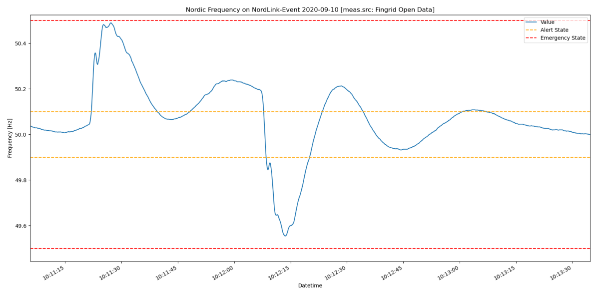
The strong linkage created to its transparent sources allows for additional observations, analysis and validation to be made directly within the model

Making searches on the systems dynamic responses, in datasets such as Nordic kinetic energy and high accuracy real time frequency measurements hosted on the Fingrid platform, accessed using the fingridopendata.py client, Nordic operational responses is discovered.

From search on the Nordic frequency, measured system responses violating with the Nordic operational security requirements is used to discover Nordic contingency events and the Nordic response to the event. In search results, a major contingency event was discovered as shown in Figure 4.13b. From literature search, the discovered event was found to be the incident of a test error on NordLink, causing a minute lasting step import of +1400MW from Germany into southern Norway. In-model discovery and analysis of similar Nordic responses using the transparency linkage, as one of this models key features, ensures improved model tuning and results validations.



(a) Full day



(b) Closeup

Figure 4.13: Nordic State Frequency Response to NordLink 2020

Chapter 5

Discussion

5.1 Accessing Transparency for Research

In this work, great effort and energy is spent on discovering, accessing and linking key transparency data sources concerning Nordic and European Electrical Power System Topology and Operations to this projects model and modelling platform. At several stages in the process, different paths has been assessed, as to make reasonable assumptions on the Nordic topology and operations for the data not initially discovered or made easily available. Anyways, this works focus on transparency data at its center, further research and work was continued, building the strong transparency links contained in this works built transparency client service modules to search transparency results.

Keeping focus on data transparency in power system modelling, *first-principles* dynamic models i able to be created at any instance, providing high validated, quality data as results.

5.2 Transparent Power System Cyber-Attacks

As showcased in this work, transparent data in the Nordic, and other systems, exist and is utilizable for implementation into models for analysis. As researchers with aims on improving the power systems analysis and operational understanding now are able to gain high quality power systems data, the same data may also be accessed and utilized with malicious intends. With profound knowledge of the electrical power systems operations, and the increased penetration of digital power system devices, a common concern is the possibilities for cyber-attacks on system operations and grid elements.

5.3 Open Researchers Nordic Models

As high quality power system data is now being made openly available, and in this and similar works implemented into open researcher platforms, great possibilities is set in making the transition from commercial researching software's into detailed analysis on free open analysis platforms. As for electrical power system analysis in the python scientific environment, dynamic data may be implemented from their sources directly, as in this work, and analysed using prominent open tool-sets as the power system analysis tools in the PyPSA-, ANDES- and pandapower libraries.

Chapter 6

Conclusion and further works

High value transparent modelling data now exist, not only describing the Nordic Electrical Power Systems operational states, but also its high detailed complex networks topologies. Although, not initially made easily accessible for use in dynamic modelling on open scientific platforms, as the python programming environment platform used in this work. Putting work into building the linkage between scientific platforms, and the Nordic transparency data platforms, foresight's great benefits in the continuation of dynamic modelling, analysing and maintenance of high quality open power system models for analysis.

From the created applications ensuring strong linkages between the transparency data platforms, and the scientific analysis and modelling platform, a power system analysis models topology and responses in results may be actively tuned, altered and validated.

As this works has identified, linked, and implemented high quality transparent data sources concerning the Nordic power system topology and operations into a open researchers platform, further works should be put on actively utilizing the transparency linking applications been built in this work. In doing so, to further investigate the Nordic, and possibly other, Transparency Models operational analysis results and use in actively maintained, system representative models for analysis.

Appendices

Appendix A

A.1 Data, Results, Modules in Repository

Due to the large datasets obtained and created in this work, all data, results and created modules related to this work is for for all convenience been made accessible at this projects online web page and repository at https://ocrj.github.io/Nordic-T/. All major transparency sources in addition is referenced to in this work for other direct access.

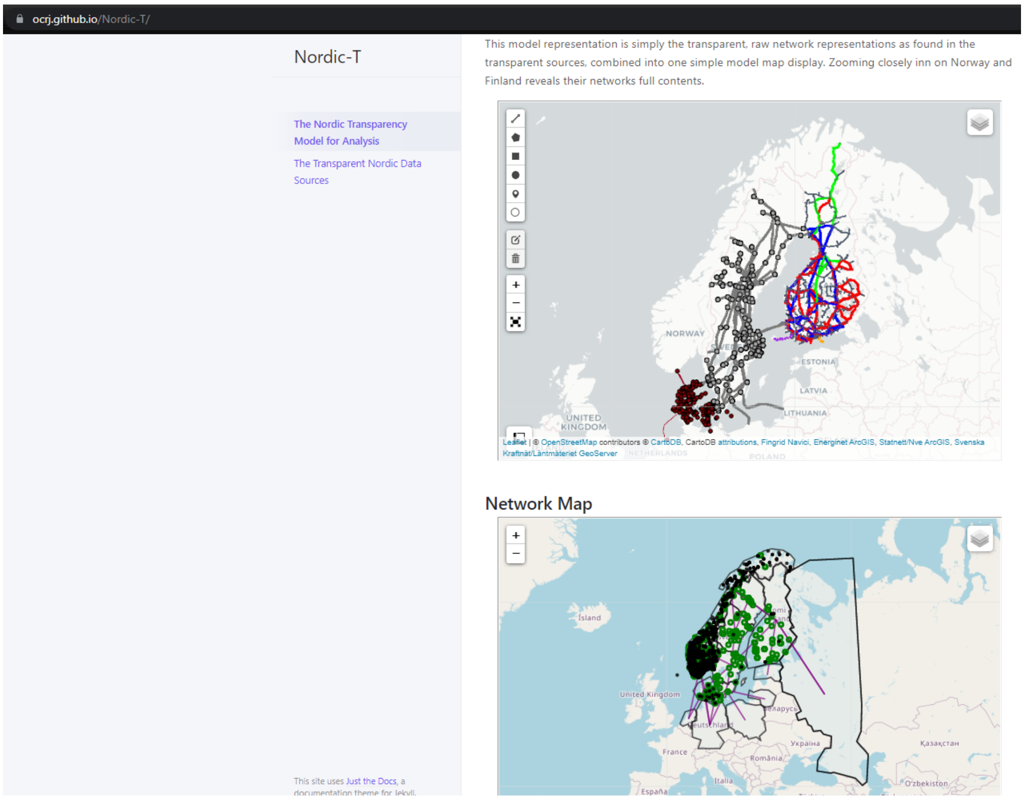


Figure A.1: The Nordic Transparency Model Repository

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