SAFER2028-SINARP Deliverable report,

D1.1.1: Refining the scenarios (T1.1)

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1 Introduction

Considerable work has been done in the first year of SINARP on the generation side, with the addition of Olkiluoto 3, a few residential CHP generators in the south of Finland [1], and numerous new wind parks, first modelled as low-inertia synchronous machines, but by the end of 2023, Floran's wind park modelling [2] was ready for implementation in the external grid model. Early work by Phong, a scholarship Master's student, was able to be harnessed in terms of appropriately lumping the correct amount of wind generation to each relevant 400 kV connection point in the grid model by utilising [1], [3] and [4]. This work has been delivered to VTT for the co-simulations. Phong had also made good progress in lumping consumption, allocated in terms of type, to each connection point, utilising [5], but this was not quite ready for delivery to the team at VTT by the end of the year. Nevertheless, Phong's work brings the scenario modelling up to date, and because he has identified the types of load and generation at each connection point, this will aid future scenario modelling in 2024. What remains, on the generator side, is better modelling of the synchronous machines, perhaps via digital twins to reduce simulation times, and continued effort to better model the power system stabilizers. All this, in addition to keeping up with the connection of new wind parks, photovoltaics, EV charging, and the projection of these activities into the future, will provide plenty of work in the next year or two, but the harnessing of a scholarship funded master's student has been of great benefit in this deliverable.

The other side of scenario modelling is of course the type of fault scenarios we investigate with the full co-simulation model, which consists of the imperfect transmission model (which is rapidly improving!), the internal electrical grid of Loviisa NPP (nuclear power plant) and the Apros thermo-mechanical modelling of the nuclear plant. In 2023, given the multitude of changes (of which only some are implemented) in the transmission grid and the late delivery of the model to VTT for the co-simulations meant that we considered only one type of fault, the tripping of Estlink 2, which causes a voltage rise and frequency disturbance at Loviisa NPP.

2 Generation Modelling

A generic model for synchronous generators has been kept in use from the COSI project, which would warrant refinement in the future, but the main work in scenario modelling has been to lump the wind generation to the appropriate 400kV connection points and utilize the work by Floran Martin in T1.2 [2] to provide generic models of a type IV turbine scaled appropriately to reflect the capacity of the wind power connected to each connection point. The values used at the end of 2023 are given in Table 1. With a scale factor of unity, the installed capacities sum to approximately the maximum available wind power in Finland at the end of 2023, about 5.8 GVA. A more elaborate modelling of generation allocation to the connection points will be available in Phong's Master's thesis, which should be ready by mid-2024.

Table 1

`CoSim.GenPower.MutkalampiWind`	`windScaleFactor * 426e6;`
`CoSim.GenPower.PiipurinmakiWind`	`windScaleFactor * 211.5e6;`
`CoSim.GenPower.VihtavuoriWind`	`windScaleFactor * 151e6;`
`CoSim.GenPower.Pursiala1and2Wind`	`windScaleFactor * 147.7e6;`
`CoSim.GenPower.KristinestadA`	`windScaleFactor * 322e6;`
`CoSim.GenPower.KristinestadB`	`windScaleFactor * 322e6;`
`CoSim.GenPower.TuovilaWind`	`windScaleFactor * 209e6;`
`CoSim.GenPower.MustilankangasWind`	`windScaleFactor * 92.4e6;`
`CoSim.GenPower.OltavaWind`	`windScaleFactor * 91.2e6;`
`CoSim.GenPower.KarppioWind`	`windScaleFactor * 481e6;`

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CoSim.GenPower.KeminmaaWindA	windScaleFactor * 248e6;
CoSim.GenPower.KeminmaaWindB	windScaleFactor * 248e6;
CoSim.GenPower.ValkeusSurplusWind	windScaleFactor * 510e6;
CoSim.GenPower.SimojokiWind	windScaleFactor * 475e6;
CoSim.GenPower.VuolijokiSurplusWind	windScaleFactor * 222e6;
CoSim.GenPower.HirvisuoWind	windScaleFactor * 373e6;
CoSim.GenPower.UlvilaWind	windScaleFactor * 294e6;
CoSim.Genpower.PysaysperaWind	windScaleFactor * 208e6;
CoSim.Genpower.PirttikoskiWind	windScaleFactor * 196e6;
CoSim.Genpower.SeinajokiWind	windScaleFactor * 176e6;
CoSim.Genpower.IsokangasWind	windScaleFactor * 147e6;
CoSim.Genpower.AlajarviWind	windScaleFactor * 143e6;
CoSim.Genpower.PetajaskoskiWind	windScaleFactor * 117e6;

The rest of the generation parameters used in the current grid model are listed in Appendix A.

The scenarios are formed by adjusting the scale factors for generation and consumption according to maximum winter load and minimum summer load, each coupled with high and low wind, with some other seasonal adjustment of generation.

The four sets of scenario settings (listed as Scenario Choices 7 to 10) are given in Table 2.

Table 2 Scale factors used in the four scenarios

Scale factor	Scenario Choice			
	7	8	9	10
windScaleFactor	8.6e-4;	1	8.6e-4	0.6
synchScaleFactor	2.0;	1	0.1	0.1
industrialSynchScaleFactor	2.0;	1	0.5	0.3
urbanCHPscaleFactor	2.0;	1	0.1	0.1
loadScaleFactor	2.0;	2	0.9	0.9

3 Demand modelling

The research to analyse the load types and magnitude at each 400 kV connection point has commenced at the end of 2023, and was not ready for implementation in the co-simulations. The co-simulations used more-or-less homogeneous loading (large industrial loads were included where known), scaled to match the Finnish summer and winter demand using the final parameter in Table 2. Further work may have to refine the present PQ load blocks used in the grid model, as these as well as the voltage source swing bus are compromising the transient responses to faults and other events of interest in the grid relevant to the NPPs. In fact, the changing nature of loads has been pointed out by the steering group as a significant unknown in power systems generally, where most recent effort has been to model the new forms of renewable generation.

The results of Phong's analysis of demand, utilizing data obtained from [Phong's reference 2]

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4 Fault scenario used in 2023 Co-simulations

The final scenario-related consideration concerns the type of fault scenario we consider. In contrast with previous simulations in the COSI project, which consisted of short-circuit faults, NPP tripping and HVDC connections to Sweden tripping while importing power, we decided, in the first year of SINARP, to study an overvoltage event near the Loviisa NPP, namely, the tripping of Estlink2, which is normally exporting 650 MW of power to Estonia. Two main phenomena arose from these simulations. The first was the expected overvoltage. The second was high frequency harmonics, evident in the voltage and frequency waveforms. We have yet to benchmark these simulated results with measured harmonics in the grid, but this is a real phenomenon, although clearly exaggerated in simulation, that may have an adverse impact on the nuclear plant, as can be seen from grid-only simulation results for Scenario 10 (high wind and low demand, with Estlink 2 tripping at 10 seconds). It should be noted that the high frequency disturbance in the results is very dependent on the settings of a saturation block and also a global gain setting in the Phase Lock Loop of the wind turbines. It may be that these will have to be bench-marked with high frequency noise measured by Fingrid in the grid, but at present it would seem these oscillations are overstated in our simulations.

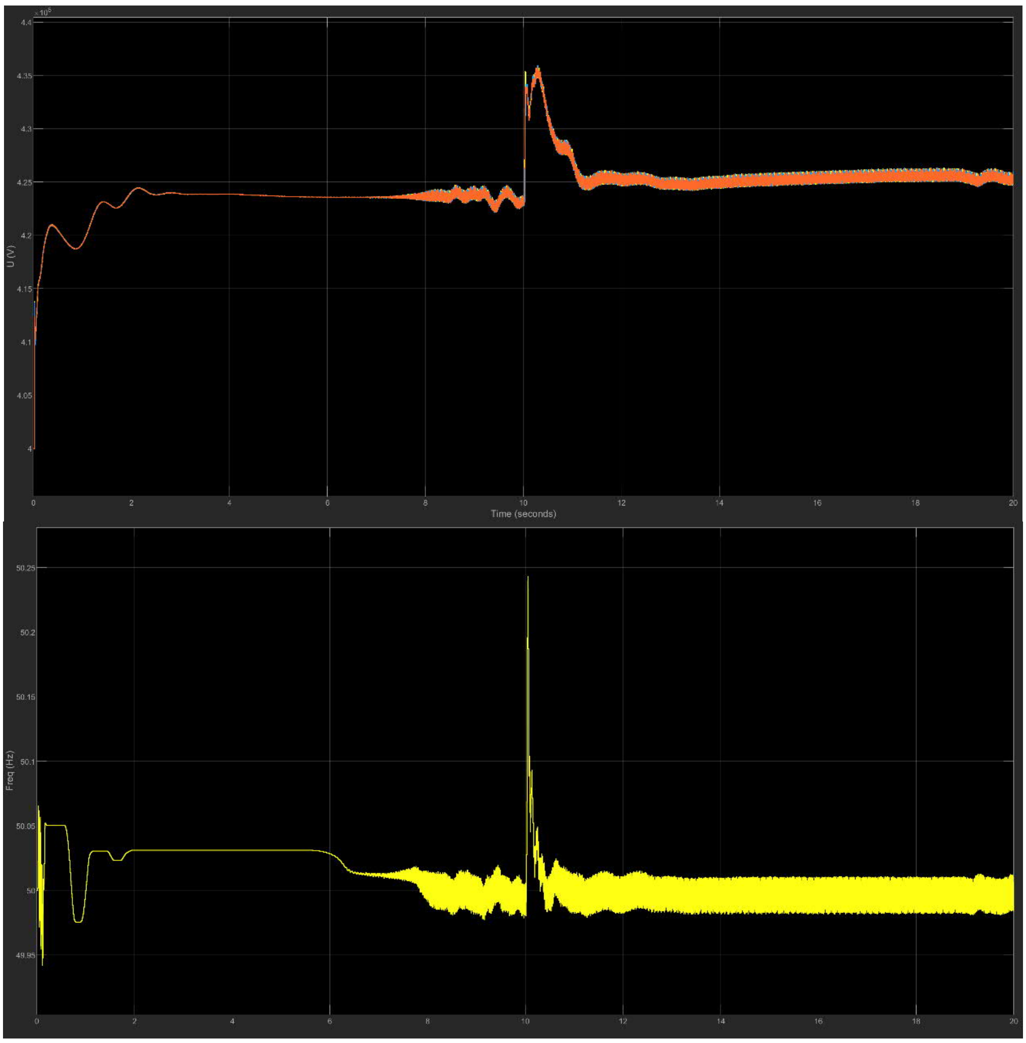

Figure 1 Scenario 10 plots of voltage (above) and frequency (below). It takes about 8 simulated seconds for the model to converge, but harmonics appear when the wind turbines are connected at about 6 seconds.

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5 Discussion

Good progress has been made in terms of grid generation and demand scenarios, with 2024 promising to refine the geographic distribution of demand in Finland, and also produce future scenarios focusing on 2035. Continuing problems with the grid model, however, particularly with its present inability to properly model transients, has restricted the fault scenarios we felt were worth simulating in 2023. To that end, we have only studied the effect tripping Estlink 2 on Loviisa NPP, which is generally felt as a loss of demand in the south of Finland, as Finland is normally exporting power to Estonia through this connection. It nicely compliments investigations of voltage collapse at the end of the COSI project.

References

[1] Energiaviraston voimalaitosrekisteri, 14 November, 2023, https://energiavirasto.fi/toimitusvarmuus

[2] SAFER2028-SINARP deliverable D1.2.1, Digital twin of a wind farm equipped with type IV generator and a grid following controller, Floran Martin, Robert John Millar, and Janne Sepännen

[3] Suomen Tuulivoimayhdistys web page: https://tuulivoimayhdistys.fi/

[4] Fingrid interactive map service: https://karttapalaute.fingrid.fi/

[5] Energiateollisuus, Electricity consumption by municipality 2007-2022: https://energia.fi/en/statistics/electricity-consumption-by-municipality-2007-2021/

Appendix A Generation and demand parameters

Table A1 Generation and demand parameters. Scenario scale factors are given in Table 2

% Swing Bus (420 kV AC) at Djuptjärn	
% HVDC links from Sweden	
CoSim.GenPower.Finnbole	800e6
CoSim.GenPower.Dannebo	400e6
% HVDC links to Estonia	
CoSim.Pdemand.Estlink1	350e6
CoSim.QindDemand.Estlink1	0
CoSim.QcapDemand.Estlink1	0
CoSim.Pdemand.Estlink2	650e6
CoSim.QindDemand.Estlink2	0
CoSim.QcapDemand.Estlink2	0
% Nuclear	
CoSim.GenPower.Loviisa_1	280e6 %507e6 *note: 507e6 was used in grid only simulations
CoSim.GenPower.Loviisa_2	280e6 %507e6 *note: 507e6 was used in grid only simulations

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CoSim.GenPower.Olkiluoto_1	890e6
CoSim.GenPower.Olkiluoto_2	890e6
CoSim.GenPower.Olkiluoto_3	1600e6 - (0 * 350e6)
% Hydro and bio CHP	
CoSim.GenPower.Harjavalta	synchScaleFactor * 105e6
CoSim.GenPower.Isohaara	synchScaleFactor * 106e6
CoSim.GenPower.Letsi	synchScaleFactor * 420e6
CoSim.GenPower.Ossauskoski	synchScaleFactor * 120e6
CoSim.GenPower.PetajaskoskiPM1	synchScaleFactor * 56e6
CoSim.GenPower.PetajaskoskiPM2	synchScaleFactor * 56e6
CoSim.GenPower.PetajaskoskiPM3	synchScaleFactor * 56e6
CoSim.GenPower.Pirttikoski1	synchScaleFactor * 84.5e6
CoSim.GenPower.Pirttikoski2	synchScaleFactor * 84.5e6
CoSim.GenPower.Seitakorva	synchScaleFactor * 142.5e6
CoSim.GenPower.Taivalkoski	synchScaleFactor * 133.2e6
CoSim.GenPower.Imatra	synchScaleFactor * 192e6
CoSim.GenPower.PyhakoskiAndMontta	synchScaleFactor * 198e6
% Industrial CHP (Bio etc)	
CoSim.GenPower.Aanekoski	industrialSynchScaleFactor * 280e6
CoSim.GenPower.Anjalankoski	industrialSynchScaleFactor * 160.5e6
CoSim.GenPower.Kaukopaa	industrialSynchScaleFactor * 105e6
CoSim.GenPower.OuluInd	industrialSynchScaleFactor * 100e6
CoSim.GenPower.PietarsaariInd	industrialSynchScaleFactor * 95e6
CoSim.GenPower.RaaheInd	industrialSynchScaleFactor * 94e6
CoSim.GenPower.KuusaanniemiInd	industrialSynchScaleFactor * 87e6
CoSim.GenPower.KuusankoskiInd	industrialSynchScaleFactor * 76e6
CoSim.GenPower.Kotka	industrialSynchScaleFactor * 72e6
% Urban CHP	
CoSim.GenPower.VuosaariAandB	urbanCHPscaleFactor * 648e6
CoSim.GenPower.Salmisaari	urbanCHPscaleFactor * 163e6
CoSim.GenPower.VantaanJatevoimala	urbanCHPscaleFactor * 81.4e6
CoSim.GenPower.Suomenoja	urbanCHPscaleFactor * 358e6
CoSim.Pdemand.Alajarvi	loadScaleFactor * 160e6
CoSim.QindDemand.Alajarvi	60e6
CoSim.QcapDemand.Alajarvi	0
CoSim.Pdemand.Alapitka	loadScaleFactor * 160e6
CoSim.QindDemand.Alapitka	6e6
CoSim.QcapDemand.Alapitka	0
CoSim.Pdemand.Anttila	loadScaleFactor * 180e6
CoSim.QindDemand.Anttila	1e6
CoSim.QcapDemand.Anttila	0
CoSim.Pdemand.Espoo	loadScaleFactor * 200e6
CoSim.QindDemand.Espoo	60e6
CoSim.QcapDemand.Espoo	0

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CoSim.Pdemand.Forssa	loadScaleFactor * 160e6
CoSim.QindDemand.Forssa	6e6
CoSim.QcapDemand.Forssa	0
CoSim.Pdemand.Hikia	loadScaleFactor * 160e6
CoSim.QindDemand.Hikia	6e6
CoSim.QcapDemand.Hikia	0
CoSim.Pdemand.Hirvisuo	loadScaleFactor * 160e6
CoSim.QindDemand.Hirvisuo	60e6
CoSim.QcapDemand.Hirvisuo	0
CoSim.Pdemand.Huittinen	loadScaleFactor * 160e6
CoSim.QindDemand.Huittinen	60e6
CoSim.QcapDemand.Huittinen	0
CoSim.Pdemand.Huutokoski	loadScaleFactor * 160e6
CoSim.QindDemand.Huutokoski	6e6
CoSim.QcapDemand.Huutokoski	0
CoSim.Pdemand.Inkoo	loadScaleFactor * 160e6
CoSim.QindDemand.Inkoo	60e6
CoSim.QcapDemand.Inkoo	0
CoSim.Pdemand.Isokangas	loadScaleFactor * 160e6
CoSim.QindDemand.Isokangas	0e6
CoSim.QcapDemand.Isokangas	0
CoSim.Pdemand.Jylkka	loadScaleFactor * 160e6
CoSim.QindDemand.Jylkka	0
CoSim.QcapDemand.Jylkka	0
CoSim.Pdemand.Kangasala	loadScaleFactor * 160e6
CoSim.QindDemand.Kangasala	6e6
CoSim.QcapDemand.Kangasala	0
CoSim.Pdemand.Keminmaa	loadScaleFactor * 900e6
CoSim.QindDemand.Keminmaa	6e6
CoSim.QcapDemand.Keminmaa	0
CoSim.Pdemand.Koria	loadScaleFactor * 160e6
CoSim.QindDemand.Koria	1e6
CoSim.QcapDemand.Koria	0
CoSim.Pdemand.Kristinestad	loadScaleFactor * 160e6
CoSim.QindDemand.Kristinestad	60e6
CoSim.QcapDemand.Kristinestad	0
CoSim.Pdemand.Kymi	loadScaleFactor * 160e6
CoSim.QindDemand.Kymi	6e6
CoSim.QcapDemand.Kymi	0

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CoSim.Pdemand.Lansisalmi	loadScaleFactor * 350e6
CoSim.QindDemand.Lansisalmi	0
CoSim.QcapDemand.Lansisalmi	0
CoSim.Pdemand.Letsi	loadScaleFactor * 160e6
CoSim.QindDemand.Letsi	60e6
CoSim.QcapDemand.Letsi	0
CoSim.Pdemand.Lieto	loadScaleFactor * 160e6
CoSim.QindDemand.Lieto	6e6
CoSim.QcapDemand.Lieto	0
CoSim.Pdemand.Loviisa	loadScaleFactor * 160e6
CoSim.QindDemand.Loviisa	60e6
CoSim.QcapDemand.Loviisa	0
CoSim.Pdemand.Nurmijarvi	loadScaleFactor * 160e6
CoSim.QindDemand.Nurmijarvi	1e6
CoSim.QcapDemand.Nurmijarvi	0
CoSim.Pdemand.Petajaskoski	loadScaleFactor * 160e6
CoSim.QindDemand.Petajaskoski	6e6
CoSim.QcapDemand.Petajaskoski	0
CoSim.Pdemand.Pikkarala	loadScaleFactor * 160e6
CoSim.QindDemand.Pikkarala	60e6
CoSim.QcapDemand.Pikkarala	0
CoSim.Pdemand.Pirttikoski	loadScaleFactor * 160e6
CoSim.QindDemand.Pirttikoski	6e6
CoSim.QcapDemand.Pirttikoski	0
CoSim.Pdemand.Pyhanselka	loadScaleFactor * 160e6
CoSim.QindDemand.Pyhanselka	60e6
CoSim.QcapDemand.Pyhanselka	0
CoSim.Pdemand.Rauma	loadScaleFactor * 160e6
CoSim.QindDemand.Rauma	60e6
CoSim.QcapDemand.Rauma	0
CoSim.Pdemand.Seinajoki	loadScaleFactor * 160e6
CoSim.QindDemand.Seinajoki	60e6
CoSim.QcapDemand.Seinajoki	0
CoSim.Pdemand.Tammisto	loadScaleFactor * 450e6
CoSim.QindDemand.Tammisto	0
CoSim.QcapDemand.Tammisto	0
CoSim.Pdemand.Toivila	loadScaleFactor * 160e6
CoSim.QindDemand.Toivila	6e6
CoSim.QcapDemand.Toivila	0
CoSim.Pdemand.Tuovila	loadScaleFactor * 160e6

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CoSim.QcapDemand.Tuovila	0
CoSim.Pdemand.Ulvila	loadScaleFactor * 160e6
CoSim.QindDemand.Ulvila	6e6
CoSim.QcapDemand.Ulvila	0
CoSim.Pdemand.Vuolijoki	loadScaleFactor * 160e6
CoSim.QindDemand.Vuolijoki	60e6
CoSim.QcapDemand.Vuolijoki	0
CoSim.Pdemand.Yllikkala	loadScaleFactor * 450e6
CoSim.QindDemand.Yllikkala	1e6
CoSim.QcapDemand.Yllikkala	0

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