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Project Number: **870620**

Technical Report Lab Access User Project

Primary Support in Finland (PPiF)

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29/07/2022	v1.0	Raphael Caire	Final version

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List of Abbreviations

CO	Project Coordinator
EC	European Commission
LA	Lab Access
UG	User Group
UP	User Project

Executive Summary

Purpose: Demonstration of a process aiming at stabilizing the frequency of a network consisting on distributed loads and intermittent energy sources: Primary Support.

A test bench had been configured between the G2Elab (Grenoble, France) and VTT IntelligentEnergy (Espoo, Finland) to assess the interest of Finnish companies on the concept of frequency support by distributed loads and reinforce the scientific exchanges between both institutions. 8 energy boxes had been deployed on both sites and the frequency had been recorded together with the implementation

Context: The development of decentralized renewables in distribution networks may induce some adverse effects for the grid. Due to Distributed Renewable Energy Sources (DRES), power flows are becoming bidirectional and lowering the inertia, increasing the frequency deviations and reducing the self-healing reaction efficiency of our modern power systems. To be able to accept more and more renewables and integrate them in the best manner into the grid, the development of the smart and flexible grids is required. Flexible grids are achieved by integrating the demand side to interact with the grid and offer their flexibility in the critical times of the grid.

Primary Support consists in a platform to provide primary frequency control from distributed resources.

The goal of this project was to validate the technical feasibility of the proposed technology in Finnish regulatory framework. The proposed technology was installed at the IntelligentEnergy testbed at VTT premises in Espoo, Finland. The objective was to test if the technology functions as it is supposed to be and if it fulfils the national prequalification requirements set for Frequency Containment Reserves (Primary Support) in Finland. The piloting had been conducted at the IntelligentEnergy testbed with the purpose of participating with marginal resources in the Frequency Containment Reserves. A real participation with revenue generation is not feasible during the demonstration, since it would require a constant power of 100 kW for both directions (up- and down regulation). However, the test enables us to estimate the capability of the technology to pass the real prequalification requirements set by Finnish TSO Fingrid.

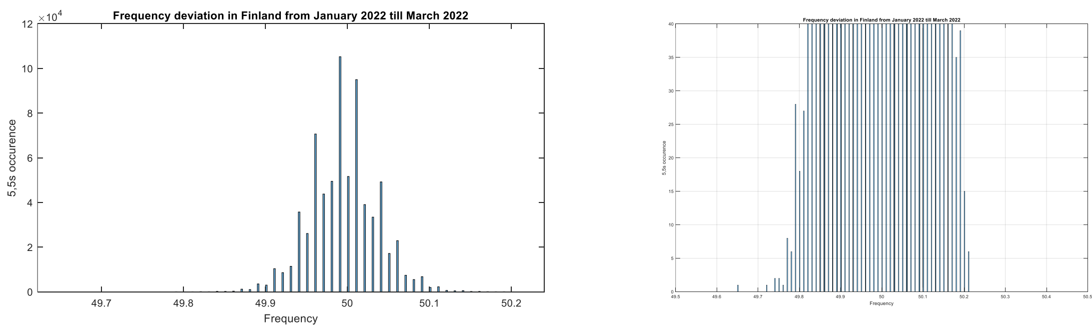

Figure 1. histogram of frequency deviation during the tests

The frequency deviations (see Figure 1) observed during the winter months are very interesting and allows any aggregator to derive a business model out of the requested support for frequency on those days.

Unfortunately, the loads were not empowered during the whole test duration and the technology was not fully validated, see Figure 2.

Figure 2. Controlled load (heater) connected but not empowered in the showroom of VTT as of end of April 2022

To support the dissemination of the Primary Support solution toward finish companies, VTT researcher (Aro Matti) had been organizing a wrap up event and 3 companies attended (Niko Korpela from flexens.com – remotely - and Alapera Ilari from fortum.com and Sonja Salo from capacity.io who did attend on site), see Figure 3.

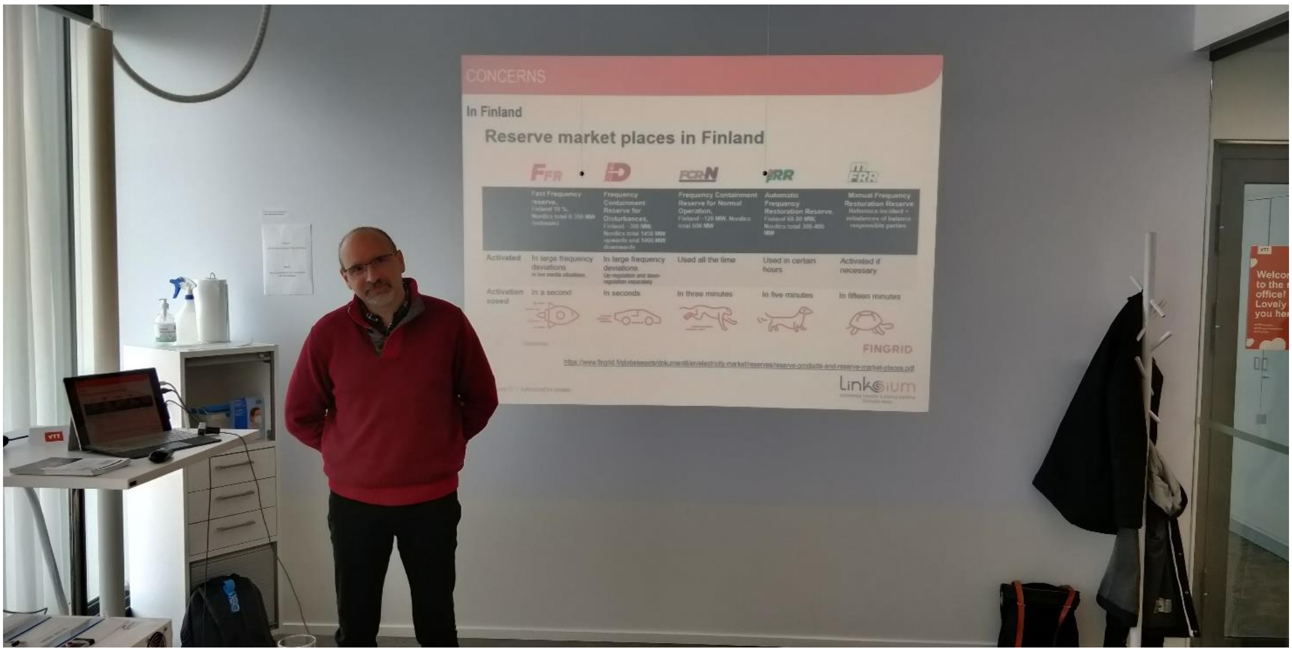

Figure 3. Final presentation with on bottom left hand side an energy box supporting FCR during the meeting

Discussions had been fruitful during the wrap up event but not further contacts happen at later stages.

1 Lab-Access User Project Information

1.1 Overview

Purpose: Demonstration of a process aiming at stabilizing the frequency of a network consisting on distributed loads and intermittent energy sources: Primary Support.

A test bench had been configured between the G2Elab (Grenoble, France) and VTT IntelligentEnergy (Espoo, Finland) to assess the interest of Finnish companies on the concept of frequency support by distributed loads and reinforce the scientific exchanges between both institutions. 8 energy boxes had been deployed on both sites and the frequency had been recorded together with the implementation

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1.2 Research Motivation, Objectives, and Scope

Objectives:

- Validate the ability of the energy boxes to full fill their tasks and provide a high level/quality of distributed FCR with (zero) low marginal cost resources.
- Present the technology to the Finish ecosystem and initiate patent transfer.
- Evaluate the possibilities to further extend collaboration between VTT and Grenoble INP on any additional features we could create on the energy box.

Expected outcomes and fundamental scientific and technical value:

- Building KPIs about FCR support with Loads from VTT in the showroom with classical residential loads using performance metrics to assess the compliance with Finish grid code.
- Getting direct contacts with finish industrials to further develop the technology

– Writing a conference paper about the tests to strength the collaboration between both institutions.

Risk assessment:

Risk	**Level**	**Mitigation actions**
IT troubles to have connexion between energy box and coordination platform hosted in France	High	The energy box in a simplified version will be sent in advance (december) to assess and anticipate all the possible issues. Different connection are foreseen from Wifi connection to 4G dongles.
Cybersecurity risks (the solution should not create any risk for VTT infrastructure).	Medium	Current hardening of the solution is ongoing in Grenoble INP laboratory. Encryption, firewall, fail2ban, account and cyber interaction is under improvement.
Remote access for the update of the IoT solution	Low	The use of standardized solution including MQTT should reduce the problems, nevertheless, some automatic update of the Operating System will take place to ensure the last version to be running

Type of infrastructure needed and installation:

The system is designed to run with multiples sources but is more efficient if they are of similar loads. Therefore, in this project, we will use the kitchenware and radiators, and the PV system at the laboratory. Currently, the platform supports single-phase loads up to 16 A, thus 10 to 15 loads with this connection size will be sufficient for the demonstration. Examples of a number of suitable load at the laboratory are listed in the table below including their power ratings.

Figure 4. Illustration of possible loads to be interconnected

Load	Power [W]
Heating fan	1450
PV inverter (several)	250
Resistor	1840
Radiator	1500
Hot plate	1000
Indoor heater (several)	1250
Heating unit (several)	1000
Heating unit (several)	1250

The intelligence of the system relies on:

- a software running at the G2eLab (France) : the Coordination Platform for Primary Support,
- a software running in the energy box that will be installed on each device to be disconnected in the IntelligentEnergy testbed (Finland).

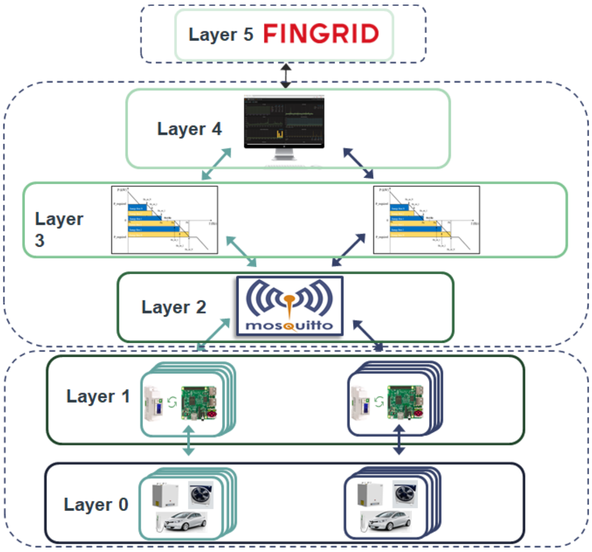


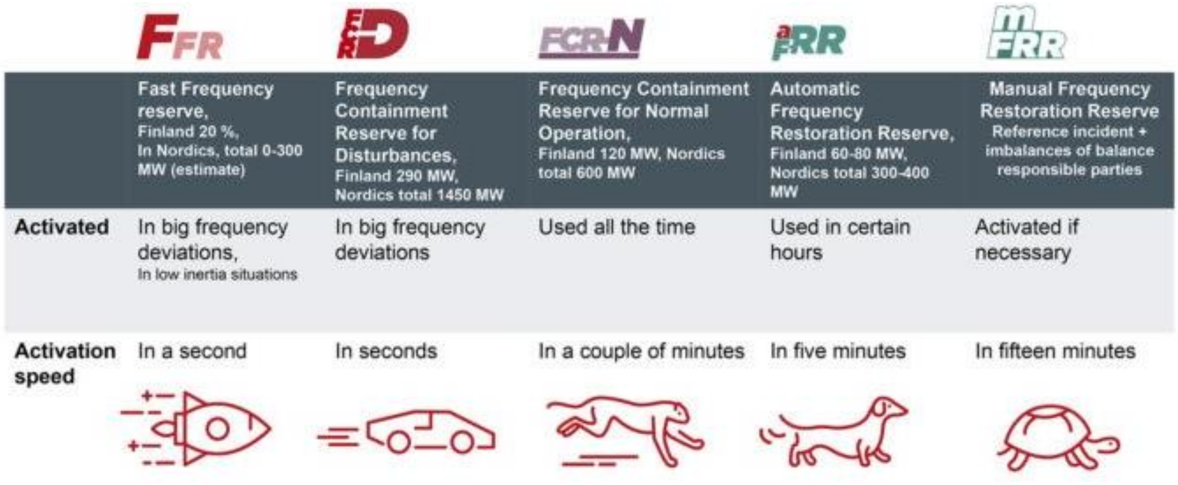
Figure 5. Overall structure targeted in the project

Energy boxes help the coordination platform to aggregate DERs for the primary frequency control.

The G2ELab will send energy boxes to the IntelligentEnergy testbed, which will connect them to the selected devices. Both systems work together and provide primary frequency control. Two processes are involved in the coordination platform, monitoring and operational process. The first part is for the monitoring issue. In the second part computation of threshold frequency is done and send to end-user, to provide primary support control for the grid. Communication between the coordination platform and end-users is realized through the MQTT protocol.

Technical validation

The proposed technology is installed at the Intelligent Energy testbed at VTT premises in Espoo, Finland. It is designed to aggregate distributed energy resources into controllable entities that could be used to provide frequency support for the power system. Frequency regulation is a critical part of power system management and thus it is quite heavily regulated to ensure standard delivery of frequency support. Fingrid, as the Finnish TSO, is responsible for the frequency regulation in Finland. They do this by operating a reserve market where flexible power capacity can be offered. Reserve market rules and requirements can be found from the Fingrid's website.



	FFR	FCR-D	FCR-N	aFRR	mFRR
	Fast Frequency reserve, Finland 20 %, In Nordics, total 0-300 MW (estimate)	Frequency Containment Reserve for Disturbances, Finland 290 MW, Nordics total 1450 MW	Frequency Containment Reserve for Normal Operation, Finland 120 MW, Nordics total 600 MW	Automatic Frequency Restoration Reserve, Finland 60-80 MW, Nordics total 300-400 MW	Manual Frequency Restoration Reserve Reference incident + imbalances of balance responsible parties
Activated	In big frequency deviations, In low inertia situations	In big frequency deviations	Used all the time	Used in certain hours	Activated if necessary
Activation speed	In a second	In seconds	In a couple of minutes	In five minutes	In fifteen minutes

Figure 6. Reserve market places in Finland – illustration © Fingrid[1]

Reserve markets in Finland consist of five products that are activated at different thresholds. Four of those products follow the grid frequency and activate automatically if the frequency threshold is met. The activation time depends on the reserve product. The fastest reserves should activate in one second whereas the others should delay their activation in case the frequency deviation is only temporary and ends without the need for reserves. In the picture below the reserve products and their activation times are presented.

In addition to the requirements related to the activation of the reserves, some open questions remain to be tested during the piloting phase. For example, the assessment of available capacity that individual DERs have for the next 15 min is not straightforward as the DERs typically serve a local purpose (e.g. space heating, EV charging etc.) and at this point it is not clear how the potential to provide this frequency support is estimated. Also, the manner of prioritization of the DERs in the coordination platform is unclear at this point and will be tailored made and setup for Finish purposes.

Another objective of the demonstration phase is to evaluate the reliability of the solution in terms of ICT connections. If the proposed technology is dependent on functioning communication between the energy boxes and the coordination platform, the communication characteristics such as latency, reliability, and jitter etc. should be evaluated. The proposed technology is able to deliver the frequency support even during a communication failure between the coordination platform and energy boxes, but that is presumably only when the individual energy boxes are assigned to a certain task. Assigning new tasks, on the other hand, still needs functioning communication between the two nodes and for that reason the location and accessibility of the coordination platform is not insignificant.

The possibility of the energy box to control the individual DERs linearly, or in small steps, is also a question to be answered. If the solution is only able to use relay-based control, i.e. cut DERs off the grid, it somewhat diminishes the feasibility of the proposed solution. This is true at least in the case of energy storages where the potential could be much bigger if the controlling would be more allowing.

Lastly, the cost/benefit -ratio of this technology is a question to be answered during the demonstration phase. Compensation from the Frequency Containment Reserves is dependent on the demand and supply for the service at each hour and thus not easily forecasted beforehand.

[1] Page 5 of Page 10 of https://www.fingrid.fi/globalassets/dokumentit/en/electricity-market/reserves/reserve-products-and-reserve-market-places.pdf

However, prices from the previous year's give us information about the range of compensation that is possible to obtain from the reserve markets. For example, if the compensation from participating in FCR-N market would be the average from past few years, 25€/MW in hourly market, it would mean 12,5€ for a MW of load shedding capacity (since the compensation is calculated for a symmetrical reserve, i.e. 1 MW up- and 1 MW down-regulation). That would mean that a single load of 10 kW would get 125€ for participating 1000h in the FCR-N markets.

Technical requirements

The technical requirements for the hosting laboratory are to provide 10 to 15 small single phase loads, which are available for the duration of the testing. The loads can be located at different parts of the power system and be geographically dispersed as they are all required to be interconnected to the coordination platform via a reliable Internet connection. For the successfulness of this project it is crucial that the loads and therefore the energy boxes are connected to the power system in the Nordic countries, more specifically in Finland as they are intended to participate to the reserve markets offered by Fingrid. The location is not only important to be connected to the desired market, but also to access the correct system frequency. As the power systems in France and Finland are not synchronised, the correct frequency signal required for the participation to the Finnish reserve market cannot be accessed by interconnecting the loads and energy boxes to the power system in France.

Tests to be executed (type/numbers/test sequence/parameters):

The idea of the energy box to shed discrete loads while recreating a FCR is a step toward energy transition and reduce the cost of margins in order to enhance the interconnection of renewable resources.

The tests to be executed in the VTT showroom should allow to validate once again the feasibility of distributed FCR. The specificity of heating electric load in a northern country could support the ability to use such load with both downward and upward regulation. The tests should thus foster the ability to push forward an intelligent ranking of the load to allow the availability whenever needed (over-frequency). This feature was not completely tested. Once online, the energy boxes will run with uploaded parameters and models to enhance the frequency support during three months. The energy boxes are fully equipped with measurements for both power and frequency additional parameter of interest could be the comfort level.

1.3 Structure of the Document

This document is organised as follows: Section 2 briefly outlines the state-of-the-art/state-of-technology that provides the basis of the realised Lab Access (LA) User Project (UP). Section 0 briefly outlines the performed experiments whereas Section 0 summarises the results and conclusions. Potential open issues and suggestions for improvements are discussed in Section 0.

2 State-of-the-Art/State-of-Technology

Technology: Primary Support aims at stabilizing the frequency of the network by controlling the active power of distributed loads / sources with frequency deviation.

This is realized through five steps:

- Periodically measure the value of the load shedding potential (small/diffuse load) or the production of renewable energy for a dispatch down (source)
- Prioritize and sort within the frequency range for each site the estimated load shedding power in the next 15 minutes (considering the instantaneous load shedding power and the history of consumption of the site, or the production of renewable energy)
- Send to each site its own frequency threshold
- For a load, if the grid frequency drops below the threshold, selected loads are disconnected
- For a source, if the network frequency reaches the threshold, it reduces the injection on the network

Our targeted DER and DRES are electric heaters, air conditioners, water boilers, electric vehicles, distributed storage and renewable sources.

The advantages are of this technology are multiple:

- A reduction in the cost of operating margins for electricity networks
- An increased stability and security of the network
- A better use of distributed resources.

The technology (hardware and software) was validated within the EU project DREAM. Successful testing was realized at the ICCS Lab in Athens, the airport in Milan and the showroom at Schneider Electric. Further tests in the lab on real network simulations have been carried out. Data were managed with a cloud-based platform in Lille.

Details at: http://www.dream-smartgrid.eu/

The technology is patented (FR1362664), delivered Europe under number EP3084910 on 26.10.2016: METHOD TO STABILIZE A POWER GRID USING LOAD SHEDDING.

The software are also protected:

- “Coordination Platform for Primary Support” is protected by a deposit at the Agency for the Protection of Programs on 25/07/2019, under the reference IDDN FR.001.310061.000.S.P.2019.000.30705.
- “Energy Box For Primary Support” is protected by a deposit at the Agency for the Protection of Programs on 25/07/2019, under the reference IDDN FR.001.310060.000.S.P.2019.000.30705.

It is existing many other tests and proposition to support the Frequency Containment Reserve. Still the proposition issued by Grenoble INP from 2013 is the oldest (patent) trying to tackle at the same time the issue about security of reserve furniture as well as the guarantee of service. The security related to the loss of communication is supported by the dual asynchronous processes that are ensuring for a limited time the FCR procurement even with the loss of communication services. The implementation realized from 2019 integrates the latest IoT solutions (Mosquito) allowing an additional layer of cybersecurity and scalability.

The originality of the solution lies in

- the possibility of aggregating small loads, distributed among individuals, which consists of an important, reachable but little used reserve,

- the selection of the appropriate loads to disconnect,
- the mobilization within 15 minutes,
- to propose to the citizen a solution participating in the energy sobriety and get revenues from the service.

Objectives

The project was funded by a TTO, with the aim of making the technology mature enough to be proposed to a company wishing to acquire it through a technology transfer (the intellectual property generated consists of 1 patent, 2 software programs and a know-how).

The purpose of this demonstration was to introduce the solution to Finnish grid operators and aggregators, with the expectations that one or more companies will show interest in acquiring the Intellectual Property.

Before the demonstration the experimental set-up had been tested and validated to be suitable for the Finnish system and any modifications required to adapt the set-up had been executed to improve the suitability of the technology to be acquired by entity in Finland.

Benefits of the solution

The technology enables support of infrastructures in stressed situations on the network, which can be the case in countries where transnational interconnections are limited. This is especially relevant for Finland, as the country has only few DC link connections to Sweden and Norway, which form the synchronised power system in the Nordic countries together with the power system in Eastern Denmark. Rest of the interconnections from Finland to Russia and Estonia are asynchronous. With the other Nordic countries building several interconnections to the continental Europe in order to achieve European-wide synchronous power system, the Finnish power system could be left in solitude and require a lot of local aggregation of even smaller loads.

This technology is also interesting for aggregators, who can use it to offer grid operators a primary energy reserve that can be mobilized within 15 minutes, and to ensure a rapid financial return.

Depending on who acquires the technology, the expected revenues are flowing from the grid operator to the aggregators or service providers, but also toward the individuals or companies that will be paid for their load shedding.

The validation of secure and guaranteed distributed frequency containment reserve is of high interest in the consumer centric landscape the EU is willing to set-up. Such aggregation of DER with zero marginal cost is of great interest for our modern societies, with large benefits for the stability and the security of the system. However, it leads to difficulties to assess the realization of the local service but a very large amount of distributed device and the funding scheme is still unclear for the whole infrastructure. Such tests at high TRL level are mandatory for business exploration as well as further deployment at the level of pre under frequency load shedding that could complement the frequency containment reserve is case of larger disturbances.

The expected results were lying on the capacity of the system to reach some KPIs. At first, the reaction of the overall aggregation should be tested with results analysed from the monitoring process included in the coordination platform. The analysis of the logs will present, along with the frequency deviation, the responsiveness of the system. Primary Support fulfils 100% of the specs from Fingrid with the existing loads in VTT showroom.

At second, the (dis)comfort in the showroom premise, related to the curtailment of heating appliance in an winter season will be assessed. In an absence of sources, downward frequency regulation will be tested on load that are willing to be on. KPIs are indeed the ability to select the loads and effect them so to limit the impact on comfort. The performance metrics that will be issued to assess it will be related to the capacity to curtail and the power consumed after-while (payback effect).

3 Executed Tests and Experiments

3.1 Test Plan, Standards, Procedures, and Methodology

The technology (hardware and software) was validated within the EU project DREAM. Successful testing was realized at the ICCS Lab in Athens, the airport in Milan and the showroom at Schneider Electric. Further tests in the lab on real network simulations have been carried out. Data were managed with a cloud based platform in Lille. Details at: http://www.dream-smartgrid.eu/ . The proposed project is well aligned with ERIGrid 2.0 both from substance and approach perspectives as it aims to work on distributed energy resources and aggregation, which have been highlighted in ERIGrid 2.0 as well and the approach enables strengthening collaboration among European researchers.

The infrastructure was requiring to have several small loads available for the whole duration of the testing, which would also be resistant to constant switching on and off. The loads were connected to the synchronous Nordic power system, especially the Finnish power system in order to participate to the Finnish reserve markets. Furthermore, a reliable Internet connection was needed to connect the energy boxes, which would be provided by the project team to be interconnected to the loads at the laboratory, and the coordination platform. In addition, a demonstration area for Finnish grid operators and aggregators is needed. The host infrastructure should receive valuable knowledge on this type of an aggregation technology and its usefulness in the Finnish system. While also providing a natural continuation of research on this field, which has been previously conducted in the Smart Otaniemi innovation ecosystem.

Figure 7. Controlled load (heater) connected in the showroom of VTT as of end of April 2022

3.2 Test Set-up(s)

Tests had been running from end of January till mid-April in VTT premise. VTT teams had been very supportive in the remote preparation and the access to the communication, allowing monitoring and control of local resources. They bought 8 electric heaters to be installed in the building hosting the new showroom of VTT.

Figure 8. experimental setup in VTT premise as installed in January

After few days in February, most of the loads have been switch off locally, not allowing any further control on them. Part of it was expected but not seven of the eight energy boxes being useless. The Primary Support solution is indeed able to do the selection of the most appropriate load (based on its responsiveness). Still some very interesting analysis had been possible based on the remote measurement of the frequency in Finland during the tests.

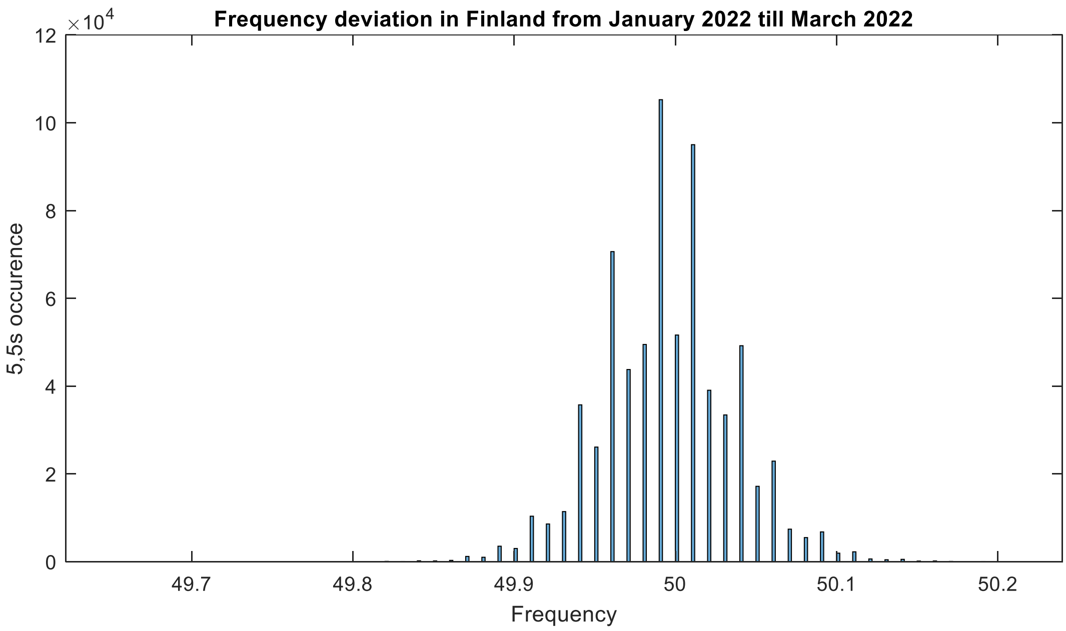


Figure 9. histogram of frequency deviation during the tests

The frequency deviations (see Figure 1) observed during the winter months are very interesting and allows any aggregator to derive a business model out of the requested support for frequency on those days. Another graphics which allow us the possibility to see wider than the continental Europe FCR rage is possible, see Figure 10.

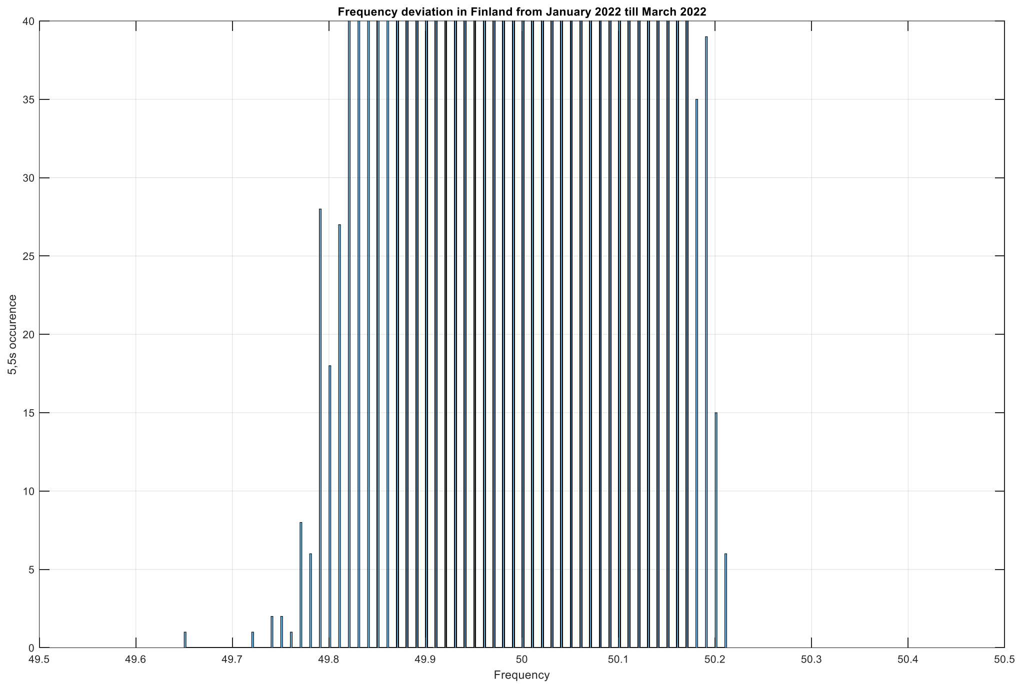


Figure 10. histogram of frequency deviation during the tests – zoom on the lower amount of occurrence

In the considered period, we can track that some occurrence (55), even limited (over 705249 periods) are outside the classical continental Europe ENTSO-e margins (of ±200mHz) but are compliant with the Nordic rules, see Figure 11.

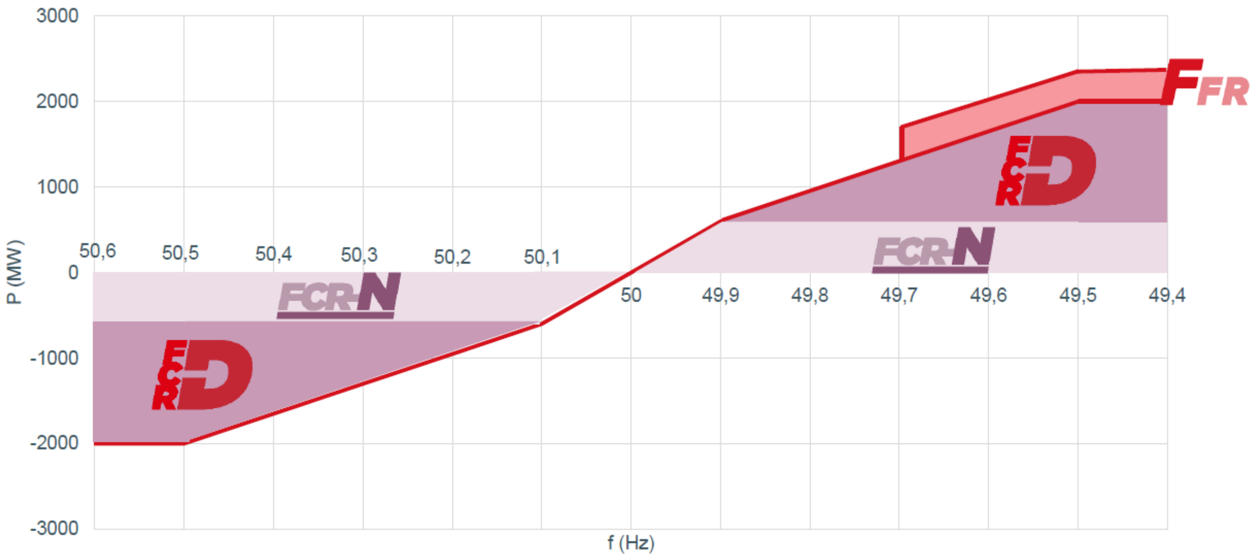


Figure 11. Activation linearly based on frequency deviation guarantees equal activation from all

providers[2]

3.3 Data Management and Processing

The project team aims to publish the outcomes of the tests in an upcoming CIRED workshop or PowerTech 2023 with thanking the ERIGrid 2.0 and EU support. Some pictures and graphical outcomes such as Performance Metrics data and figures will be produced and shared with VTT to ease reporting process toward EU reporting.

The whole set of data will be available through a graphana webpage.

[2] Page 10 of https://www.fingrid.fi/globalassets/dokumentit/en/electricity-market/reserves/reserve-products-and-reserve-market-places.pdf

4 Results and Conclusions

4.1 Discussion of Results

The frequency deviations (see Figure 1) observed during the winter months are very interesting and allows any aggregator to derive a business model out of the requested support for frequency on those days. Another graphics which allow us the possibility to see wider than the continental Europe FCR rage is possible, see Figure 10. In the considered period, we can track that some occurrence (55), even limited (over 705249 periods) are outside the classical continental Europe ENTSO-e margins (of ±200mHz) but are compliant with the Nordic rules, see Figure 11.

After few days in February, most of the loads have been switch off locally, not allowing any further control on them. Part of it was expected (as anthropological reaction) but not up to seven of the eight energy boxes being useless. The Primary Support solution is indeed able to do the selection of the most appropriate load (based on its responsiveness). Still some very interesting analysis had been possible based on the remote measurement of the frequency in Finland during the tests.

4.2 Final Event

To support the dissemination of the Primary Support solution toward finish companies, VTT researcher (Aro Matti) had been organizing a wrap up event and 3 companies attended (Niko Korpela from flexens.com – remotely - and Alapera Ilari from fortum.com and Sonja Salo from capacity.io who did attend on site).

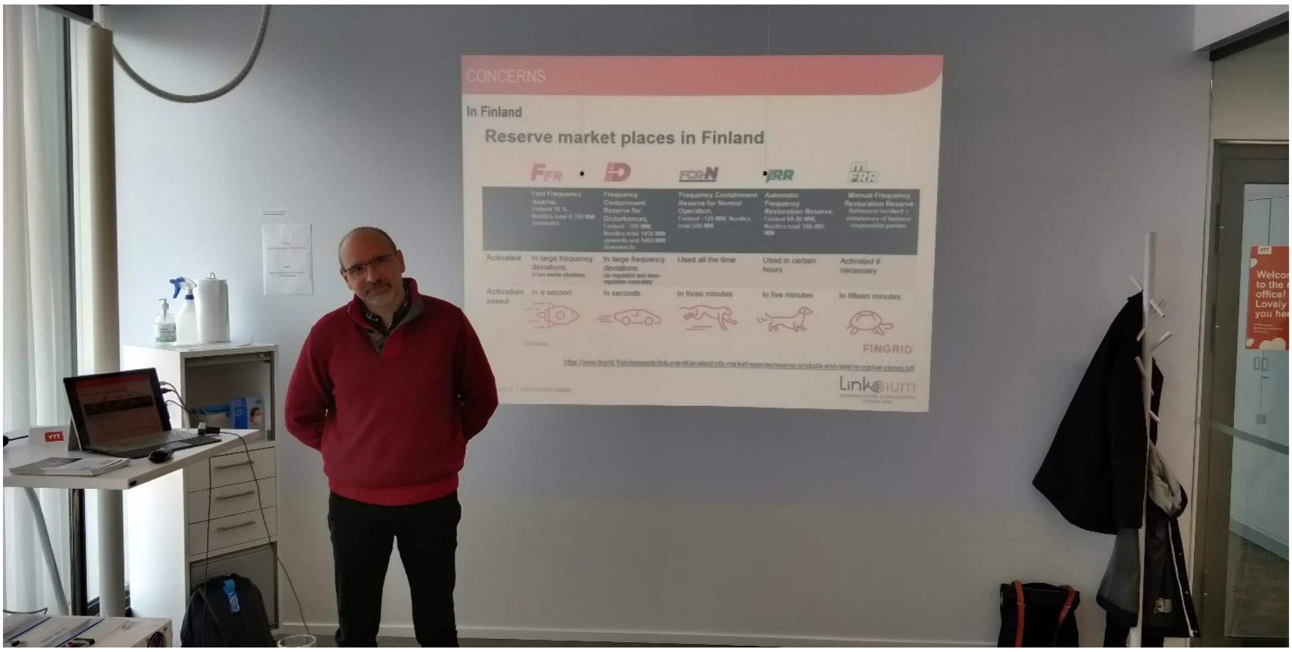


Figure 12. Final presentation with on bottom left hand side an energy box supporting FCR during the meeting

Discussions had been fruitful during the wrap up event but not further contacts happen at later stages.

4.3 Conclusions

If the results with very limited number of loads participating to the frequency support is somehow a disappointment as well as the number of companies attending the final wrap-up the 28th of April, however, the technical feedback is really important and shows the impact of Erigrid2.0 on the possible collaborations within EU research centers. VTT is having some great potential to host researchers and provide access to numerous equipment's (RT simulators, among others).

5 Open Issues and Suggestions for Improvements

Journey toward lab testing in VTT and patent transfer was great thanks to the support of the local VTT team. Final results might seem to be weak (few local reactions toward frequency deviations recorded) but thanks to the mirror setup in France, most of the technology was possible to validated and even with a remote information/monitoring of the frequency which is an added value compared to the patent, in line with local (Finish) regulation. Grenoble team was very happy to participate to this lab access and wish to thanks once again VTT team for their great supports, namely:

- Petra Raussi
- Matti Aro
- Mikael Opas.

References

Caire, R. (FR1362664), delivered Europe under number EP3084910 on 26.10.2016: METHODE TO STABILIZE A POWER GRID USING LOAD SHEDDING.

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