LOCAL VERSUS CENTRALIZED CONTROL OF FLEXBILE LOADS IN POWER GRID

***Joni Markkula*[1]*, Ville Tikka*[2]*, Pertti Järventausta*[1]**

[1]*Faculty of Information Technology and Communication Sciences, Tampere University, Tampere, Finland*
[2]*Laboratory of Electricity Market and Power systems, School of Energy Systems, Lappeenranta-Lahti University of Technology LUT, Lappeenranta, Finland*
**joni.markkula@tuni.fi*

Keywords: ELECTRIC VEHICLE, BATTERY, FREQUENCY, RESERVE, DEMAND RESPONSE

Abstract

Electric vehicle (EV) charging and their batteries are recognized as a future solution for power system demand flexibility but also a potential source of problems for the network due to increasing power requirements in new locations. In either case the amount of EVs will grow and the amount of available energy storage with them. EV batteries can provide the necessary energy storage in distributed, variable power generation networks where wind and solar power are used in larger scale and increase grid's ability to handle higher share of variable renewable energy (VRE) production. Operating EV batteries as controllable storages without major downsides has it challenges. In this study three different strategies of controlling EV charging power based on grid frequency are compared: 1. utilizing distribution system operator's (DSO) existing metering infrastructure, 2. using centralized measurement with dedicated flexibility server, and 3. using local measurement and control. In our testing, operating through the DSO infrastructure caused significant delays and prevents EV's batteries to be offered on the primary reserve markets with given conditions. The dedicated systems built for EV charging power control offers faster response, more reliability and control.

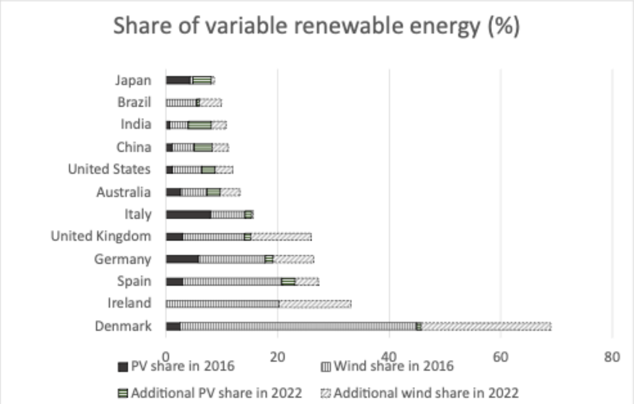
1. Introduction

In 2019, the total number of plug-in hybrids and full electric vehicles was over 7 million [1], and scenarios expect the number to grow somewhere between 150 and 250 million by 2030. This will be one of the main drivers to increase lithium-ion battery production from 300 GWh to 2000 GWh per year [2]. The production ramp up in the past decade has already reduced the prices of batteries at an incredible speed dropping from 668 $/kWh to 137 $/kWh during 2013-2020 which is on average 20% price decrease per year and the development is continuing, pushing battery prices below 100$/kWh [3]. This development makes battery energy storages (BESS) suitable for new applications. Dedicated BESS systems and EV batteries together are creating new energy storage capacity for the power grid. *How much energy storages now in the world? How much wind and solar? How much storage is needed for them?*

At the same time variable renewable energy (VRE) production is growing quickly and thus power system will require flexible consumption, energy storages or in best case both. In some cases, VRE might account for over half of the annual energy production, and more often there will be growing number of hours during the year where VRE portion is significant (see picture 1) [4]. This added to the EV charging that is projected to require up to 6-9% of peak electricity demand [5].

To avoid the foreseeable problem different flexibility options and energy storages have been proposed [maybe source]. The advancements in telecommunication and remotely controlled systems can provide cost-effective way of tackling the future problems.

Finland's power system has a well-developed Supervisory control and data acquisition (SCADA), automatic meter reading (AMR) and mobile telecommunication infrastructure. These together provide a test platform where different kinds of remote-control mechanisms can be examined within real, operational systems.



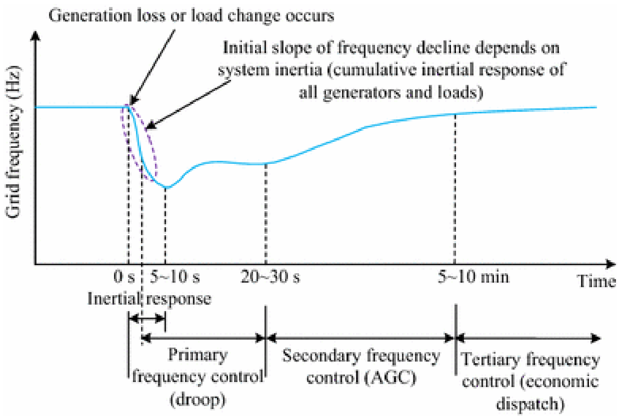
Picture 1: Variable renewable energy in power system in selected countries [4]

2. Demand response markets

Demand side flexibility and energy storages provide value for several actors in the power system: customers can limit their connection power, size of fuses or their energy bill, energy retailers can keep their hourly balances in check, distribution system operators (DSO) can avoid investment costs and interruptions, and transmission system operators (TSO) can maintain the power balance in the grid even in rapid, unexpected changes. This study concentrates on TSO frequency containment markets as it currently has the highest financial value. Finnish TSO, Fingrid, has open frequency containment markets and large, unified markets under construction for Central Europe [6,7].

2.1. TSO frequency containment markets

Power system frequency indicates the balance between electricity consumption and production. When there is more consumption in the system than production, the grid frequency decreases. In the same way, if there is more production than consumption, the frequency increases. The frequency is essentially the same in all points of the grid and every generator and load contributes to the frequency.
What is special about frequency containment reserves, is that the first response to frequency changes must be fast and accurate in order to prevent further frequency deviation and restore the system power balance. The grid frequency is always changing as production and consumption vary and normally this deviation is small (+/- 0.05 Hz). The grid frequency is kept close to nominal by adjusting production capacity and the final responsible party is TSO for maintaining the system frequency. The different response times and classification of inertial, primary, secondary and tertiary control is found in picture 2.



Picture 2: Power system reaction to changes in grid frequency [8]

Finnish and also European frequency reserve markets consist of three categories: 1. Fast Frequency reserves FFR (e.g. 0.7-1.3s activation time), 2. Frequency Containment Reserves for Normal operation (FCR-N) that are meant to keep the frequency close to nominal value (activation in seconds), and 3. Frequency Containment Reserve for Disturbances (FCR-D), which is meant to be used to when frequency has deviated too far from nominal value and larger actions need to be taken (activation during 3-30 s). All of these Frequency Containment Reserves act automatically based on preset rules and contracts.
Automatic frequency reserves are activated on daily basis and the volumes for the markets are in the scale of hundreds of megawatts per reserve type in the Nordics. Picture 3 shows in graphical form the ramp up/down curve that is required from systems participating in automatic frequency containment market. Relay controlled loads can have stepwise sloping when it stays within required limits. FCR-D has dead-band area between 49.9-50.1 Hz and FCR-N deadband of +/- 0.01 Hz.

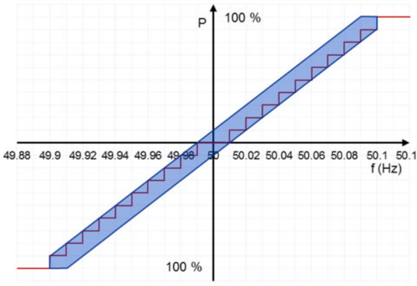


Figure 3.2 Piecewise linear control curve, FCR-N

Picture 3: FCR-N frequency [9]

The value of yearly contract for the FCR markets is presented in table 1.

Table 1: frequency reserve yearly market [10]

	FCR-N volume (MW)	FCR-N price (€/MW,h)	FCR-D volume (MW)	FCR-D price (€/MW,h)
2017	55	13,00	455,7	4,70
2018	72,6	14,00	435,0	2,80
2019	79	13,50	445,6	2,40
2020	87,1	13,20	458,3	1,90
2021	105,8	12,50	425,0	1,80

Also the hourly market for both exists and the average hourly market value of FCR-N during 2020 in Finland was 20,83 €/MW,h and average volume was 34,6 MW. Thus providing +/- 1kW of flexibility for every hour of the year to the FCR-N market would yield ca. 180 € income for provider. EV controllable power could be much higher than 1 kW but on the other hand it wouldn't be all the time available. This extra income is the motivator for EV charging control as it technically feasible to implement.

3. Methodology

3.1. Vehicles

Measurements were conducted with commercially available equipment. To measure the charging power behaviour in real life, four different passenger EVs were tested in first two cases: Tesla Model S (3x16 A), Nissan Leaf (1x16A), Opel Ampera (1x16A), Mitsubishi Outlander (1x16A). All vehicle batteries were depleted to 30-70% state of charge so that the batteries wouldn't limit the charging current. The temperature outside was about +5°C and it was not limiting the charging current which was tested before testing started. All vehicles had IEC 61851 compliant chargers. In the last test Volvo V60 plugin hybrid was used.

3.2. Electric Vehicle Supply Equipment (EVSE)

The EVSE in use was Ensto ECV100, which has IEC61851 compliant proprietary controller and RS-485 interface for external load management signals. Requirements for passenger EV chargers are defined in IEC 61851 (communication protocols) and ISO 62196-2 (plugs and sockets) standard. IEC 61851 standard describes the analog sequence which is needed to initiate the charging process and the PWM modulation that enables the charger's controller to give maximum current limit instructions to EV charger. The IEC 61851 defines the following values for dynamic power regulation events during the charging:

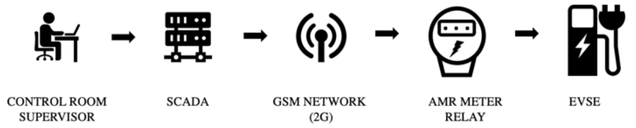
- External system to EVSE PWM max duration: 10 s
- EVSE PWM to vehicle on board charger current change: max 5 s
- Termination of energy supply when pilot contact is opened: 100ms
- Stop charger current draw: 3 s

The standard leaves quite much flexibility for EVSE and EV manufacturers to make their own decisions on the ramp up/down times, expect when pilot contact is lost which is a safety related feature. [11].

3.3. Test setups

Tests were conducted with three different setups: 1. DSO's AMR infrastructure with GPRS modem connection, 2. Centralized frequency measurement and control with dedicated service, and 3. With fully local control.

Test 1 - Distribution System Operator infrastructure: First tests were run through the DSO provided SCADA and AMR infrastructure, where AMR meter remote controllable relay would be used as input to computer IO pin and transformed into RS-485 message for EVSE controller, which outputs required PWM signal.



Picture 4: DSO's control infrastructure

Test 2 - Centralized measurement and control over internet:
Custom made electronics was created in order to consider, how local frequency measurement could be done cost effectively for a large number of devices. Electronics bill of materials cost for this was ca. 3 euros. Power system frequency was verified with a Fluke 83 multimeter that provides 0.01 Hz frequency accuracy which would be sufficient for actual use also.

Test 3 - Local measurement and control: Third testing was using Siemens Sentron PAC 3200 frequency measurement device and power limitation signal was fed directly to the charger controller which provided the PWM for EV.

3.4. Locally controlled vs remote system

The benefits of locally operating systems are that it is not dependent on remote data connections and response times are faster. The disadvantages are the cost of implementing frequency measurements on every device and creating the direct connection to EVSE controller instead of back office service. These add up costs, but also provide speed and independence, which adds resilience to the system.

4. Results

4.1. Charging power control with DSO's infrastructure

First test with DSO's AMR infrastructure showed that GPRS network and SCADA systems create delays that are documented in tables 2 and 3. "DSO delay" means the duration, how long it took from the manual triggering on DSO control room to AMR relay state change, "Start of ramp" means when charging power has changed over 10% from existing value, and "Power final" means when power is within 10% of the new, given setpoint (i.e. 6A or "max").

Table 2: Decrease charging power

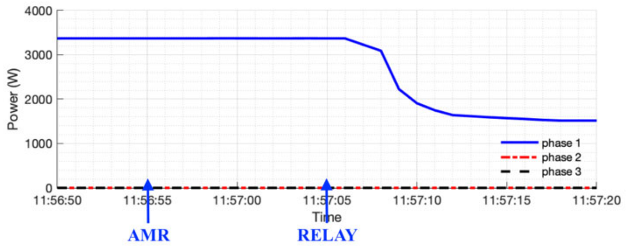
	Ampera	Leaf	Outlander	Tesla
DSO delay	10 s	6 s	12 s	13 s
Start of ramp	4 s	3 s	4 s	4 s
Final power	2 s	1 s	2 s	2 s
TOTAL	**16 s**	**10 s**	**18 s**	**19 s**

Table 3: Increase charging power

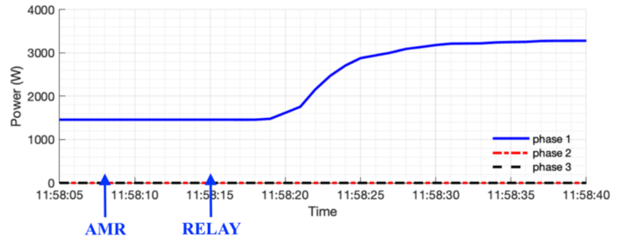
	Ampera	Leaf	Outlander	Tesla
DSO delay	7 s	10 s	13 s	11 s
Start of ramp	6 s	4 s	4 s	8 s
Final power	5 s	2 s	2 s	12 s*
TOTAL	**18 s**	**16 s**	**19 s**	**31 s**

** charger's three phases were not in sync, see picture 12*

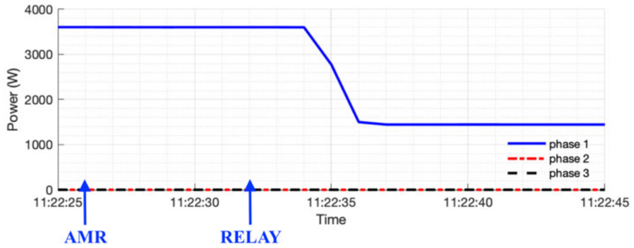
Vehicle specific charging power curves are presented in pictures 5-12. Manual trigger signal is marked as "AMR" text, and relay activation as "RELAY" text in the picture.



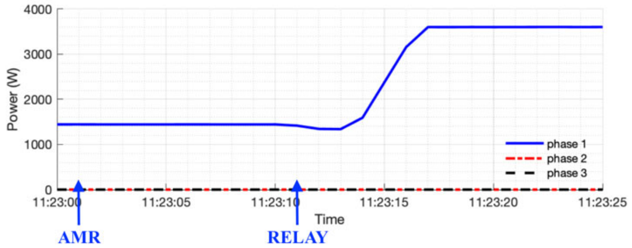
Picture 5: Opel Ampera down



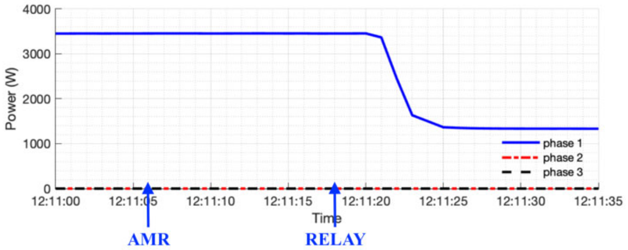
Picture 6: Opel Ampera up



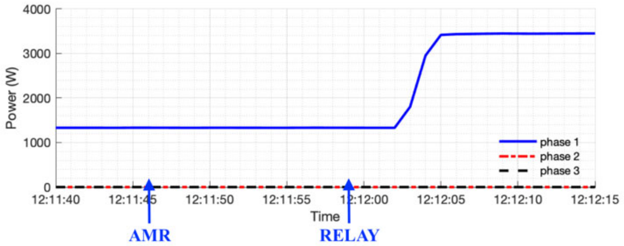
Picture 7: Nissan Leaf down



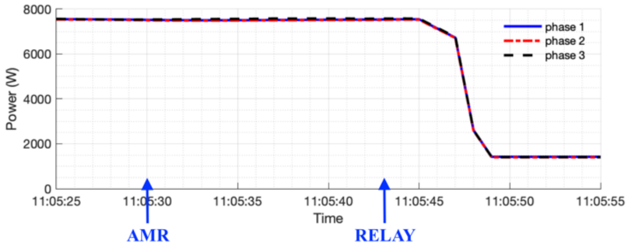
Picture 8: Nissan Leaf up



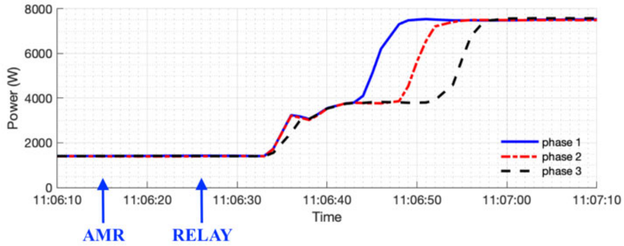
Picture 9: Mitsubishi Outlander down



Picture 10: Mitsubishi Outlander up



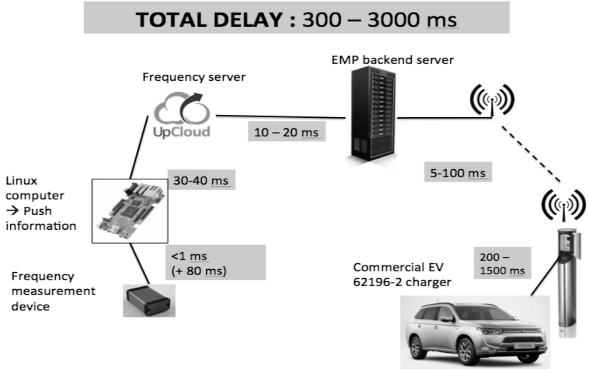
Picture 11: Tesla Model S down



Picture 12: Tesla Model S up

4.2. Centralized frequency measurement, dedicated EV power control server

Second tests were done with frequency monitoring hardware and micro-service built for EV load management. Test setup with delays is shown in picture 13.

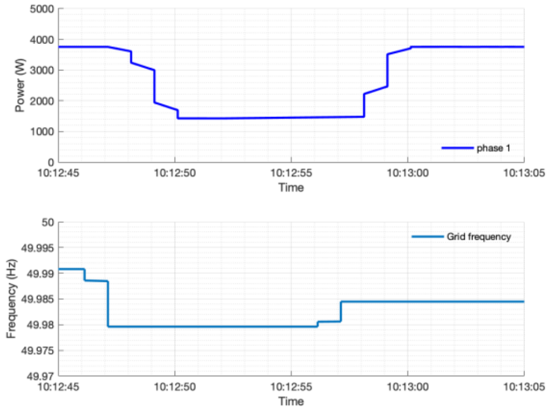


Picture 13: From frequency measurement to EV power control on dedicated platform

Compared to previous test, the DSO delay was replaced by delay from dedicated flexibility system, and was cut from 6-13s to ca. 2s. The delay from frequency measurement to PWM control signal was varying between 0.3 and 3 seconds. This change alone, with the added controllability and possibility to get feedback from EVSE meets the criteria of primary frequency reserve markets.

4.3. Control with local measurement and local control

Last test was done with Volvo V60 plugin hybrid. Frequency limit was set to be 49.98 Hz for signal automation for testing purposes. The response pattern is show in picture 14.



Picture 14: Volvo V60 plug-in hybrid

Response from observed frequency deviation to start of ramp was only 1 second and final value was achieved in 3 seconds on power down and 4 seconds in power up events. Also it is noteworthy that in local setup the delays do not change based on internet traffic duration.

5. CONCLUSION

The flexibility market is open for new service providers and market model offers quite easy access to reserve markets. In present situation investments to EV batteries and the charger infrastructure are made, independent of possible smart charging cash flows. Thus, the income from demand response provides additional value to charging service users and providers. Demand response financial value is at its highest on the primary market, where power adjustment speed requirement is measured in seconds.

Electric vehicles battery response times were benchmarked against two Frequency Containment Reserves: FCR-N, where reserves must be in use within 3 minutes and follow the change of frequency linearly or stepwise linearly, and FCR-D where reserves must activate within 5 seconds and provide full power in 30 seconds.

This study showed that EVs can be used as part of primary reserves (FCR markets) in power system when used with local control, and in some cases with dedicated demand response infrastructure (measurement, servers, services, telecom). Using existing AMR infrastructure from DSO created delays that currently do not allow providing EV batteries' flexibility on primary reserve markets.

What is needed is a socket based, constantly open, communication path if EV demand response is controlled by a central system. GSM network latencies vary greatly and the limited reliability of GSM connections must be taken into account when planning the system. Varying latencies do bring some benefits in the form of unintended randomization of up and down regulations, but the latencies must be well understood when designing the system for real use.

6. DISCUSSION

In the future we expect better network connections, e.g. 5G, to help with real time control of demand response resources. Also the EVSE and EV manufacturers presumably will shave off seconds from the delays where it is easy. DSOs could be helping with providing easy access to customer's equipment with their existing infrastructure, but that would require interfaces to give control of the customer devices to third parties. These interfaces don't exist at the moment but are in development.

7. References

[1] IEA (2020), Global EV Outlook 2020, IEA, Paris

[2] Bloomberg article: "Global Demand for Batteries Multiplies" fetched 19.12.2020 from https://www.bloomberg.com/news/articles/2018-12-21/global-demand-for-batteries-multiplies

[3] BNEF, https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/

[4] IEA, VRE share in annual electricity generation in selected countries, 2016-2022, IEA, Paris https://www.iea.org/data-and-statistics/charts/vre-share-in-annual-electricity-generation-in-selected-countries-2016-2022

[5] IEA, Contribution of electric vehicles to hourly peak demand by country and region in the evening and night charging cases in the Sustainable Development Scenario, 2030, IEA, Paris https://www.iea.org/data-and-statistics/charts/contribution-of-electric-vehicles-to-hourly-peak-demand-by-country-and-region-in-the-evening-and-night-charging-cases-in-the-sustainable-development-scenario-2030

[6] Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing

[7] Entso-E. Frequency Containment Reserves (FCR). Retrieved on 15.2.2021 from https://www.entsoe.eu/network_codes/eb/fcr/

[8] WU, Z., GAO, W., GAO, T. et al. State-of-the-art review on frequency response of wind power plants in power systems. J. Mod. Power Syst. Clean Energy 6, 1–16 (2018). https://doi.org/10.1007/s40565-017-0315-y

[9] Fingrid FCR, Appendix 2 to the Yearly Market Agreement: The technical requirements and the prequalification process of Frequency Containment Reserves (FCR)

[10] Fingrid. Frequency containment reserves (FCR-N, FCR-D), transactions in the hourly and yearly markets. 2021. fetched 25.1.2021 from https://www.fingrid.fi/en/electricity-market/electricity-market-information/reserve-market-information/frequency-controlled-disturbance-reserve/

[11] IEC61851 Electric Vehicle Conductive Charging System part 1. 2017