IMPLEMENTATION AND VALIDATION OF SYNTHETIC INERTIA SUPPORT EMPLOYING SERIES PRODUCED ELECTRIC VEHICLES

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ABSTRACT

The high integration of renewable energy resources (inverter connected) replacing conventional generation reduces the available rotational inertia in the power system. This introduces the need for faster regulation services including synthetic inertia services. These services could potentially be provided by electric vehicles due to their fast response capability. This work evaluates and experimentally shows the capability and limits of EVs in providing synthetic inertia services. Three series produced EVs are used during the experiment. The results show the performance of the EVs in providing synthetic inertia. It shows also that, on the contrary of synchronous inertia, synthetic inertia might lead to unstable frequency behavior.

INTRODUCTION

The displacement of conventional generation by converter connected resources reduces the available rotational inertia in the power system which leads to faster frequency dynamics and consequently a less stable frequency behaviour [1]. One of the main concerns of transmission system operators (TSOs) is the fast rate of change of frequency (RoCoF) which might lead to a cascade tripping of conventional and distributed generators connected by means of RoCoF relays [2], [3].
Traditionally, inertial response has not been considered as an ancillary service, but rather as a natural characteristic of the power system. Due to the high integration of converter connected resources, several TSOs began to recognize the value of synthetic inertia response [4], [5].
Simultaneously, the growing number of electric vehicles (EVs), on one hand is seen as an additional load on the grid from system operators' perspective. On the other hand, EVs are also one of the candidates for providing grid regulation services (i.e. frequency and voltage control) due to their fast response capability [6], [7]. In principle, they are able to provide fast regulating power in both directions in case of Vehicle-to-Grid (V2G), or just to modulate the charging power [8]. Nevertheless, EV's technical characteristics introduce different challenges such as limited individual power and energy ratings, single phase connection that imply potential source of unbalances and fast, but variable response time.

The total response time of the EV can be divided into different parts:

- Measurement time, which is the time necessary to the measurement device to measure the controller input signal.
- Communication time, which is the time required to send the control signal from the metering location to the location where the EVs are connected to the grid. The two locations can be identical, but it is possible actually to remotely control the EVs as explained in [7].
- EVs' response time, which is the time necessary for ramping up (or down) the power to meet the requested value by the controller.

In this study the V2G capability, which implies the possibility of reversing the power flow, is not considered and the service provision is possible only by controlling the charging current as defined by IEC 61851 standard [9]. The standard defines that EVs can be controlled by modulating the charging current between 6 and 16 A with 1-A steps. It also defines that EVs have to respond within 3 seconds and the current has to be limited to the set value. Because of the previous requirements and depending on the EV model and year of production EVs may show different performances (i.e. the EVs response can vary from under a second to few seconds) [10]. Since this study focuses on synthetic inertia support, the time response is of a crucial importance [11].
In this work three single phase EVs are employed to provide synthetic inertia and tested in one islanded configuration of the experimental low voltage grid SYSLAB PowerLabDK research infrastructure.

METHODOLOGY

Synthetic inertia in the power system could be emulated if the active power delivered (or absorbed) by the dedicated unit (EVs in this case) is controlled in inverse proportion to the variation of the grid frequency over the time ($\Delta f/\Delta t$) [12]. The experimental setup and power components are shown in Fig. 1 and detailed in the experimental layout.

Power components

The experiments are executed in the experimental infrastructure SYSLAB which is part of the PowerLabDK platform.

SYSLAB represents a small scale low voltage power system. It consists of a number of real power components interconnected by a three-phase 400 V AC power grid, distributed (more than 1 km) over the Risø campus of the Technical University of Denmark [7]. SYSLAB is also characterized by its communication and control nodes allowing a strong controllability over the grid and the ability of employing different control architecture (e.g. centralized architecture, distributed architecture). The following components are used during the experiment:

- Three controllable EVs: Two Nissan leaf – each equipped with single phase 16A charger and 30kWh lithium battery storage, both are produced in 2016 (addressed in this work as EV1 and EV3). One Nissan e-NV200 with single phase 16A charger and 24kWh lithium battery storage, produced in 2015 (addressed as EV2).
- Diesel gen-set equipped with a 60 kVA synchronous generator, capable of providing an active power output up to 48 kW.
- A controllable resistive load, named dumpload. The maximum load which is the sum of all the resistors is 78 kW.

All the devices are connected to the same bus-bar and the EVs' initial charging level is chosen so that there is room to increase and decrease the charging level equally [12].

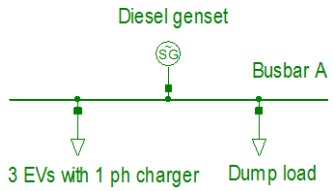

Fig. 1 The grid layout

EVs Controller description

The 3 single phase EVs are connected to the grid by means of 3 electric vehicle supply equipment (EVSE), each connected to a different phase. As the time of response is crucial for the synthetic inertia services and is dependent on the whole control loop, each EV/EVSE pair is controlled independently and in parallel using multithreading.

The communication and control setup are shown in Fig. 2 and detailed in [10].

It consists of the following components:

- Smart Charging Controller – receives the measurements from the power meter and sends control signals to the EVSE.
- DEIF MIC-2 – multi instrument measurement device for voltage, current and power measurements with 0.5% accuracy. The device is polled every 0.2 seconds.
- DEIF MTR-3 – multi instrument measurement device used here for fast frequency measurements.
- EVSE – Electric Vehicle Supply Equipment rated for 16A.
- EV – the 3 tested EVs.

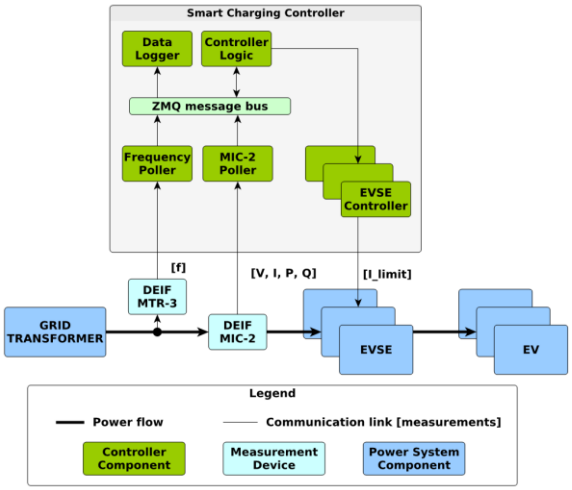

Fig. 2 Communication and control setup

- Grid – grid connection at the SYSLAB experimental facility.

The smart charging controller consists of many sub-components as described here:

- Controller logic – reads the latest frequency measurements from the message bus and determines the $\Delta f/\Delta t$. It calculates the set-points and sends control signals directly to the EVSE controller.
- EVSE controller – acts as an interface between the physical EVSE and the controller logic.
- Frequency poller – acts as an interface to the frequency measurement devices. In this case DEIF MTR-3 measurements instrument would be used for frequency sampling every 0.2 seconds with accuracy of ±10m Hz.
- MIC-2 poller – multi instrument interface.
- Data logger – monitors the data exchange on the message bus and logs it to the database.
- ZMQ message bus – message bus used for representing the data exchange between the various components.

EXPERIMENTAL SETUP AND RESULTS

The experiments are intended to test the EVs' capability of providing synthetic inertia support limiting the RoCoF in case of load variations. The experiments are executed in an islanded configuration where the frequency is set by the diesel generator. Three test scenarios are tested, where the frequency variation is triggered by several load events. The load events include an alternate load increase and decrease so that over and under frequency dynamics can be investigated. The amplitude of the load event in the three scenarios is equal to 40% of the installed power (i.e. 20 kW), which is 80 times more compared to the expected load step in the European synchronous area. The choice of this large event is to compensate the high inertia value of the diesel genset (2H = 50 s), allowing for the EVs the time to participate with synthetic inertia support. The diesel's moment of inertia is very high since it has been designed to operate in island mode.

In this study the primary frequency control is delivered by the diesel governor and automatically activated by the diesel internal controller, while the secondary frequency control has been disabled.

The three test scenarios are reported below and summarized in Table 1:

1) 20 kW load power steps from the dumpload to investigate the diesel response and the frequency behavior. No EVs are connected.
2) Load power steps with the EVs controlled by a synthetic inertia controller (controller's thresholds are ±1.5 Hz/s with a deadband (DB) of ±0.8 Hz/s, addressed as α droop).
3) Load power steps with the EVs controlled by a synthetic inertia controller (controller's thresholds are ±1 Hz/s with a DB of ±0.35 Hz/s, β droop).

Table 1 Components initial conditions and controller parameters

	Components initial conditions			EVs controller parameters	
	Diesel [kW]	**Load** [kW]	**3 EVs** [kW]	**Thresholds** [Hz/s]	**DB** [Hz/s]
Scen.1	28	28	-	-	-
Scen.2	35.5	28	7.5	±1.5	±0.8
Scen.3	35.5	28	7.5	±1	±0.35

Scenario 1

In this scenario only the dumpload and the diesel generator are connected. Since the experiments are performed in island configuration and the diesel governor is active, the scenario aims at investigating if the frequency dynamics are the same for the same load event. For example, investigating if the same load event applied several times implies the same frequency nadir, meaning a precise replicability of the conditions. It is important to note that the RoCoF is determined as Δf/Δt, where the frequency is measured every 0.2 seconds and therefore Δt is also 0.2 seconds.

The grid frequency, the RoCoF and the active power of diesel and dumpload are presented in Fig. 3.

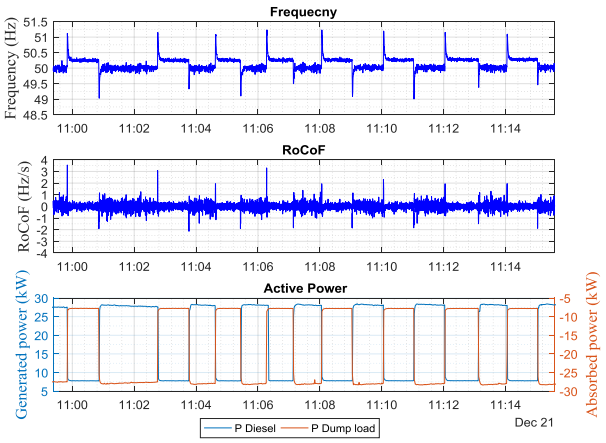

Fig. 3 Grid frequency, RoCoF and the absorbed and generated active power

One can notice that, the active power generation and consumption, respectively from the diesel and the dumpload, are varying with the same amplitude over the time. In theory this variation should case the same frequency change over the time.

However, frequency nadir and zenith are not the same over the time. This behavior is due to the mechanical dynamics of the diesel and small variation in the fuel injection rate during each cycle. Unfortunately, this behavior limits the possibility of performing a precise comparison of the EVs effects on the RoCoF with and without synthetic inertia support.

In other words, it is not possible to guarantee if the RoCoF improvement is due to the synthetic inertia or to the mechanical dynamics of the diesel. However, it is of high interest to investigate how EVs respond and if the controller and the communication infrastructure are properly designed rather than performing a numerical assessment of the frequency improvement.

Scenario 2

In this scenario the diesel generator, the dumpload and the three EVs are connected. The EVs are equipped with a synthetic inertia controller. The controller calculates the Δf/Δt and it changes the EVs' current setpoint in function of the applied droop. In this study two different droops are considered: α (the RoCoF limits are ±1.5 Hz/s with a DB of ±0.8 Hz/s) and β (RoCoF limits of ±1 Hz/s and DB of ±0.35 Hz/s). The two droops are RoCoF-Current droops and are presented in Fig. 4. The solid lines represent the 1-A step functions implemented in order to comply with the IEC 61851 standard.

The α droop is used in scenario 2 while the β droop is used in scenario 3. It is important to highlight that the voltage regulator of the diesel tries to maintain the voltage equal to 230 V, therefore setting the current is like setting the active power.

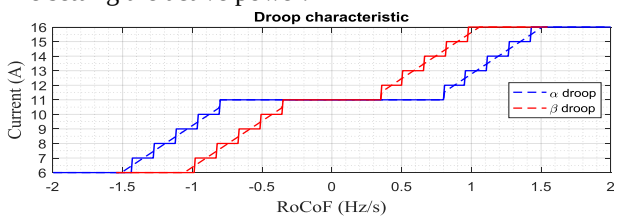

Fig. 4 Current – RoCoF droop characteristic

As for scenario 1, the load events include an alternate load increase and decrease of the same amplitude, so that over and under frequency dynamics can be investigated. The amplitude of the load event is 20 kW.

As it can be seen in Fig. 5, due to the mechanical dynamics, the large inertia value of the diesel and the limited number of EVs, it is not possible to appreciate improvements in the RoCoF.

However, in Fig. 6 it can be seen that the EVs' current setpoint is following the RoCoF variation as desired.

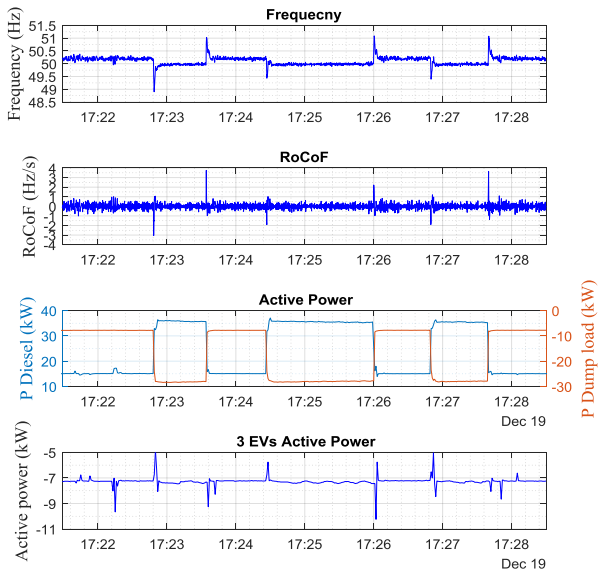

Fig. 5 Frequency and RoCoF dynamics and the absorbed and generated active power

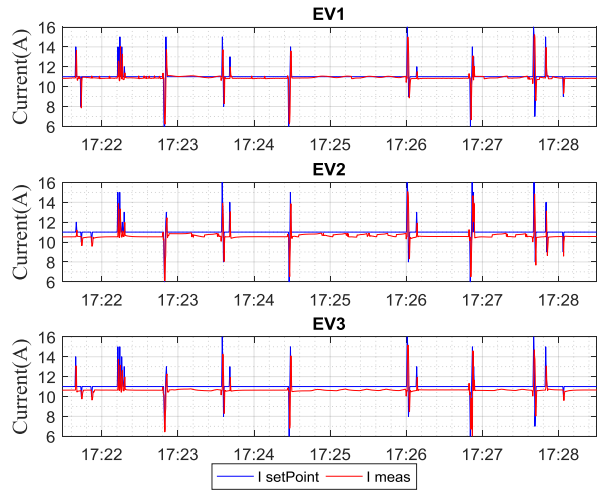

Fig. 6 EV's current setpoint sent by the controller and the EV's measured current

This variation can also be seen in Fig. 7, which shows a zoom of two consecutive load steps. In Fig. 7 only EV1's current is shown. The delay between the current setpoint and the absorbed one depends on the EV model and the year of production, in this case it is in the range of 200÷400 ms.

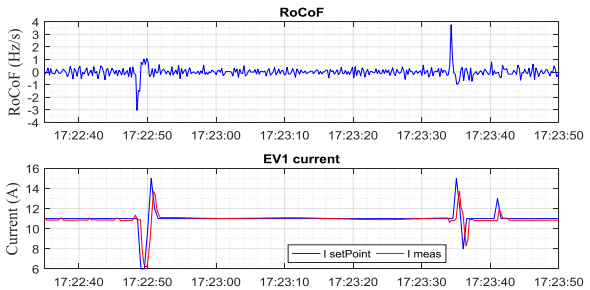

Fig. 7 RoCoF and EV's current

Scenario 3

This scenario aims at demonstrating the importance of choosing the appropriate controller's thresholds as well as the DB. In this scenario the authors decided to apply a higher gain and a smaller DB, namely β droop, to show that on the contrary of the synchronous inertia, synthetic inertia might lead to unstable frequency behaviour if the controller is not well tuned. The results are shown in Fig. 8 and Fig. 9, which show the frequency, the RoCoF and the absorbed and generated power.

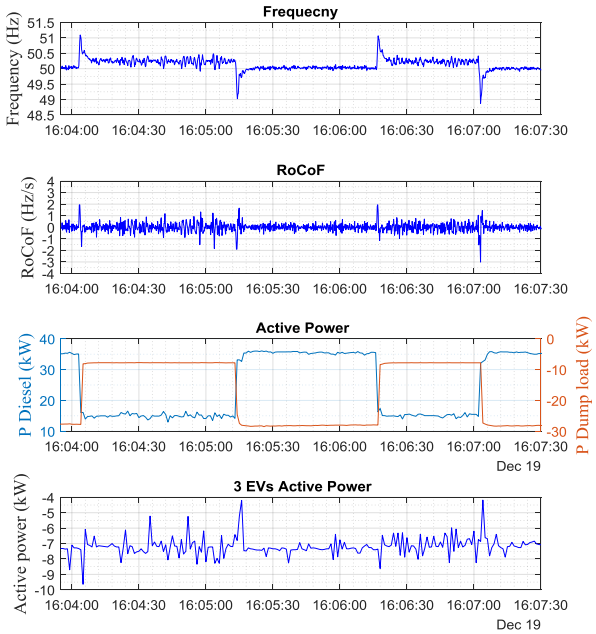

Fig. 8 Frequency and RoCoF and the absorbed and generated active power

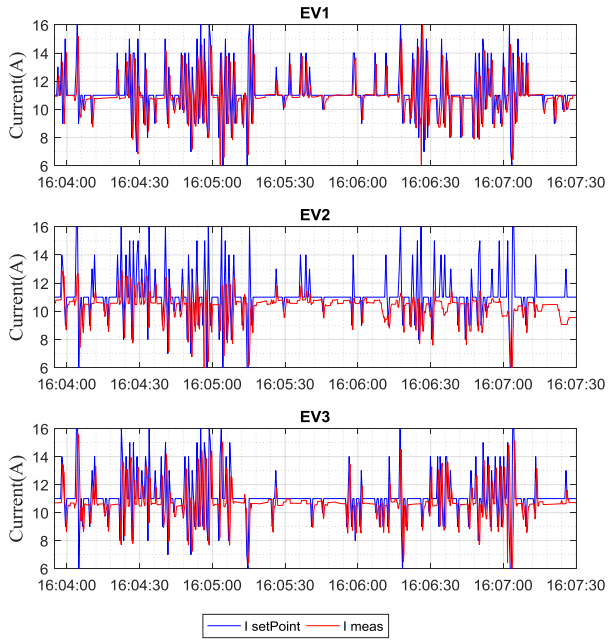

Fig. 9 EV's current setpoint sent by the controller and the EV's measured current

On the contrary of the previous scenario, one can notice that the RoCoF is larger which it can be also appreciated from the EVs' current setpoint. To prove so, the standard deviation for frequency and RoCoF for scenario 2 and 3 is calculated.

For scenario 2, it is equal 0.15 Hz and 0.32 Hz/s respectively, versus 0.19 Hz and 0.39 Hz/s for scenario 3.

To be mentioned, the grid frequency change and RoCoF are relatively limited due to the diesel large inertia. The smaller dead band and the higher gain induce more frequent changes in the current setpoint.

One can notice that, due to the different models and production year among the EVs, EV2 founds difficulty in following the setpoint as shown in Fig. 9. This difference can be seen as under or overshooting of the measured current as well as a delay between the current setpoint and the measured current.

CONCLUSION

The analysis showed the EVs' capability of providing synthetic inertia support. An experimental islanded microgrid has been set, and three series produced EVs have been controlled relying on synthetic inertia controllers. It was shown that on the contrary of synchronous inertia, more synthetic inertia (achieved by a higher gain and smaller dead band) does not guarantee a slower RoCoF and more stable behavior. Contrarily, the experiment showed that the higher gain and the smaller DB imposed the EVs to change the current set-point more frequently leading to faster RoCoF. The experiments demonstrated also that even if the EVs are all equipped by the same controller and the same standard (IEC 61851), they do not follow the setpoint in the same manner.

Further experiments will be carried out employing a higher number of EVs to appreciate more their effect on the RoCoF in case of high inertia system as well as low inertia system. Future work will also focus on comparing fast frequency control with synthetic inertia and on the capability of EVs in providing those two services. Namely, employing some EVs for fast frequency control and others for synthetic inertia. Consequently, testing the capability of providing synthetic inertia and fast frequency control from the same unit

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