



Electric vehicles contribution for frequency control with inertial emulation



P.M. Rocha Almeida, F.J. Soares*, J.A. Peças Lopes

INESC TEC – INESC Technology and Science (formerly INESC Porto) and Faculty of Engineering, University of Porto, Portugal

ARTICLE INFO

Article history:

Received 22 August 2014
Received in revised form 26 May 2015
Accepted 30 May 2015
Available online 16 June 2015

Keywords:

Electric vehicles
Power system dynamics
Primary frequency control
Islanded systems
Inertial emulation
Droop control

ABSTRACT

This work proposes a novel primary frequency control technique with electric vehicles (EV), the combination of inertial emulation and droop control, for isolated systems. Being EV dispersed along the grids, the impacts of possible delayed actions are assessed. Islanded systems have reduced inertia and so load/generation imbalance situations may lead to large frequency deviations. Therefore, this paper focuses essentially on the EV contribution for primary reserves provision, in order to allow a safe integration of further intermittent Renewable Energy Sources (RES). An avant-garde generation dispatch was adopted for the test system used in this work, fully reliant on RES, mainly conventional hydro units and some wind generation. The studied disturbances include a rapid shortfall on wind power production and a sequence of consecutive events caused by the variability of the wind resource in an ordinary situation.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

There are countless frontlines that need to be tackled in the pursuit of sustainability. Environmental awareness and the instability of the crude oil markets are pushing modern world toward a future less dependent on fossil fuels. As alternatives, energy efficiency and Renewable Energy Sources (RES) are being more and more exploited. At a global level, regarding final energy consumption by sector of activity, it is verified that the transport sector is the one that leads, followed closely by the industry and only after the residential [1].

This paper is devoted to the exploitation of the impacts and potential benefits that the electrification of the vehicle fleet may provoke on isolated electric power systems, namely in what regards the expansion of intermittent RES. Regarding transportation, sufficient recharging facilities will have to be provided to electric vehicle (EV) owners, charging either at home or at public charging infrastructures. In any case, in the electricity sector, Distribution System Operators (DSO) will have to handle with a new load that before was not included in planning and operation.

In addition, as EV have a high potential to participate in several ancillary services [2], this paper also addresses the grid operational

management and control strategies that should be available with the presence of these new elements.

Whether providing peak load demand or participating in the spinning reserves or in frequency regulation, the potential to control EV charging process is new to the current structure of the electricity grids. In this way, the growing prospects of an EV market expansion may strengthen the concepts that aim at the active network management.

The work presented in [3–5] promoted the first steps into EV integration in power systems as controllable loads and set the path for the exploration of EV batteries as storage elements for the provision of several ancillary services to the electricity grid.

Four power markets with relevance for EV were analyzed in [6]: base load, peak, spinning reserves, and regulation. As EV main purpose while connected to the grid is to acquire energy to fulfill its transportation needs, the authors suggest that EV should initially provide regulation and spinning reserves. Another work, [7], addressed the participation in regulation by EV, performing a valuation of EV power for the provision of regulation up and down. The work presented in [8] addresses the technical grid related issues of using EV in regulation. Technical operation is alongside with market integration a pillar that supports EV advanced management techniques. EV were used in voltage support and frequency regulation with the application of control droops.

Stationary battery applications for frequency control have been studied, for instance in [9,10], but they always considered relatively large battery systems, which imply large investments costs in a dedicated asset for the grid. EV presence in electricity grids may be

* Corresponding author at: INESC TEC (formerly INESC Porto), Campus da FEUP, Rua Dr. Roberto Frias, 378, 4200–465 Porto, Portugal. Tel.: +351 22 209 4212; fax: +351 22 209 4050.

E-mail address: fsoares@inescporto.pt (F.J. Soares).

exploited for the same purpose, while avoiding the investment cost. Nevertheless, EV presence is not certain in time and space as the vehicles commute and may be plugged-in in different locations. In addition, the State-of-Charge (SOC) of the EV batteries is also variable for the system operator.

This work builds upon the research developed in [11], to assess the effectiveness of EV participation in frequency control in isolated system. These systems have reduced inertia and so imbalance situations between load and generation may lead to large frequency deviations. Therefore, EV contribution in these systems should focus on primary reserves provision. In this paper a novel control approach that emulates the generators inertia effects in combination with the previously described droop control loop that mimics conventional generators governing actions is proposed. In a second stage, this work tests the performance of the EV local frequency control units when their action is disturbed by delays that may differ with the EV charging equipment and control. The test system is a representation of a small islanded system, based on real data, with high potential for RES expansion, but with very low load conditions during valley and peak hours. For this reason the island has to depend on fossil fuels to guarantee quality to the power supplied to the consumers. The presented scenarios assume an avant-garde generation dispatch, fully reliant on RES, mainly conventional hydro units and some wind generation. As referred, the developed control techniques should be able to allow further integration of intermittent RES in these systems.

2. Methodology and modeling

As it was explained in Section 1, this paper aims at identifying new procedures and assessing the efficacy of EV in frequency control provision for isolated systems.

The European norm EN50160 [12], defines that the admissible operation conditions for isolated system and introduces a limit of ± 1 Hz for frequency deviations.

To do so, a disturbance on Renewable Energy Sources (RES) power availability was defined in order to create a worst case scenario. To evaluate EV potential for frequency control the methodology presented next is as follows:

1. The isolated network dynamic model was characterized in terms of electricity grid and generation system.
2. With the defined disturbance, a dynamic simulation was conducted for the case where EV are regarded as simple loads.
3. The same simulation was conducted using EV to perform frequency control.

The obtained results allow analyzing the power system reaction in terms of frequency, the dispatched conventional units' power and torque and the EV load.

2.1. Control scheme

In [11,13] a droop control that mimics the governors of conventional generators was adopted to implement primary frequency control on EV. In this paper, a novel control loop is proposed in addition to the droop control, the inertial control, which also emulates the behavior of conventional generator allowing EV to provide inertia to the system. This technique has been applied in different contexts, for instance in [14].

For both control loops frequency must be read locally and the reaction to frequency deviations is performed autonomously. This reaction should consist on providing new set-points for the electronic power converter that interfaces EV batteries and the electricity grid. As described in [15,16] the control scheme should

be installed on individual Vehicle Controllers (VC), which should be located next to the vehicle charger, establishing the link with the smart electricity grid communication infrastructure. This allows upstream controllers to be logged about the activity of the VC concerning primary control provision and, if needed, redefine the droop control settings for the inertial emulation.

So, apart from an eventual set-point imposed by an EV market aggregating entity, named Aggregator, as proposed in [15], or by local control actions, the load value of the EV may be influenced by one of or both the control loops. Eq. (1) presents the active power change requirement for the EV due to the influence of the droop. The load will change by an amount that is obtained by multiplying a proportional gain by the actual frequency change. While a frequency error is sustained the proportional controller will always impose a change in the load of the EV.

Eq. (2) provides the amount of active power change, in case of a load/generation imbalance, that results from the inertial emulation implementation in the controllers of EV. In this case the load will change by an amount equal to the product of a gain by the derivative of frequency change in respect to time. The derivative gain is a measure of the sensitivity of the controller to the rate of change of frequency, expressed in units of power per units of frequency per unit of time. The influence of this type of control is bigger for periods when frequency is changing fast and will be null when frequency stabilizes, independently of how big the absolute frequency error may be. The action of this control is mainly noticeable in the initial moments succeeding a disturbance.

$$\Delta P_{Droop} = k_p \cdot \Delta f \quad (1)$$

$$\Delta P_{InertialEmulation} = k_{in} \cdot \frac{d}{dt} \Delta f \quad (2)$$

where

- ΔP_{Droop} is the load change provoked by the droop control.
- $\Delta P_{InertialEmulation}$ is the load change provoked by the inertial emulation control.
- k_p is the proportional gain.
- k_{in} is the derivative gain of the controller.
- Δf is the frequency deviation.

However, EV should not react to every small mismatch in power and so a dead band must be added and a fixed power rating should be maintained whenever possible. The dead band should be considered to guarantee longevity of the batteries and thus a beneficial synergy between parties, the grid operator/Aggregator and the EV owners. The charging reference power, P_{ref} , may be defined in different ways:

- Set-point from the Aggregator or the DSO for EV that adhere to smart charging schemes, depending on the strategies for minimizing charging costs and the occurrence of possible grids technical violations.
- Or, by local decision of EV owners who do not adhere to smart charging.

A margin between the actual power rating and the maximum power rating may be imposed to EV participating in primary frequency control, in order to allow the participation in downwards regulation. The maximum power rating is the nominal charging power of the EV, whereas the minimum power rating is the nominal discharging power, zero, a value between the minimum and maximum power ratings or even a value below zero if drawing power from the EV batteries is allowed.

As to the inertial emulation loop, it may be wise to introduce a saturation following the derivative of the frequency deviation to

متن کامل مقاله

دریافت فوری ←

ISIArticles

مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات