Potential For Plug-In Electric Vehicles To Provide Grid Support Services

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Abstract— **Since the introduction of Plug-in Electric Vehicles (PEVs), scientists have proposed leveraging PEV battery packs as distributed energy resources for the electric grid. PEV charging can be controlled not only to provide energy for transportation but also to provide grid services and to facilitate the integration of renewable energy generation. With renewable generation increasing at an unprecedented rate, most of which is non-dispatchable and intermittent, the concept of using PEVs as controllable loads is appealing to electric utilities. If incentivized suitably, this could serve as an additional driver for PEV adoption. It has been widely proposed that PEVs can provide valuable grid services, such as load shifting to provide voltage and frequency regulation. The objective this work is to address the degree to which PEVs can provide grid services and mutually benefit the electric utilities, PEV owners, and auto manufacturers.**

Keywords—electric vehicles; grid services; renewable generation; controllable load; voltage support

I. INTRODUCTION

Plug-in Electric Vehicles (PEVs) offer many advantages over conventional vehicles. PEVs reduce dependence on oil, decrease greenhouse gas and toxic emissions, and are energy efficient. It has been suggested that widespread adoption of PEVs will be necessary for California to meet its goal of an 80% reduction in greenhouse gas emissions below 1990 levels by 2050 [1].

As the market penetration of PEVs increases, the number of PEVs charging on the electric grid will also increase. This increase in PEV charging has the potential to impact the electric grid. For example, distribution feeders with a large amount of PEV charging may need to make significant infrastructure investments to integrate the PEV charging load [2]. In addition to the extra load, widespread PEV charging may also cause undesirable congestions and voltage problems on the distribution network during the charging process [3]. All these factors bring new challenges to power system operators. As an outcome, controllable charging solutions are needed in order to make PEVs an asset to the grid rather than a merely traditional non-controllable load.

In spite of the increased load and voltage instability caused by the non-controlled charging of PEV, if proper charging controls are used it can be shown that additional transmission capacity [4] and mitigation of power fluctuations caused by the high penetration of intermittent renewable energy sources [5,6,7] can be supported by the controlled charging of electric vehicles.

There are several technology, policy, and market mechanisms have gaps to enable individual and fleet of loads such as the PEVs to provide grid services. Few challenges that can be noted in this context are lack of communications, controls, suitable optimization, metering, and financial incentive. Research shows that few markets have more flexibility that others for fleet of loads, if coordinated, with suitable benefits. For example, markets such as UK and the Nordic, have rules and policies requiring larger capacity and ancillary service requirements have greater opportunities [8].

Potential benefits of loads providing ancillary services are several - optimal electricity prices, market efficiency, enhanced reliability, greater flexibility, etc. PEVs have the ability to be controlled very quickly without much effect on their typical charging operation. Aggregator based controls and communications with smarter controls on the electric vehiclescan hence ensure that they are well within the optimal efficiency range and provide grid benefits. Different response times that can suit different products in the power markets can hence be ensured by the fleet of responsive EVs. With advanced controls, responses of fleet of EVs can also be coordinated to be automated rather than negotiations-based leading to better response times. Voltage regulation, which is a local phenomenon, can be considered as one of the promising services that fleet of PEVs can provide. Additionally, energy market and reserves, if coordinated well, can also be suitable avenues for fleet of EVs to participate. Market constructs and policies need to be flexible enough to allow these entrants to be compensated suitably [9].

Finally, the added cost of instrumentation, metering, and compensation mechanism has to be accounted within this framework. From a technology perspective, a notable gap that exists is regarding the non-uniformity of interconnection and interoperability mechanisms that will lead to the successful provision of grid services by the fleet of PEVs. Several standards and associations are working towards harmonization of these requirements to lead to a better overall coordination of various technologies, markets, and grid operation. To address the grid services capability by the fleet of PEV, this work simulates, emulates and validates the concept of using electric vehicles with controlled charging to provide grid voltage and frequency regulation.

II. MATERIALS AND METHODS

A. *Hardware in the Loop Environment*

In order to demonstrate grid service capabilities, a notional 36 node distribution feeder was programmed using Digital Real Time Simulator (DRTS). The 36-node notional feeder was based on publicly available feeder information physically located in the California's Bay Area, spanning major distribution and coupling transmission lines (from 69 kV to 138 kV). This study used the DRTS to provide grid real time data and behavior. As shown in figure 1, a Power-Hardware-in-the-Loop (PHIL) has been executed by connecting the DRTS analog outputs to a regenerative grid simulator (CHROMA model 61860), in order to provide real power to an Electric Vehicle Supply Equipment (EVSE) connected to a 2015 Nissan Leaf whose charging could be controlled. The Leaf's level 2 charging was controlled by a National Instruments (NI) CompactRIO platform manipulating the SAE J1772 [10] control pilot signal to the vehicle.

In addition, as shown in figure 2, a Controller Hardware in the Loop (CHIL) setup was assembled by connecting the DRTS through TCP/IP with an ARM compatible programmable controller (Raspberry Pi 3). The controller receives feedback from real-time node voltage, real-time node frequency and feedbacks control current to the NI platform (actual vehicle controller) and to DRTS (emulated vehicle controller).

In order to better tune the controller with the actual power hardware (electric vehicle), the transfer function for power response of electric vehicles was characterized and implemented for emulated response on Raspberry PI boards. Figures 3, 4, and 5 show examples of the characterization process of the electrical vehicles: Figure 3 shows the behavior of a Chevy Volt charging at Level 2 (240VAC), with the control current set to 16A. Figure 4 and 5 show the behavior of a Chevy Volt charging at Level 2 (240VAC), with the control current set to 16A, after a voltage sag of 90V (the line voltage dropped from 240V to 150V).

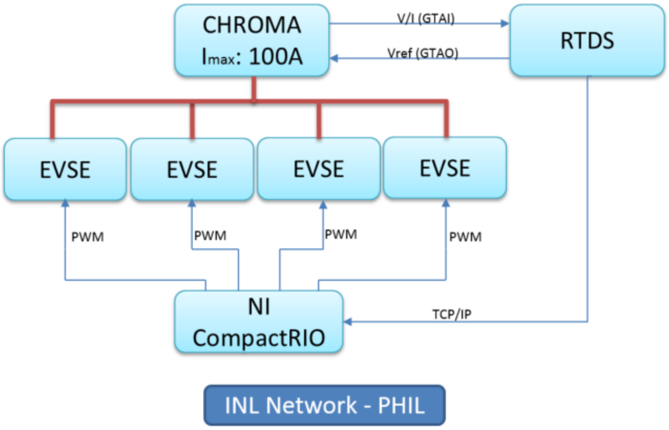

Fig. 1. Power Hardware in the Loop setup

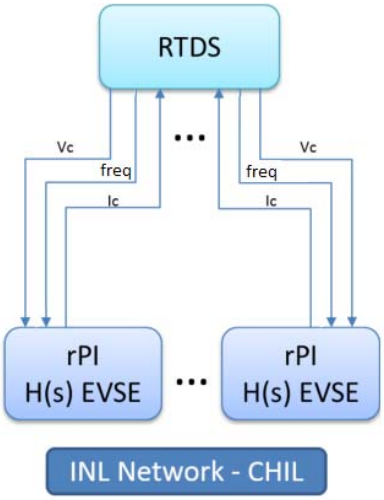

Fig. 2. Controlller Hardware in the Loop setup

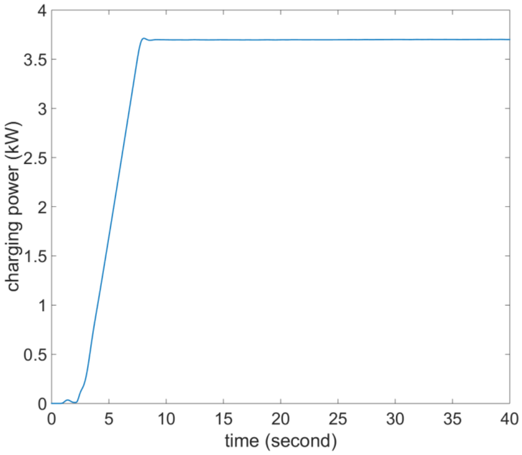

Fig. 3. Chevy Volt at Level 2 charging with control current set at 16A Controlller Hardware in the Loop setup

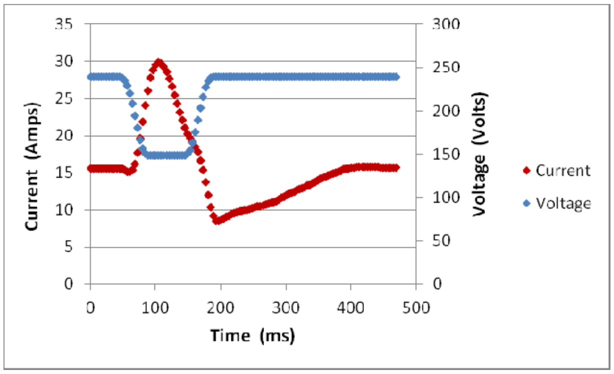

Fig. 4. Voltage Sag on Chevy Volt charging at Level 2

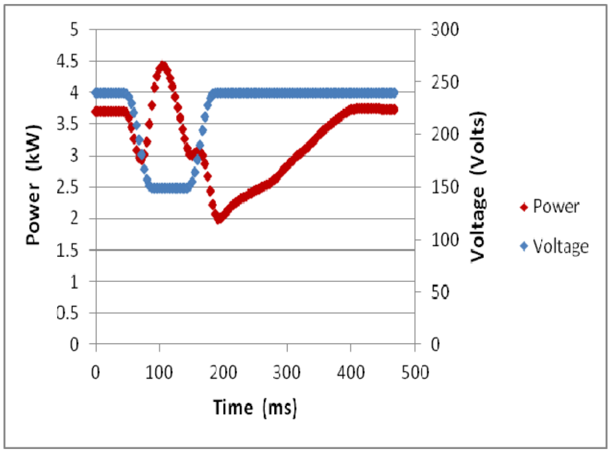

Fig. 5. Voltage Sag on Chevy Volt charging at Level 2

B. Control Specfications

A Python 3 code for the ARM compatible programmable controller was developed and tuned with the local node voltage droop, system frequency droop and dead band response. The following results were achieve for optimized controller response:

1) Minimal Vehicle Power: 0.22 pu,
2) Voltage Droop Control: 3.3% pu Node V / PEV power,
3) Frequency Droop Control: 3.3% freq / PEV power,
4) If there is no droop, the vehicle will return to maximum power at a rate of 0.1 pu per second,
5) If there are both voltage and frequency droops, the controller will choose the maximum power droop, and
6) Dead Band: 0.5% pu node Voltage and frequency.

III. RESULTS

A. Simulation Results

As the first step to establish the proof concept of grid services with a controllable load of pure real power, as is the actual case for PEVs (power factor at nominal power in the order of 92-98%), an internal simulated load equivalent to 4,000 vehicles was used with and without a controller. A grid event of sudden load unbalance is triggered and the results with and without the controllable load capability are evaluated. Figure 6 and Figure 7 show the comparison of the grid frequency response with a passive load and with a controllable load responsive to frequency droop, respectively. Figure 8 and Figure 9 show the comparison of the local node voltage with a passive load and a with a controllable load responsive to the local node voltage droop, respectively. It can be observed that voltage and frequency deviations are of lesser magnitude when the controllability feature is activated.

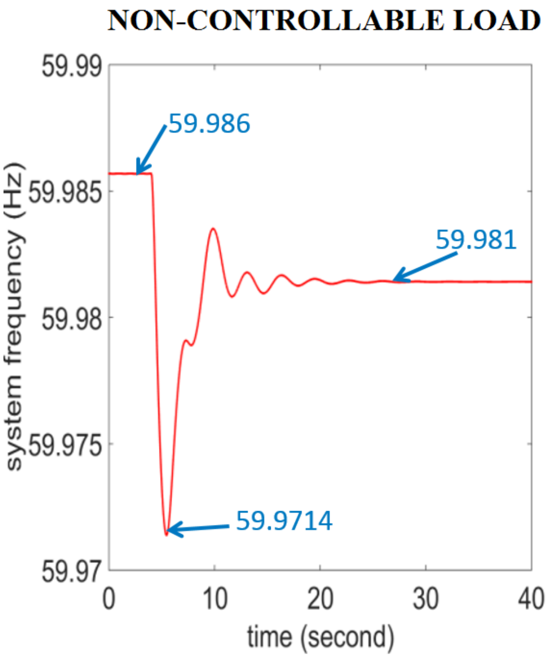

Fig. 6. Frequency deviation after event- non-controllable load

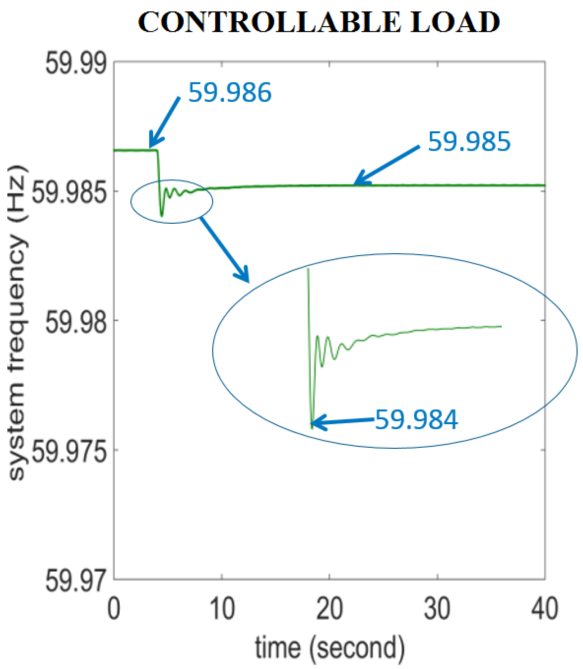

Fig. 7. Frequency deviation after grid event- controllable load

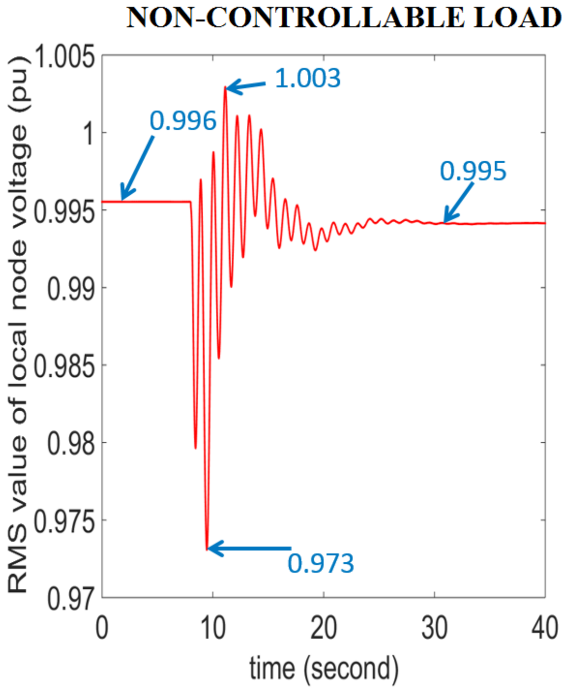

Fig. 8. Voltage deviation after grid event- non-controllable load

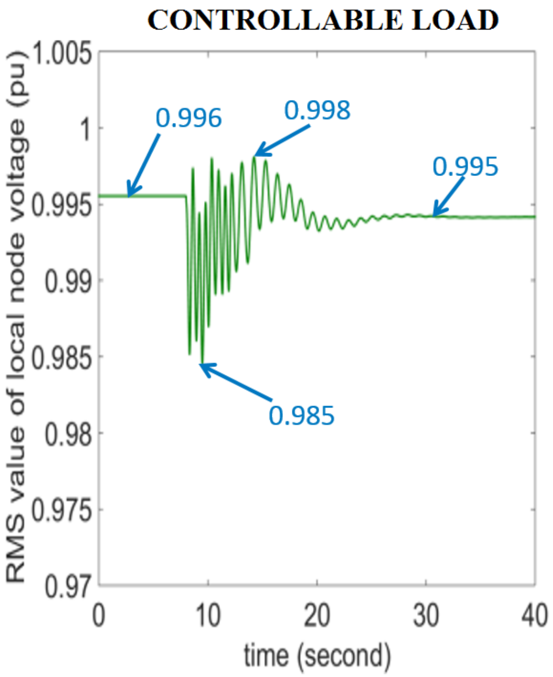

Fig. 9. Voltage deviation after grid event- controllable load

B. *Controller Hardware-In-The Loop Results*

Thereafter, the external Raspberry Pi with the programmable droop controller and transfer function relating power response of the 2015 Nissan Leaf with time and control pilot current was connected with DRTS through TCP/IP connection, as shown in fig. 2. A individual load multiplier of 4,000 vehicles was used after the input signal on DRTS, with a total load of 26 MW. A grid event of sudden load unbalance is triggered and the results with and without the controllable load capability is evaluated.

The results without controllable load always keep the output power at nominal vehicle power. Figure 10 shows the result of the vehicle active power control after the grid event. Figure 11 shows the comparison of the local node voltage response when the 4,000 vehicles are charging without control (blue), acting as a non-controllable load, and when the vehicles are charging controlled by a centralized feedback control pilot (red). Figure 12 shows the comparison of the grid frequency response when the vehicles are charging without control (blue), acting as a non-controllable load, and when the 4,000 vehicles are charging controlled by a centralized feedback control pilot (red). It can be observed that voltage and frequency deviations are of lesser magnitude when the controllability feature is activated. It is also important to notice that as the vehicles doesn’t have a fast response (e.g. 2015 Nissan Leaf has a maximum response rate of 10 A/s), the upcoming oscillations are better amortized than the first voltage or frequency sag due to the load unbalance grid event.

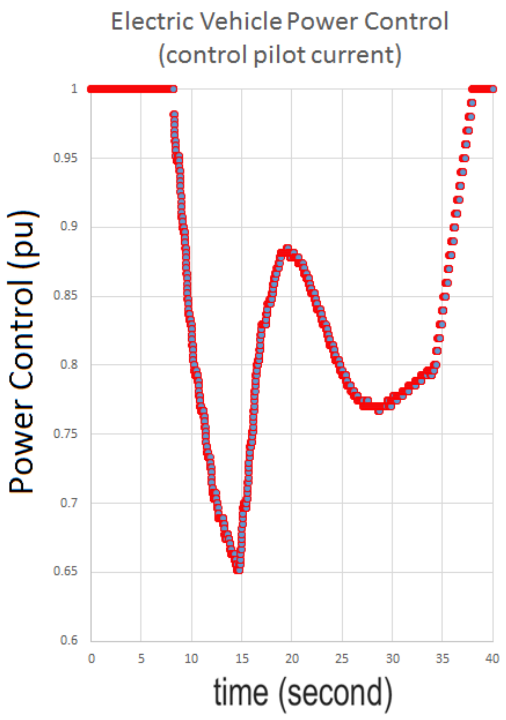

Fig. 10. Electric Vehicle power control pilot response after grid event

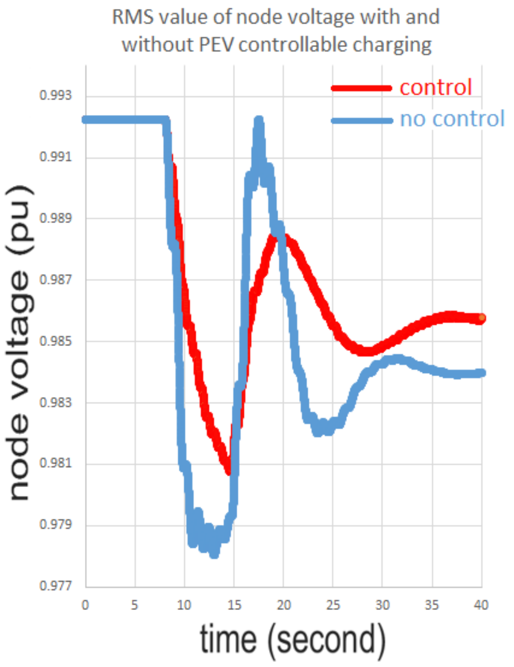

Fig. 11. Voltage deviation after grid event - controllable charging (red) and non-controllable charging (blue)

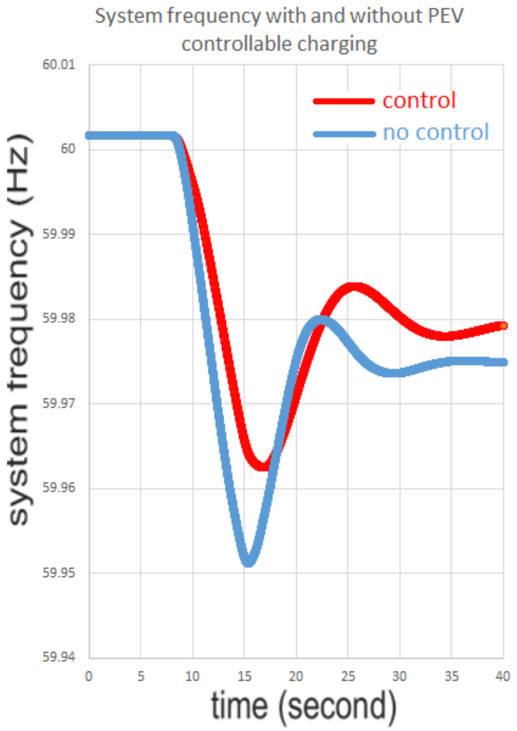

Fig. 12. Frequency deviation after grid event - controllable charging (red) and non-controllable charging (blue)

C. Power Hardware-In-The Loop Results

Finally, the power setup with RTDS connected and controlling 2015 Nissan Leaf node voltage, with current feedback from the electric vehicle to RTDS multiplied by 4,000 and the programmable Raspberry Pi droop controller connected to the NI platform and providing power control through SAE J1772 to 2015 Nissan Leaf was implemented, as shown in fig. 1. A grid event of sudden load unbalance is triggered and the results with and without the controllable load capability is evaluated.

The result without controllable load always keep the output power at nominal vehicle power. Figure 13 shows the result of the vehicle active power control after the grid event, with control pilot frequencies of 1 Hz (1 second/control) and 0.5 Hz (2 seconds/control). Figure 14 shows the voltage comparison of the local node response when the 4,000 vehicles are charging without control (blue), acting as a non-controllable load, and when the vehicles are charging controlled by a centralized feedback control pilot (red). Figure 15 shows the comparison of the grid frequency response when the vehicles are charging without control (blue), acting as a non-controllable load, and when the 4,000 vehicles are charging controlled by a centralized feedback control pilot (red). It can be observed that voltage and frequency deviations are of lesser magnitude when the controllability feature is activated. Furthermore, it is observed that as the control pilot frequency increases, faster the vehicles will respond to grid events, to the price of lesser voltage stability (2015 Nissan Leaf has a maximum measured response rate of 10 A/s).

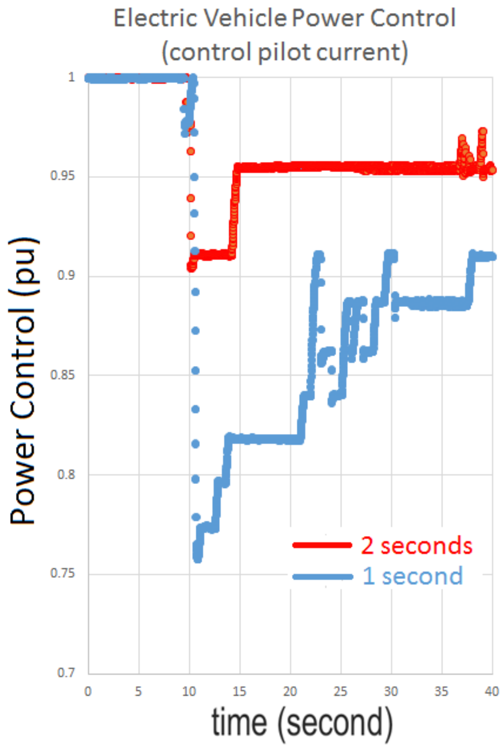

Fig. 13. Electric Vehicle power control pilot response after grid event

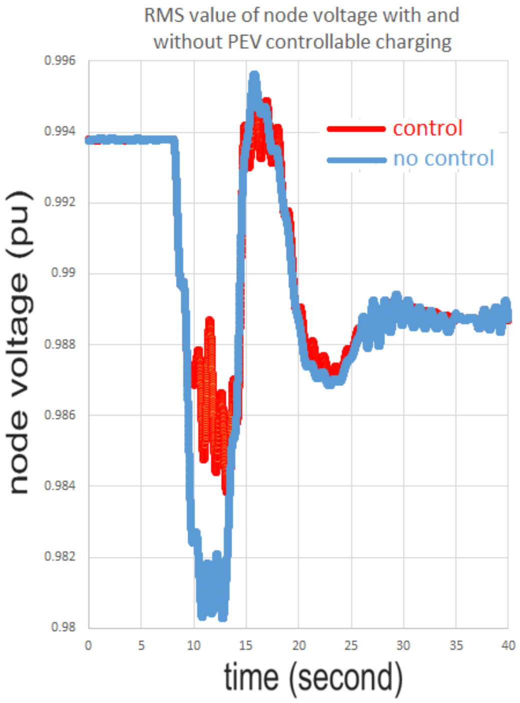

Fig. 14. Voltage deviation after grid event - controllable charging (red) and non-controllable charging (blue)

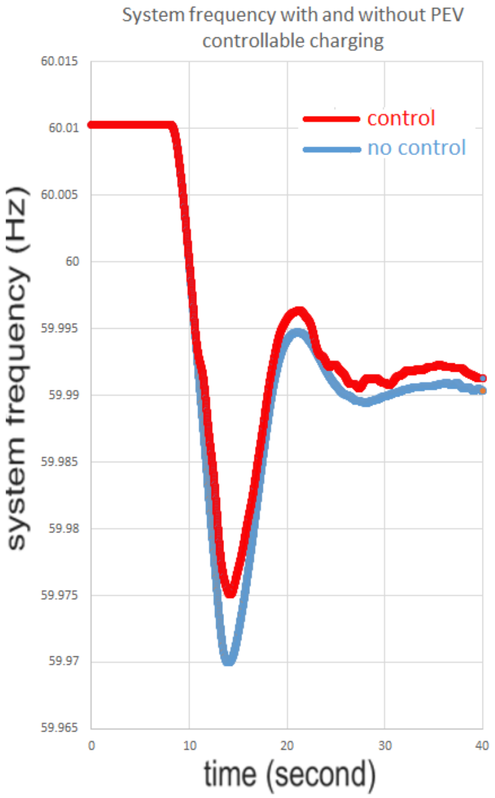

Fig. 15. Frequency deviation after grid event - controllable charging (red) and non-controllable charging (blue)

IV. CONCLUSIONS

Aforementioned as active resistive loads can provide several energy-balancing ancillary services, this article introduces, simulates, emulates and validates the concept of electric vehicles being used to provide grid services, such as voltage and frequency regulation. The article used a fixed meaningful number of PEV (four thousand) as a feedback to the grid simulator in order to bring the proper scalable degree of impact to the grid. No study was conducted to verify the interaction between different vehicles and their integrated response, as the droop controller was centralized and fixed at a specific grid node. In this context, the concept of front-end integration and aggregation plays a key role on grid services, whereas this may be one of the areas where vehicle aggregators can play a major role. Aggregator's optimization objective functions and proper communications algorithms are an important priority for the national science agenda in that context, as the vehicle's optimized aggregation can bring improved grid services and optimized demand response for the utilities as it concurrently could provide better economic opportunities to the PEV owner.

Furthermore, with renewable generation increasing at an unprecedented rate, most of which is non-dispatchable and intermittent, the concept of using aggregated PEVs as controllable loads is appealing to electric utilities, by playing an important role both as grid services providers and as demand responders, hence mitigating the ever increasing variability brought by renewables integration to the grid.

ACKNOWLEDGMENT

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REFERENCES

[1] Williams, J. H., A. DeBenedictis, R. Ghanadan, A. Mahone, et al., “The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity,” Science (2012) 335(6064): 53-59, doi: 10.1126/science.1208365.

[2] C. Roe, F. Evangelos, J. Meisel, A. Meliopoulos, and T. Overbye, “Power system level impacts of PHEVs,” in Proceedings of the 42nd Hawaii International Conference on System Sciences, Waikoloa, HI, 2009.

[3] C. Søndergren, “electric vehicles in a distributed and integrated market using sustainable energy and open networks”, EDISON Deliverable 2.3 Report: Electric Vehicles in Future Market Models.

[4] Pearre, Nathaniel S., and Lukas G. Swan. "Electric vehicle charging to support renewable energy integration in a capacity constrained electricity grid." Energy Conversion and Management 109 (2016): 130-139.

[5] M. Fadaeenejad,A.M. Saberian,Mohd. Fadaee,M.A.M. Radzi,H. Hizam,M.Z.A. AbKadir, “The present and future of smart power grid in developing countries”, Sustain EnergyRev 2014;29:828–34.J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[6] C. Gouveia, D. Rua, F.J. Soares, C. Moreira, P.G. Matos, J.A.P. Lopes, “Development and implementation of Portuguese smart distribution system”. ElectrPower Syst Res2015;120:150–62.

[7] K. Parks, P. Denholm, and T. Markel, “Costs and emissions associated with plug-in hybrid electric vehicle charging in the Xcel energy Colorado service terrority”, Golden, Colo. : National Renewable Energy Laboratory, [2007].

[8] G.Heffner, C. Goldman, B. Kirby, and M. Kintner-Meyer, "Loads Providing Ancillary Services: Review of International Experience", Ernest Orlando Lawrence Berkeley National Laboratory,<https://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/Loads_providing_Ancillary_Services_main_report_62701.pdf>

[9] B. Kirby, E. Hirst, "Load As A Resource In Providing Ancillary Services", Oak Ridge National Laboratory and Consultants in Electric-Industry Restructuring Oak Ridge Tennessee, <http://wind.ucdavis.edu/rpsintegration/library/Load%20as%20resource%20in%20ancillary%20services%20Jan99%20Kirby%20Hirst.pdf>

[10] SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler, SAE International, <http://standards.sae.org/j1772_201001/>