DSM of Electric Vehicles using Future Internet

Balancing the grid in cases of unplanned events causing frequency instability

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***Abstract* — Transitioning to a more automated grid requires changes and enhancements to grid operations, to the network structure and to end-user interaction. Concurrently, a desire to integrate renewable power sources into the grid imposes significant strains on existing electricity infrastructures and can lead to critical volatility in the grid frequency as a result of these unreliable supply sources. Of all the elements of frequency control available to a Transmission Systems Operator (TSO), by far the most valuable is the availability of an autonomous 5-15 second response window. In this paper, we demonstrate the feasibility of using future internet technologies to balance the load on the grid in cases where unplanned events e.g., a drop in Renewable Energy Supply (RES), has caused fluctuations in grid frequency. This is done by, but not limited to, remotely controlling the load drawn by the domestic Electric Vehicle (EV) charge points.**

Keywords – demand side management; electric mobility; electric vehicles; renewable energies; future internet; smart energy

I. INTRODUCTION

The European Commission outlines ambitious targets for "raising the share of EU energy consumption produced from renewable resources to 20%" [1]. In Ireland, this is even more ambitious, with a target of "40% electricity consumption from renewable sources by 2020" [2]. Due to the abundance of wind in Ireland (see Figure 1, where dark grey indicates high wind speeds), this will be the predominant source of renewable energy to meet these targets [3].

However, this desire to integrate renewable power sources

Figure 1. On/Offshore Wind Availability in Ireland

(other proposed sources include solar, tidal) into the grid imposes significant strains on existing electricity infrastructures. Figure 2 illustrates that short term fluctuations in wind energy supply are random, frequent and, though weather modeling plays a crucial role in predicting wind patterns and movements, it is still extremely difficult to accurately forecast this supply.

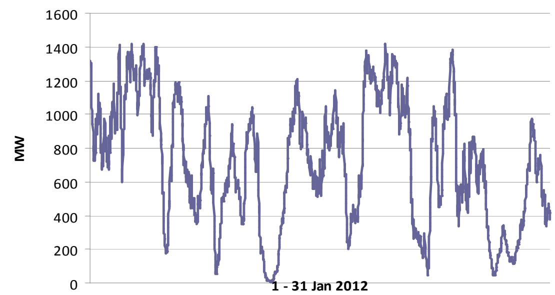

Figure 2. Wind Power Ireland - Jan 2012

A continuous balance between power generated and power consumed is required to maintain a constant, synchronous grid frequency (in Europe this is 50Hz). Any imbalance in power (generated or consumed) can result in a deviation in this frequency which, in turn, can adversely affect the transmission and distribution of electricity around the grid. Frequency control can ensure that the system remains within acceptable limits, and one such element of frequency control is *Demand Side Management* (DSM), which involves controlling the power demand so that it tracks the power supply.

Electric Vehicles (EVs) are suitable candidates for DSM due to their charging power demand of 3.6 kW (single phase at 16A) on a standard residential plug. For every 1000 Electric Vehicles (EV) charging on the grid, the load drawn is approximately 2.5-3.5MW. By reducing the charge rates of EV's on the grid by just 50% during the initial minutes of the disturbance, a grid can be stabilized while spinning reserve is ramped up to take up the slack. Here, generators are available to provide power typically within 10 minutes. These reserves are used when another generator on the system goes down or deactivates unexpectedly [4]. The effect on EV charging is negligible over the course of a 6-8 hour night-time charging period.

Charging independent of external EV requirements (i.e., non-battery related) is known as *smart* or *intelligent* charging. Several investigations have been conducted with respect to

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different external requirements. Most of these investigations focus on charging in dependence of availability of Renewable Energy Supply (RES) in the grid [5][6], others investigate coherence with driving profiles [7][8]. External requirements such as local or global grid parameters (frequency, voltage) are mainly considered under the umbrella of the potentially bi-directional power flows called Vehicle-to-Grid (V2G) [9-12] or by simulations [13]. Therefore, the following scenario focuses on uni-directional power-flows in dependence of grid parameters. It leverages Future Internet (FI) technologies and uses a testbed approach instead of pure simulations.

In order to allow for a scenario where EVs support grid stability as part of DSM, several general requirements are to be fulfilled, such as secure and fast communication, sufficient availability of EV (time and place) as well as effective market integration. These requirements where considered when defining the scenario (section II) and designing the testbed (section III).

Section II describes the DSM scenario and provides further background details about the issues that have given rise to this work; Section III details the connectivity requirements, the critical response requirements of the scenario and testbed architecture; Section IV describes technical implementation of a future internet frequency response framework; Section V outlines some of the challenges that are yet to be addressed; and finally, Section VI offers some conclusions.

II. Scenario

In day-to-day operations, generating stations can experience protective load shedding events. These events are protection actions which de-rate the generated power of a turbine until a stable operating condition is reached. The load shedding takes place under a pre-determined ramp rate (typically 3MW/sec). As generation is lost, this requires a balancing of the load in order to stabilize the grid.

The speed of reaction in applying this load balancing is crucial. Direct Unit Trips (DUT) are available which can drop generation by hundreds of MW instantly – for example, wind turbines can shut down in blocks due to gusting winds, dropping 10’s of MW generation from the grid instantly. Generators who experience protective load shedding send signals to the grid controller. These signals notify of imminent events. Instantaneous disturbances will first be identified by a frequency drop.

Of all the elements of frequency control available to a Transmission Systems Operator (TSO) (apart from DUTs), by far the most valuable is the availability of an autonomous 5s-15s response which constitutes *Primary* frequency control. Following that, a secondary (15s-900s) and tertiary (900s+) response period provides the operator with an opportunity to control additional resources in order to restore stability to the grid as well as to react to changes in the anticipated load pattern. Figure 3 shows the system frequency profile as it is restored through these periods.

The grid is designed to absorb limited frequency fluctuations (positive and negative). For example, if the frequency deviates from 50Hz to 49.8Hz, then the system will continue to operate as normal.

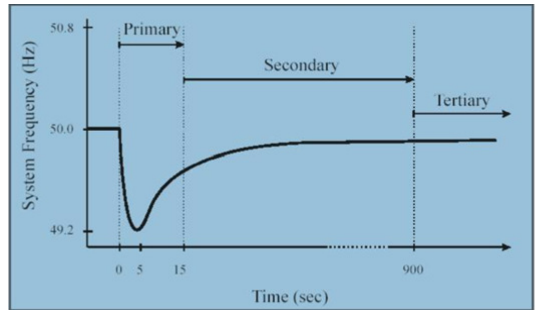

Figure 3. Frequency control phases

The response to more critical frequency deviations can be considered in a stepwise manner. Table I presents the nominal sliding scale of response to frequency fluctuations (this was defined for the purposes of testing, though can be considered as indicative of a step-wise response to frequency fluctuations).

TABLE I. Sliding scale of response

Frequency	Reaction
50 to 49.8 Hz	• No reaction
49.8 to 49.5 Hz	• Reduce current 25 % (5 min)
49.5 to 49.3 Hz	• Reduce current 50 % (5 min)
Below 49.3 Hz	• Stop charging (10 min)
Post-Stability	• Ramp back for 15 minutes

The scenario presented here uses Future Internet (FI) ICT to provide a smarter, more efficient, autonomous Demand Side Management system. This system empowers operators to manage the demand for energy across the network – in this case, by limiting or stopping the load drawn by EVs. This is done by remotely controlling the Electric Vehicle Supply Equipment (EVSE) i.e., the EV charge point. EVs represent a special type of load in this case, whereas DSM is not limited to controlling a particular demand, but may utilize additional controllable loads, e.g., air conditioning systems. In doing this,

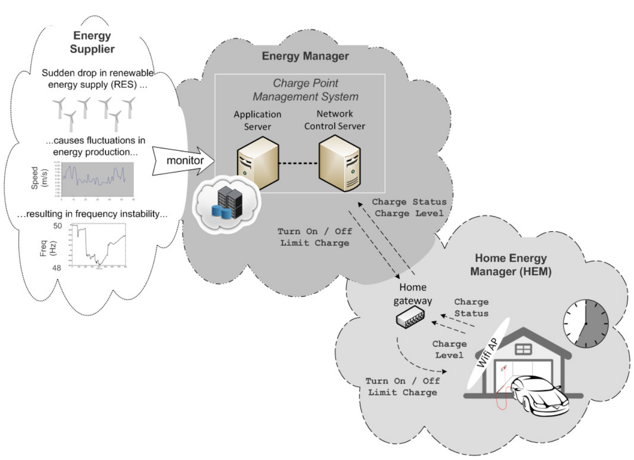

Figure 4. DSM of EV charge points using Future Internet

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TSOs can offset decreases in energy supply, and any corresponding grid frequency fluctuations, by regulating the load being drawn down by, e.g., EVs as they are charging.

Figure 4 is a storyboard that illustrates the basic setup of the scenario – (from top left to right) the Energy Supplier has ever-increasing volumes of RES to be supported on the grid. RES generation can vary dramatically thus causing fluctuations in the overall energy supply and, as a consequence, cause grid frequency instability. The grid frequency is continuously monitored via a high-capacity management system. If the grid frequency fluctuates, then the Operator can use the energy management system to offset the drop in supply by controlling the load drawn down by the EVSE via the home energy manager (HEM), say, in a similar fashion to those reactions outlined in Table I (these are illustrative responses, rather than standard).

III. Scenario Architecture

Once the grid frequency simulation is initiated, it is assumed the grid frequency is becoming unstable. A *Grid Event* is then recognized and acted upon by the TSO. Following that, real-world management and control of the load on the network (e.g., electric vehicles) demonstrates the feasibility of the use case by allowing the TSO to stabilize the grid.

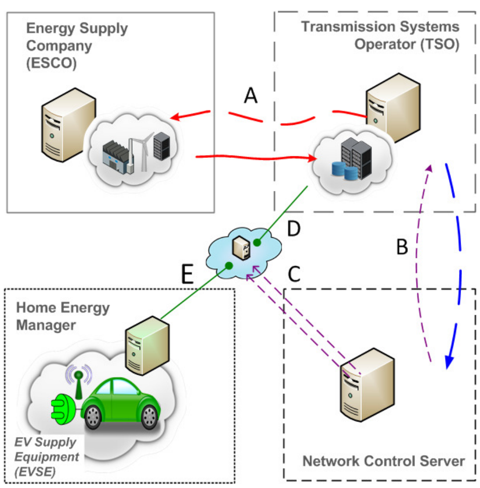

Figure 5. Connectivity diagram for testbed

The three main entities involved in this scenario are:

- *Energy Supply Company (ESCO):* trades on the Energy Market. Expected to be included in this trading is the sale of spinning reserve, a reserve that is very quickly available (this is currently not possible however is likely to be possible in future dynamic markets). The quantity of spinning reserve available is dynamic and regularly sent to the Transmission System Operator (TSO).
- *Transmission Systems Operator (TSO):* operates the transmission grid.
- *HEM:* monitors and manages the energy consumption with the Home Area Network (HAN). The EVSE is an element of the HAN and, as a result, can be remotely controlled and managed via the HEM.
- *Network Control Server:* establishes network paths, subject to specific requirements, between the TSO and the HEM

As illustrated in Figure 5, this scenario makes use of VPNs and network API's to dynamically configure links, thus ensuring that end-to-end connectivity is available. The main interfaces are:

A. From the *ESCO* to the *TSO* – a bi-directional interface that allows frequency notifications to be sent from TSO to ESCO, and tradable power information from ESCO to TSO.

B. & C. From the *TSO* to *Network Control Server* – the TSO instructs the Network Control Server to initialize the process to establish links between the TSO and HEM. The Network Control Server then uses the Network API to dynamically configure the various interfaces i.e., to the TSO and HEM.

D. & E. From the *TSO to the HEM* – connectivity is verified so that an end-to-end connection is available between the TSO and the HEM. This enables the TSO to remotely control the load being drawn down EVSE via HEM.

IV. Implementation

The overall operation of the end-to-end scenario is captured in Figure 6, where the different stakeholders (ESCO, TSO, HEM and EVSE) are encapsulated in an *Autonomous Frequency Response Framework.*

This figure illustrates the interaction between the different components that, together, help deliver an end-to-end demand side management solution. The framework is comprised of both simulated and real-world elements and the algorithm is designed so that, as the frequency breaches the thresholds defined by Table I, a proportional response is implemented to reflect the severity of the respective breach.

(1) The *Device Communication Layer* is a bi-directional component that takes in the data from various sources e.g., from the grid, electric vehicle or from the user, while at the same time it can affect change by communicating the required response commands to the end-user devices i.e., EV charge point

(2) The *Service Management* component receives all of the necessary information from the various sources in the system, models the service in order to determine whether it is behaving appropriately or not, and makes the decisions to affect change by defining the correct responses to be implemented.

Following that, the development environment and related testbed was configured as in Figure 7. The EVSE was connected to a WIFI access point. The WIFI network is

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managed by a HEM and this allows the TSO to instruct the HEM to stop / start / control the load of the EVSE.

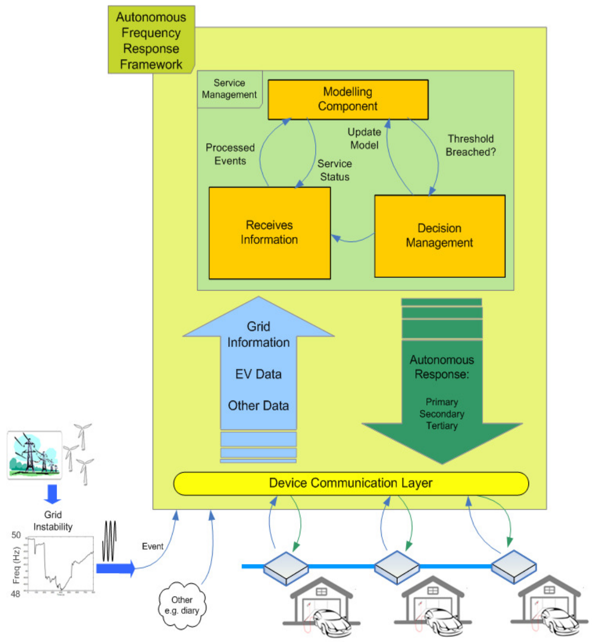

Figure 6. Autonomous frequency response framework

The TSO supports a service that provides the frequency data and a timestamp from the ESCO. When the TSO receives this request, it checks to see if the timestamp is greater than the previous timestamp. This is to ensure that the TSO has received a new frequency value. If the timestamp is greater, it proceeds with its work and, if it is not, it informs the user of this.

The TSO checks the received frequency value as according to thresholds outlined in Table I.

So if, for example, the frequency is in the 49.8-50Hz range, the TSO contacts the Home Energy Manager (HEM) to find out the current status of the charge point (on/off).

For the HEM to get this status information it has to communicate with the charge point (CP) through a Telnet session. Telnet is a network protocol that can be used to enable devices in separate locations to remotely connect. Initially, when the TSO sends a request to the HEM, it opens up a telnet session to the charge point. The HEM parses the data that it receives from the CP so that it can see the current status of the CP. The status information is then returned from the HEM to the TSO. If the CP is currently on it sends a message from the TSO to the ESCO stating that the CP is on. This information is then displayed as the log entry (see Figure 8).

When the frequency is below 49.3Hz, the TSO sends a request to the HEM for an updated status message. If the HEM sends a response to the TSO stating that the CP status is on, the TSO will send a request to the HEM to turn off the CP. The HEM will open up a session with the CP and send a command to turn the CP off. The HEM will then send a response back to the TSO stating the current status (off) of the CP. This current status of the CP and the frequency is sent from the TSO to the ESCO. This information is then added to the.

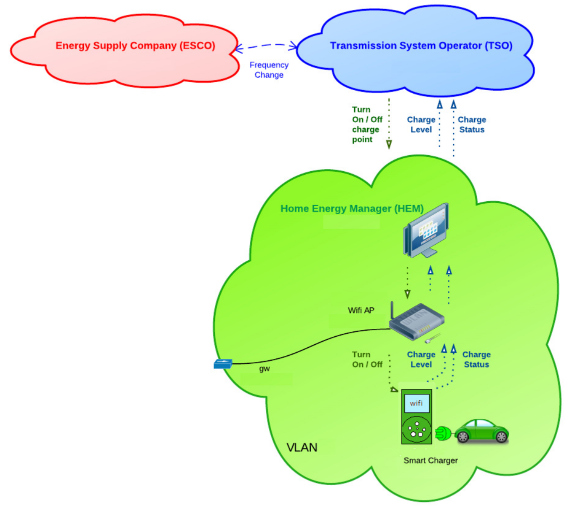

Figure 7. Testbed infrastructure

When the frequency is above 49.3 Hz, the same process as above takes place where the HEM sends an "on" command to the CP which will turn the CP on again. The new status of the CP and the frequency will be recorded as a log entry.

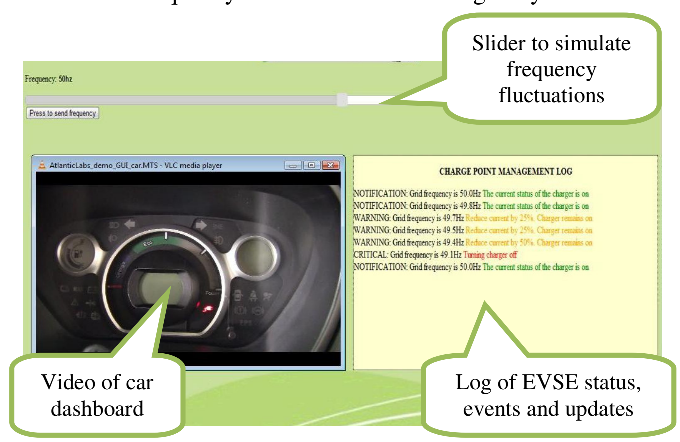

Figure 8. DSM demo interface

V. CHALLENGES

A. Scalability

With a target of 10% of all Irish vehicles on the road to be electric by 2020 [2], the demand side management application would potentially have cater for up to 250,000 electric cars.

Web services may not be a solution that scales efficiently for a large scale deployment of a management solution such as this and, though using web services has provided valuable insights to the design and engineering of the solution, further investigations are required to evaluate the most effective technology. Potential alternative technologies may include the use of FI-WARE [14] platform and technologies to deliver generic capabilities (e.g., QoS, connectivity, security), upon which specific components (e.g., smart chargers) can be developed and integrated.

B. *Extendibility*

As well as EVs, other *controllable* loads ought to be considered for this application – for example, smart public street-lighting, televisions and fridge-freezers within the HEM, etc. Furthermore, it may be useful to consider the aggregation of these loads e.g., by towns, cities, regions, so that the TSO is able to apply a regional demand side solution to a regional supply problem.

C. *Speed of Response*

Due to the severe impact of a frequency drop on the energy grid, communications to the cars must be prioritized over delay tolerant Internet applications. In this case, the telecoms network should support contractual service level agreements with smart grid applications and should have interfaces to the network to actively manage its capacities and services in real time.

D. *Security*

There are a number of security considerations to this research - consideration for user identification and verification, anonimization of information, identity management and secure data handling will need to be considered. Secure communication tunnels between endpoints (e.g., TSO and HEM) will encrypt the data, ensure privacy and prevent snooping and spoofing.

E. *User incentivisation*

It is envisaged this scenario can deliver dual benefits to both the consumer and the grid operator. For the former, an incentivisation scheme could ensure that users who subscribe to the event scheme could partake of a loyalty system and avail of having potential kWh credits or reduced kWh tariffs while interruptible. Operators could benefit from increased acceptance of renewables on the grid and could additionally offset grid penalties and reward loyal customers who opt-in to allow them to control their charge points to ensure grid stability.

Not all users will be able to participate in this scenario – for example, an on-call doctor would not like to have the charging of their car interrupted. However, it is important to get users to opt-in to this scheme and one way to do this is through incentivisation e.g., if a user partakes in this scheme and their charge is interrupted, say, twice in 3 months then the energy provider could compensate them through reduced tariffs on their next bill.

The transfer of benefit data and loyalty benefits will need to be exchanged and redeemable. All quantities such as kW's and credits will require to be validated for audit and transparency purposes.

VI. CONCLUSIONS

Frequency control can be called upon for a variety of conditions ranging from a gradual change in load levels over time to a sudden loss of generation or step increase in demand.

The solution presented here, while demonstrated using electric vehicles smart charge points, can utilize other interruptible loads to gain greater advantage of demand side management – including additional loads from within the home or through the aggregation of loads within a region in order to provide a localized solution.

Providing grid operators with the real-time ability to stabilize the grid frequency by controlling the demand can become a critical tool for the future energy consumption of EV in the smart grid.

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