

# DSM of Electric Vehicle using Future Internet

Balancing the grid in cases of unplanned events causing frequency instability

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**Abstract** — 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 (RSE), have caused fluctuations in grid frequency. This is done by remotely controlling the load drawn down by the domestic electric vehicle (EV) charge points.

The paper is structure as follows – Section I introduces the paper and presents the scope of the work that has been carried; Section II describes the demand side management 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 an 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.

**Keywords**-component; demand side management; electric mobility; renewable; future internet; smart energy

## I. INTRODUCTION

In [1], the European Commission outline ambitious targets for “raising the share of EU energy consumption produced from renewable resources to 20%”. 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 and Figure 2 where purple indicates high wind speeds), this will be the predominant source of renewable



Figure 1 On/Offshore Wind Availability in Ireland

energy to meet these targets [3]:

However, this desire to integrate renewable power sources (other proposed sources include solar, tidal, wave) 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 modelling plays a crucial role in predicting wind patterns and movements, it is still extremely difficult to accurately forecast this supply.

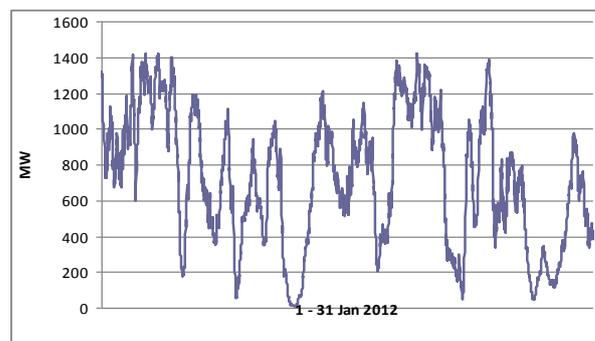


Figure 2 Wind Power Ireland - Jan 2012

*Power* is the total energy over a period of time, and 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 a grid. Frequency control can ensure that the system remains within acceptable limits, and one such element of frequency control is *demand side management* – which involves controlling the energy demand so that it tracks the energy supply.

For every 1000 electric vehicles (EV) charging on the grid, the load drawn is approximately 2.5-2.75MW. 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 stabilised while spinning reserve<sup>1</sup> is ramped up to take up the slack. The effect

<sup>1</sup> generators available to provide power typically within 10 minutes. These reserves are used when another generator on the system goes down or deactivates unexpectedly [4]

on EV charging is negligible over the course of a 6-8 hour night-time charging period.

## II. SCENARIO

In day-to-day operations, generating stations will 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 stabilise the grid.

The speed of reaction in applying this load balancing is crucial. Direct Unit Trips (DUT) can drop generation by 100's 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.

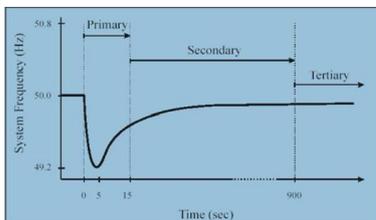


Figure 3 Frequency control phases

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. The response to more critical frequency deviations can be considered in a stepwise manner. Table 1 presents the sliding scale of response to frequency fluctuations.

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

Table 1 Sliding scale of response

The scenario presented here uses Future Internet (FI) ICT to provide a smarter, more efficient, autonomous demand side management system for TSO. It empowers TSOs to limit or stop the load drawn by EVs by remotely controlling the electric vehicle supply equipment (EVSE) i.e. the EV charge point. In doing this, TSOs can offset decreases in energy supply and any corresponding grid frequency fluctuations by regulating the load being drawn down by EVs.

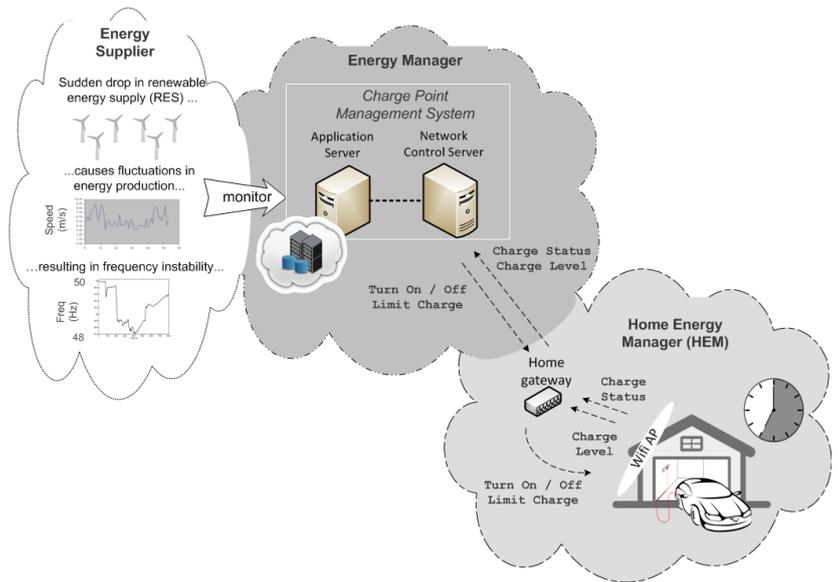


Figure 4 DSM of EV charge points using Future Internet

Figure 4 is a storyboard that illustrates the basic setup of the scenario – (from top left to right) the TSO has ever-increasing volumes of renewable energy supply (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 beyond the thresholds defined in Table 1 then the TSO can use the energy management system to offset the drop in supply by reducing the demand by controlling the load drawn down by the EVSE via the HEM.

## III. TESTBED

The testbed is comprised of both simulated and real-world elements. The fluctuation in grid frequency is simulated and an algorithm is designed so that, as the frequency breaches the thresholds defined Table 1, a proportional response is implemented to reflect the severity of the respective breach.

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

feasibility of the use case by allowing the TSO to stabilise the grid.

The three main entities involved in this scenario are:

- **Energy Supply Company (ESCO)** which trades on the Energy Market. Included in this trading is the sale of spinning reserve. The quantity of spinning reserve available is sent to the Transmission System Operator (TSO).
- **Transmission Systems Operator (TSO)** which operates the transmission grid.
- **Home Energy Manager (HEM)** which monitors and manages the energy consumption with the Home Area Network (HAN). The EVSE is configured to the HAN Wi-Fi and, as a result, can be remotely controlled and managed via the HEM.

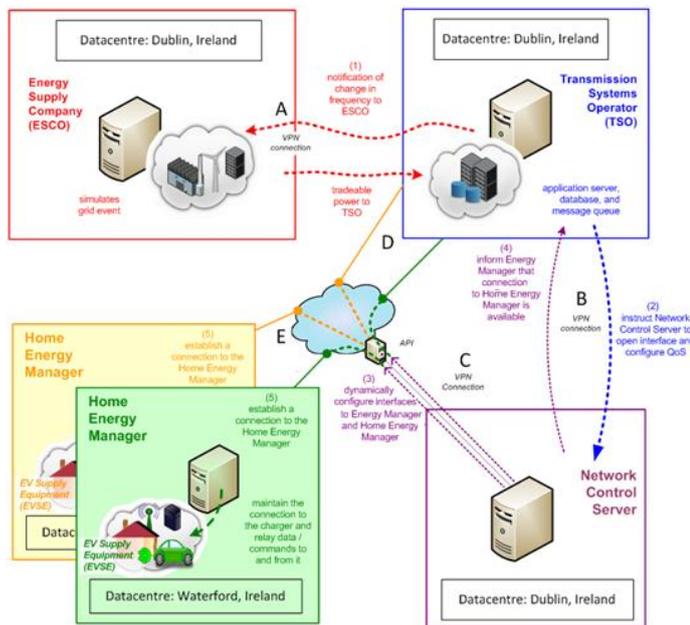


Figure 5 Connectivity diagram for testbed

As illustrated in Figure 5 above, 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 initialise 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 message sequence flow between the different stakeholders (ESCO, TSO, HEM, EVSE) is presented in Figure 6:

- (1) The TSO sends a notification to the ESCO informing them that a change in the grid frequency has occurred. In this instance, the frequency has decreased below 50Hz.
- (2) The TSO instantaneously instructs the Network Control Server to configure the required interfaces to the TSO Energy Manager and the Home Energy Manager (HEM)
- (3) Concurrently, the ESCO informs the TSO of the amount of tradable power that is available at this time. The TSO can use this information to deduce the length of time it will need to manage the load on the demand side
- (4) The Network Control Server use the Network API to interface to the Energy Manager and the HEM
- (5) The Network API informs the Network Control Server when the interfaces have been configured
- (6) The Network Control Server relays this information to the TSO

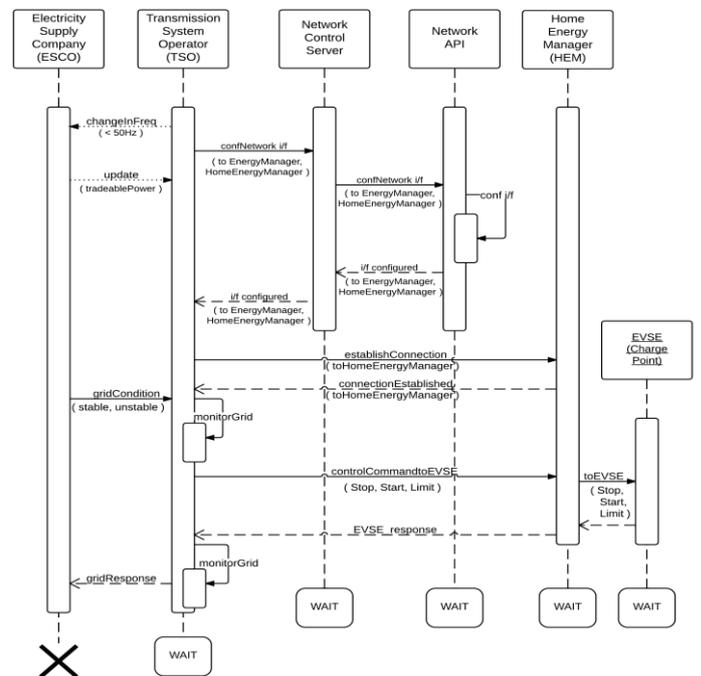
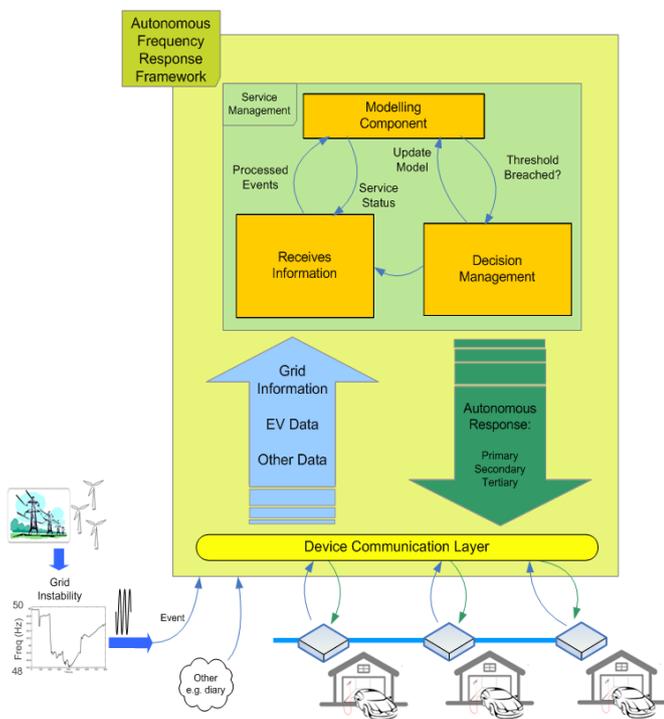


Figure 6 Scenario message sequence diagram

- (7) The *TSO* establishes a connection to the *HEM*
- (8) The *ESCO* continues to provide up to date information to the *TSO* regarding the condition of the grid
- (9) Having pre-empted that a critical decrease in the grid frequency is likely in (2), the *TSO* sends control commands to the *HEM* to stop, start or limit the charge through the *EVSE*
- (10) The *HEM* instructs the *EVSE* to stop, start or limit the charge that it is drawing down
- (11) The *HEM* sends the response to the *TSO*
- (12) In a loop with the *ESCO* in (8), the *TSO* monitors the grid condition to determine if the grid has stabilized or if further corrective action is needed e.g. to instruct the *EVSE* to begin charging again

Each entity was designed and developed in accordance with the message sequence flow. An *Autonomous Frequency Response Framework* (depicted in Figure 7) shows the interaction between the different components that, together, help deliver an end-to-end service:

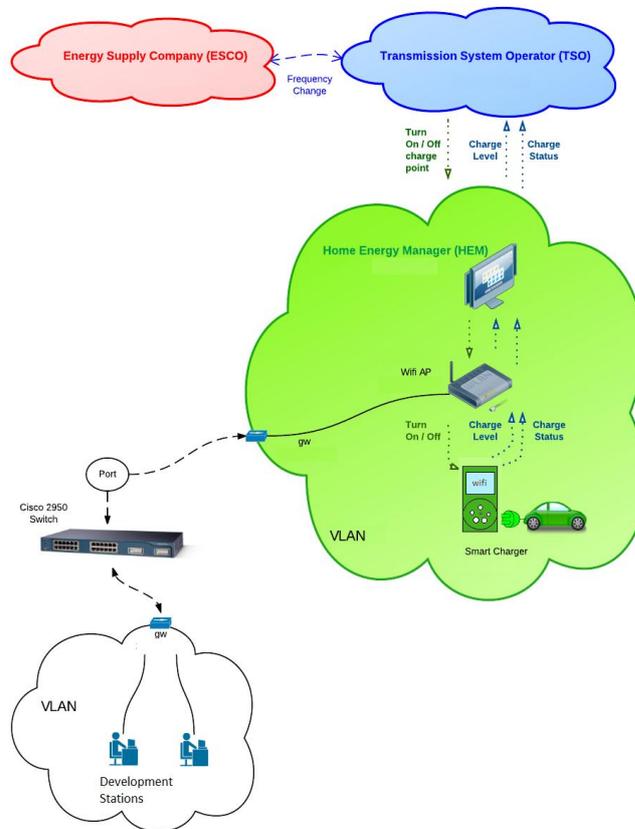


**Figure 7 Autonomous frequency response framework**

Following that, and using Figure 5 as a reference, the development environment and related testbed was configured as in Figure 8. The *EVSE* was connected to a *WIFI* access point. The *WIFI* network was managed by a *HEM* and this allowed the *TSO* to instruct the *HEM* to stop / start / control the load of the *EVSE*.

The *TSO* is configured as a web service. It has a web method called *getFrequency* which receives a frequency and a

timestamp from a slider which is on the *ESCO* *PHP* page. This information is sent in the form of a *SOAP* request [5]. When the *TSO* web service 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. If the timestamp is greater, it proceeds with its work and, if it is not, it informs the user of this.



**Figure 8 Testbed infrastructure**

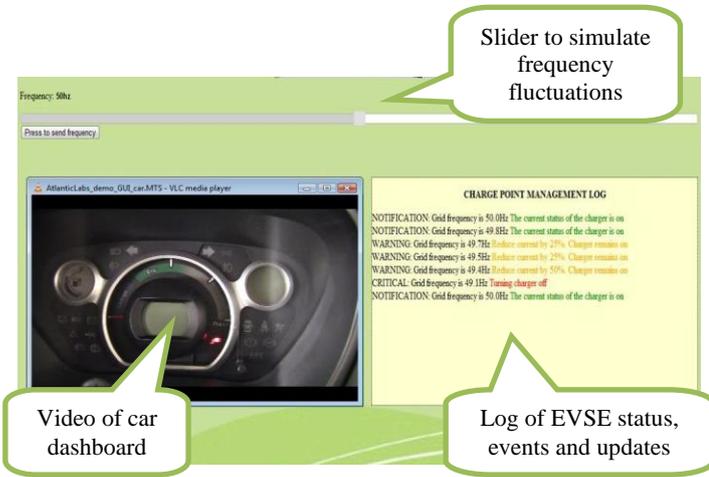
The *TSO* checks which threshold the frequency received is in:

- 49.8Hz and 50Hz inclusive
- 50 to 49.8Hz
- 49.8 to 49.5Hz
- 49.5 to 49.3Hz
- < 49.3Hz

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).

The *HEM* is configured as another web service. 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 *SOAP* request to the web method *getStatus*, the *HEM* 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 in the form of a SOAP response. If the CP is currently on it sends a SOAP message from the TSO to the ESCO stating that the CP is on. This information is then displayed on the ESCO PHP page in the form of a log entry on the page (see Figure 9).



**Figure 9 DSM demo interface**

When the slider is moved to a frequency which is below 49.3Hz the TSO sends a SOAP request to the HEM for an updated status message. If the HEM sends a SOAP response to the TSO stating that the CP status is on, the TSO will send a SOAP 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 log as a log entry which can be viewed on the PHP page. When the slider is moved to above 49.3 Hz to simulate a rise in frequency the same process as above takes place instead the HEM sends an “on” command to the CP which will turn on the CP again. The new status of the CP and the frequency will be recorded as a log entry on the ESCO in the same process as above.

The TSO and HEM web services are deployed in Tomcat v7.0 [6] which is configured in Eclipse. During the demo Tomcat is started first with the TSO and HEM deployed on it. The Apache web server in the XAMPP package [8] is then started and the demo user accesses the ESCO PHP page through a web browser.

## V. CHALLENGES

### A. Scalability

With a target of 10% of all vehicles on the road to be electric by 2020 [2], the demand side management application will 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.

### B. Extendability

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 prioritised 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, anonymization 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. All methods available to increase the availability of this type of response are extremely valuable.

## 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 in the 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 smart grid.

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