Stability Challenges & Solutions for Power Systems Operating Close to 100% Penetration of Power Electronic Interfaced Power Sources.

Exchange of Experience between Hybrid and Major Power Systems

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***Abstract*—In 2013 the authors presented a paper [1] to the wind integration workshop (WIW), the results of which demonstrated high converter penetration (typically 65-70%) at synchronous area (SA) level could introduce a type of super synchronous instability in RMS models previously unseen by the authors and TSO's. 2016 saw two related papers [2], [3] presented at a further WIW. These provided in-depth analysis of the specific high frequency instability identified in 2013, as well as considering a wider range of future high penetration stability challenges identified by the wind industry [4]. The two papers reported R&D study results using a proposed holistic approach converter control strategy. Extensive system wide studies with a new (for large power systems) control strategy for power electronic sources were used to explore the possibility of stable operation close to 100% penetration of Power Electronic Interfaced Power Sources (PEIPS). The studies demonstrated that implementation of a Virtual Synchronous Machine (VSM) converter control strategy with added stability controls, applied to about 25% of the power sources, could deliver stable operation, even at 100% penetration for a reduced model of the 2030 GB power system.**

The solutions explored in the WIW 2016 papers are included in the Grid Forming approach in a pan European Connection Network Code (CNC) Implementation Guidance Document (IGD HPoPEIPS) [5]. This contains significant ideas and experiences arising initially from the world of Hybrid Systems, such as marine power networks. In taking these ideas forward, various questions are raised by manufacturing industry experts about the necessity for this dramatic change in the context of main power systems. Some suggest it is a more fundamental change, even than the introduction of Fault Ride Through (FRT)). Also, it has been suggested that both the time needed to implement the new strategies and the associated cost will be extensive.

This paper explores the prospect of finding answers to these questions from experience already gained in the world of hybrid systems. What are the prospects for closer collaboration to establish viable solutions applicable to both small Hybrid Systems and main Synchronous Areas (SA), such as the 5 SAs in Europe as the first SAs progress towards operation sometimes close to 100% PEIPS?

Keywords-component; NSG (Non Synchronous Generation), Virtual Synchronous Machine (VSM), Converter Control, Grid Forming Controls, Penetration Level Limit, Power System Stability.

I. INTRODUCTION

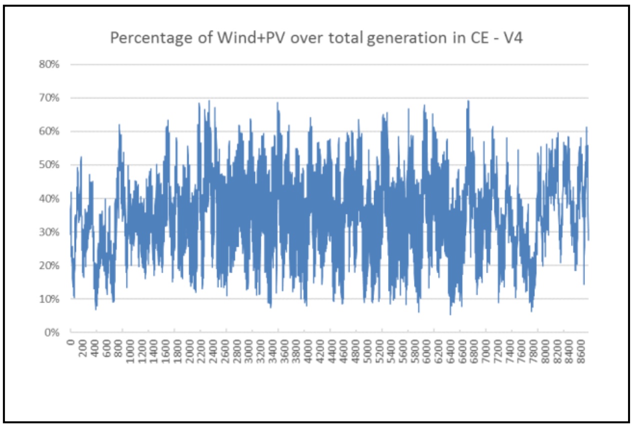
2013 saw the presentation by the authors of a paper [1] to the wind integration workshop (WIW), the results of which demonstrated high converter penetration (typically 65-70%) could introduce a type of super synchronous instability in RMS models previously unseen by the authors and Transmission System Operators (TSO's). Analysis of hourly RES production for 2030, based on recorded wind and solar intensity, could for a significant number of hours in the year more than cover the hourly electricity demand. The indicative cost of constraining off Renewable Energy Sources (RES) to keep PEIPS penetration below the tipping point was demonstrated as running into multiple (3-4) £B per year [1,5], which would be totally unacceptable. In WIW2013 a further paper by the wind manufacturing industry [4] listed a range of stability challenges likely to be facing the industry in the future, under high RES penetration scenarios, concluding that Grid Codes will need to ask for more capabilities to achieve operational viability.

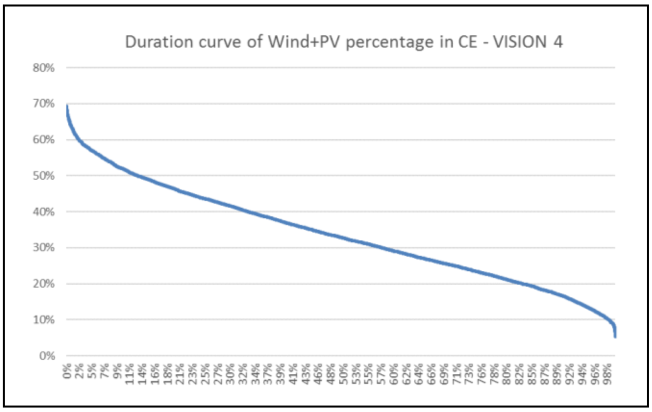
2016 saw two related papers [2], [3] presented at a further WIW. These provided analysis of the specific high frequency instability identified in 2013 [1]. They also reported R&D re proposed solutions including extensive system wide studies with a new (for large power systems) control strategy for power electronic sources. They demonstrated that implementation of a Virtual Synchronous Machine (VSM) converter control strategy with added stability controls applied to about 25% of the power sources could deliver stable operation even at 100% penetration.

In a study example from [3] of a system wide implementation of Grid Forming converters (described further in section VI A), the stability was demonstrated including extreme challenges, even beyond normal n-1 planning criteria, such as system splits. The VSM control strategy contained a prospect of additionally delivering a holistic approach with capabilities to cope with the wider challenges identified in [4].

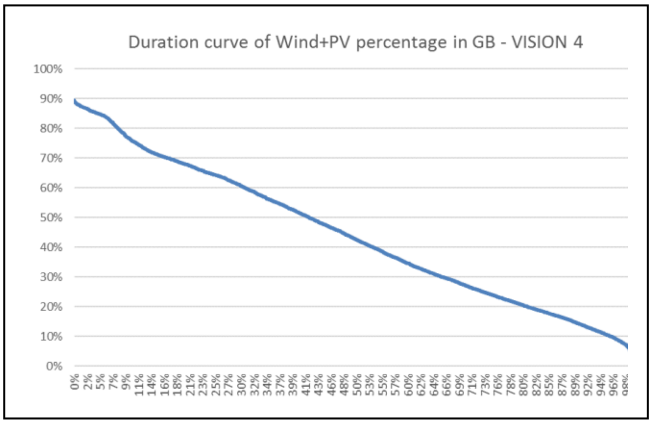
34 countries in Europe are in process of implementing the three pan European Connection Network Codes (Grid Codes). ENTSO-E has in this context issued a range of national Implementation Guidance Documents (IGDs) to the 34 countries. One of these IGDs deals with stability for systems with high penetration and is called High Penetration of Power Electronic Interfaced Power Systems (HPoPEIPS) [5]. The IGD gives guidance when concern is appropriate at national level.

The analysis starts with a focus on % penetration of wind & PV in comparison to the total demand. An example of hourly % penetration for the vast Synchronous Area of Continental Europe (CE) is shown below. The data from [5] relates to 2030 and arises from the ENTSO-E Ten Year Development Plan (TYNDP2016). Analysis is undertaken for a number of visions of the future. Below is one of these, vision V4 for the year 2030, showing how penetration varies through a year on an hourly basis, initially hour by hour and then rearranged as a duration curve:





For CE the Wind + PV penetration is above 50% for about 10% of the time.
A similar, but much more severe, duration curve is shown next for the roughly 10 times smaller Synchronous Area of Great Britain. In the GB case, penetration is predicted by 2030 in V4 to exceed 50% for more than 40% of time. It should be noted that some individual countries within the



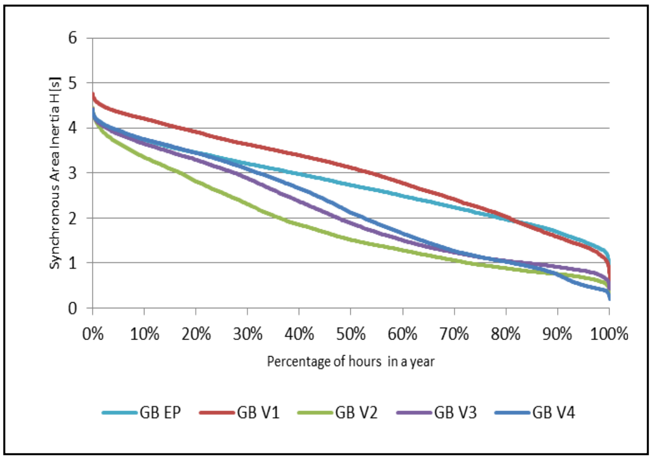
CE synchronous area expect similarly high penetration as GB, e.g. Denmark & Germany. The SA of Ireland & Northern Ireland is expected to be broadly similar to GB, but experiencing the high penetration earlier.

IGD HPoPEIPS also identifies the consequential impact on the large reduction in system strength, as expressed in terms of total system inertia. See next below for GB.

II. System Strength Reducing Towards 2030

A. Expected reduction in Inertia in GB, if contribution from PEIPS is not secured

The figure below from IGD HPoPEIPS [5], shows the % of time at different levels of Total System Inertia (TSI) for different future energy scenarios. The periods where the inertia is low, reflect the inability of the system to cope when the power balance is disturbed with the system frequency changing too quickly. By 2030 the per unit inertia (H) could be below 1s for about 20 % of time, in contrast with a typical historical value of 5s for a system mainly comprising of



synchronous generation.

The dramatic reduction in inertia (a key indicator of reduction in system strength for which good data exists) is largely attributable to the expected increase in Phase Locked Loop (PLL) current source converters which generally only inject energy in proportion to the quantity available from their renewable source. Grid forming technologies potentially reverse this trend. Similar data for countries across Europe showing a reduction in system strength in the form of total system inertia (in per unit) by 2030 is available in [5].

III. System Needs Associated With High Penetration and Low System Strength

Question:

What converter characteristics would it take to become independ of Synchronous Generators for operation close 100% PEIPS?

TSOs initial answer:

Power Sources equipped with converters which simultaneously cover the following new capabilities:

1) Creates system voltage (does not rely on being provided with firm clean voltage)

- Contributes to Fault Level -Supplies fault current in phase with the System without delay *(*PPS & NPS within first cycle).
- Contributes to Total System Inertia (limited by energy storage capacity).

2) Supports fast dynamics (first cycle) survival for system splits and from brown & black outs.

- Gives survival time (and inertial response) to allow Low Frequency Demand Disconnection (LFDD) an opportunity to operate.
- Supports restoration, Brown & Black Start.
- Contributes to first swing stability and synchronising torque, e.g. through being a voltage source, contributing damping during oscillations, and applying "dynamic braking" during faults.

3) Converter controls act to prevent adverse control system interactions:

- Avoids contribution to super synchronous instability, e.g. through controller bandwidth limitation.
- Avoids contribution to sub synchronous resonance, e.g. through controller bandwidth limitation.
- Does not make full system dynamic studies impractical through complex non-fundamental frequency interactions.
- Is compatible with existing synchronous plant. As such seeks to counteract fast vector shifts.

4) Act as a sink to counter harmonics and inter-harmonics (frequencies above the fundamental but below switching/PWM frequencies) in system voltage.

5) Act as a sink to counter unbalance in system voltage

IV. The Challenges and Emerging Solutions

A. Super-synchronous instability

For a model of the GB system in 2030, high frequency instability was identified to occur within RMS power system studies performed in 2013 [1]. They demonstrated instability for PEIPS penetration of 65-70% with the proportion of non-synchronous generation dominated by PLL current source converters. This instability probably partially results from the modelling techniques used. However, it is anticipated that real instability would also manifest itself.

The high bandwidth of many of the controllers and the inevitable delays caused by measuring volts and attempting to inject current in proportion to some voltage reference which is being tracked by a PLL results in a cocktail of potential interactions. For TSOs who must model the full transmission system against a background of different manufacturers control algorithms, this starts to become impractical, in the authors opinion.

From the evidence to date, modelling has not even been straight forward for manufacturers of relatively small systems where all the system components and operation were definable and under a higher degree of control as they fell within one project. This is also the case for a wind based offshore AC collection network with connection to shore via an HVDC link. See challenges faced for Borwind, an early such project [6].

B. The GB TSO view of the Range of Challenges and Possible Solutions

The table below is extracted from a Grid Code

With current technology/models, the system may become unstable when more than 65% of generation is Non-Synchronous

For the FES 2Degrees, Consumer Power and Slow Progression scenarios, it is currently forecast this level could be exceeded for 800-1800Hrs p.a. in 2023/24 and for 2100-2750Hrs p.a.in 2026/27.

Key

No	Doesn't Resolve Issue
P	Potential
I	Improves
Yes	Resolves Issue

Solution	Estimated Cost	RoCoF	Sync Torque/Power (Voltage Stability/Ref)	Prevent Voltage Collapse	Prevent Sub-Sync Osc. / SG Compitable	Hi Freq Stability	RMS Modelling	Fault Level	Post Fault Over Volts	Harmonic & Imbalance	System Level Maturity	Notes
Constrain Asyncronous Generation	High	I	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Proven	These technologies are or have the potential to be Grid Forming / Option 1
Syncronous Compensation	High	I	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Proven	
VSM	Medium	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	P	Modelled	
VSM0H	Low	No	Yes	Yes	No	P	P	P	Yes	P	Modelled	Has the potential to contribute but relies on the above Solutions
Synthetic Inertia	Medium	Yes	No	No	P	No	No	No	No	No	Modelled	
Other NG Projects	Low	Yes	P	Yes	No	No	No	P	P	No	Theoretical	
Timescale (Based on work by SOF team)		Now	2019	2019	Now	2020	Now	Now	2025	2025		

consultation in GB Summer 2017 [7]. It shows potential System problems encountered (across the top of the table) with high penetration of PEIPS (here denoted as NSG) with the potential solutions (listed in each row of the table) to show which solutions solve specific problems. There are additional columns in relation to the potential costs, some additional notes and the maturity of the solutions. At the very bottom of the table there is an indication of when these problems might be manifested, in the GB system according to National Grid's System Operability Framework (SOF) [8].

Whilst many of the solutions contribute to improve issues on transmission and distribution systems, only those in the top three rows can be considered as holistic, that's to say, they have the potential to fix all the problems. These are:

- Maintain a large number of conventional generators, which might be achieved running more machines but at lower load.
- Operating with a fleet of synchronous compensators
- or implementing VSM (i.e. Grid Forming Converters).

The various merits and characteristics of some of the solutions presented can be found in [1] [2] and [3] and are not discussed further here. However, this is not to say that the non-holistic solutions are not beneficial and cannot be used, rather that it's believed there needs to be a base capability providing the holistic solutions, which may be augmented with some additional help from some of the less capable solutions. This approach is taken in [3] for some of the more severe study cases.

The holistic solutions are compatible with each other and can be used in combination. VSM inherently provides a stabilizing influence as ordinarily it provides the energy required by the network, largely without the destabilizing delay incurred through measurement and control systems which is a particular issue with PLL control type strategies. This was demonstrated in [2] and [3] where the 2013 studies were repeated and found to be stable.

C. High Penetration Expert Groups and GB Consultation

In developing the European wide implementation guidance on high penetration, ENTSO-E was supported in 2016/17 by the Expert Group High Penetration (EG HP), helping to establish guidance in IGD HPoPEIPS. This IGD after analyzing penetration, reducing system strength and associated system challenges, then explore possible mitigating actions. These are examined in the context of the most extreme conditions expected (dramatically falling system strength). A holistic approach to converter controls is introduced which covers lack of inertia, super synchronous instability as well as a significant number of other stability challenges [4] associated with weak power systems. One control approach is called Grid Forming for Power Park Modules (PPMs) and for HVDC Converter Stations (HCS).

EG HP is continuing its work into 2018 and likely 2019 to refine the need case, the required characteristics and exploring what can be achieved with changes resulting in three different levels of cost increase, low (<1% increase in converter cost), medium (<5% increase) and high (up to 25% increase).

In GB, National Grid has consulted during Summer of 2017 [7] on the above, in context of implementing Requirements for Generators (RfG, one of the three European Connection Network Codes (CNCs)) [8]. It was found through studies performed by National Grid, there was an inherent link between fault current injection and fault ride through with the VSM solution providing an acceptable voltage restoration.

The GB RfG working group put forward three options for consultation. Option 1 proposed the introduction of VSM by 2021. In the event that Option 1 was not selected as part of RfG, it was proposed to separately look specifically into the implementation of VSM under the governance of a separate GB Expert Group. Due to a legal requirement to implement the broader package of RfG requirements without delay (by May 2018), the VSM aspect had to be deferred until after RfG comes into force. Option 1 was not favored by the consultation respondents largely due to the unproven practical application of these concepts. Instead, a conventional option was selected, supplemented with immediate establishment of a GB Expert Group to explore further the complex high penetration need case and appropriate solutions including VSM coupled with the use of market based solutions.

D. GB focus on Fast Fault Current contribution

Under fault conditions, grid forming technologies of the type described in [2] and [3] will typically switch from voltage source mode to a current limited mode of operation so as not to exceed the current rating of the semiconductors.

However, unlike PLL based current source converters, the voltage reference and the phase reference of the output oscillator remains constant. The "grid forming with current limiting method" allows voltage source mode to continue as much as possible during the fault, allowing unbalanced line-line or line-ground faults to be fed with unbalanced fault currents as appropriate, see also [9] and [10].

The output current typically becomes reactive because the load under fault conditions is typically reactive and not because the control system attempts to inject reactive current relative to the voltage reference at the converter terminals. As the voltage signal may have phase shifted when a fault is applied there is no guarantee the controller response is in the correct phase or at the correct magnitude.

Consequently, a grid forming converter's response can be considered to be a natural consequence of the nature of its load under fault conditions, whereas the PLL converter's fault contribution is more of an anticipated contrived response defined by the designer, in accordance with Grid Codes.

In studies performed associated with [7], it was found that the contrived response can, under certain circumstances, result in the incorrect injection of current (either delayed or at the wrong phase angle) resulting in inadequate voltage support.

Furthermore, on clearing the fault, the grid forming technologies rapidly come out of current limit and restore voltage source operation. By contrast, the PLL converters typically only stop injecting reactive current after taking measurements of the voltage and this can result in transient over voltages on fault clearance.

V. DESCRIPTION OF ONE PRACTICAL IMPLEMENTATION:

A. Grid Forming Inherent Ferformance

Grid Forming Power Park Modules (GF PPMs) or HVDC Converter Stations (GF HCSs) provide an inherent performance which results from their behaviour, as they appear to the network as AC voltage sources coupled to the network by an impedance, which is largely reactive / inductive in nature.

This is unlike many of the conventional converters currently in operation, which for the most part, use PLL's (Phase Lock Loops) and attempt to inject real and reactive power / current into the network relative to the voltage phasor measured at the point of connection to the transmission system.

Most switched events and disturbances on a transmission system e.g. faults and line or generator tripping, result in the equivalent of a step angle and / or voltage level change of the grid voltage waveform, as observed at the point of connection. Unlike the current generation of converters, Grid Forming converters attempt to operate in a voltage source mode and initially maintain the same voltage level, phase and frequency. Consequently, the only other electrical quantities, which can change in sympathy with the disturbance, are the real and reactive AC current. The following description relates to the work described in [2] and [3].

B. True voltage source characteristics

Crucially the response is inherent in the behaviour of the device, originating from the fact that it is a voltage source and is not reliant on measurement or feedback signals. This is an extremely important characteristic, as the delays in such measurements result in delays in delivery, possibly transient over volts on fault clearance and can also result in instability.

Typically after events such as faults, line and generator tripping, Grid Forming technologies only modify their frequency and voltage slowly, ensuring that any response occurs at less than an equivalent 5Hz bandwidth and additionally synthesizes an inertial response.

These characteristics are necessary to ensure compatibility with existing synchronous plant and protection systems and in the case of the 5Hz bandwidth limit, to reduce the risk of exciting torsional shaft oscillations in conventional generating plant.

In summary, grid forming technologies initially attempt to stand firm and then modulate their set point voltage, phase and frequency slowly. In this way they form the foundation for a grid system, stabilizing it. To use a simplistic analogy, just as steel girders support and hold a building steady, Grid forming converters provide instantaneous current feed to support load changes and the voltage and phase reference. However, these benefits come at a cost.

C. Managing the Current Limiting for Least System Impact

For the current to be allowed to increase independently, based on an immediate operating requirement resulting from an instantaneous change in the grid voltage and/or angle, the converter must have adequate rating / headroom to accommodate the change. Furthermore, there is potential for an increased demand of energy, or be it temporary (10-20secs), which must be provided from somewhere. This requires moderate amounts of energy storage or possibly curtailment of output (e.g. spilling wind).

Furthermore, there will be circumstances where it is simply impractical to continue operation of the converter in ideal voltage source mode e.g. during close-up faults and short circuits.

It might at first be assumed, that the above disadvantages place such extreme demands on the converter, practical implementation would not be possible. However, studies performed in [2] and [3] demonstrated that with inclusion of fast operating power and current limiters this is not the case. See also [10].

In the 2016 studies [3], these limiters ensure power is limited to 133% (for 10-20secs) of the nominal power rating (i.e. max of 33% above the operating point) and 1.5pu of the nominal current rating.

With these limitations in place, stabilization of a reduced 36 node model of the GB system is possible. The model could be operated at any point from 0 to 100% converter based generation, with only 25% of the converters using Grid Forming technology (the other 75% can be conventional PLL current source converters).

It should be noted that the fast acting current and power limiters do operate in extreme circumstances or when large close up faults / events occur. However, in spite of the converters local to the fault temporarily limiting and exiting grid forming mode for a short period, this effect was not found to propagate across the network and the remaining converters maintained the systems stability.

VI. POTENTIAL SOLUTIONS TO EXTREME HP

A. 2016 Studies undertaken for VSM option

Studies described in [2] and [3] demonstrated that RMS models of a VSM converter behaved in a similar manor to synchronous machines with angular swings in operating angle after disturbances at similar frequencies, 0.3 to 2Hz. The VSM converter also contributed power during changes in frequency in the same way as synchronous machine. It demonstrated the principal of immediate response to load change without the need for feedback measurement. It provided superior response with a simplified approach to damping power system oscillations. The ability to ride through 500ms distribution faults was also demonstrated, during which an alternative model of a synchronous machine would pole slip.

It was demonstrated in [3] that the 26 high penetration scenarios could all operate stably even up to 100% converter penetration (only 9 of these were stable with PLL-based converter control technology).

These 2016 studies also demonstrated the effect of tripping 1600MW of generation close to a VSM. Initially this showed how an unlimited VSM would exceed its power rating. However, adding the limiter to the VSM, resulted in a rapid change in the operating angle and hence reduced the VSM output power. The study demonstrated that the rapid phase angle change in the adjacent VSM (due to power limiting) did propagate to the adjacent substations / zones and that the wider population of VSM maintained system stability.

Finally [3] demonstrated that when a power system is under extreme duress, for example during a system split, where the loss of power infeed exceeds the reserves maintained for frequency response, the VSM instantly picked up and shared the load and simulated the inertial response, allowing the frequency to fall in a controlled fashion and the LFDD scheme to operate in the correct manor.

B. Suitability to apply to different technologies

When measuring the impact of the Grid Forming approach in respect of its suitability to apply to different generation types, the key measure to be considered is the improvement in performance vs. cost.

As "Grid Forming" power sources must be capable of energy output which exceeds the energy available from a renewable source, they typically require larger converters and components to store the equivalent of 5-7s of inertial energy. Whilst this arguably, isn't a large amount of energy, the cost can be significant. There are also implications for increased DC bus capacitor ripple currents, in the presence of harmonics and unbalance on the grid voltages.

Some applications, such as offshore wind incur further additional costs for equipment located at sea, because of the difficulties associated with location and working environment. Consequently for offshore applications it is anticipated that optimizing the onshore solutions is desired, as far as possible.

Whilst some application may incur significant extra cost, there are applications which would seem particularly suited. This appears to be the case where the power source already contains storage elements or has the ability to increase and reduce energy generation or consumption. These include battery systems or solar applications with batteries, car and other charging applications, any other load such as heating or cooling applications, if they are appropriately coupled i.e. by a VSM converter.

VSM on MMC HVDC is theoretically possible and might be implemented either by combining it with storage, building the necessary storage into each module or running one converter station in VSM mode taking energy from other terminals as required.

VII. Opportunities For Large Systems To Learn From Hybrid Systems.

A. Actual Hybrid Systems experience known to authors

In the 1990s, specific needs arose in some remote North American communities that had weak connections. The needs were specifically to enable a locally blacked-out power system to be operated (and black-started) from a converter-connected battery energy store, allow islanded operation in parallel with local diesel/hydro generators, operation of local difficult loads such as sawmills, seamless reconnection to the main grid, and recharging of the battery store. GE installed two converters with grid forming capability, that operated successfully for many years (and at least one appears to be still operating, only requiring a mid-life change of batteries in 2009) [11] and [12].

Similarly, within the realm of Marine power systems, for a number of years some companies have been installing "turnkey" solutions for hybrid power generation and propulsion, allowing electrical power to be generated from off-takes from the large propulsion diesels, or propulsion to be provided by electrical power from the smaller hotel-load generators. These solutions offer many design and operational advantages, but require seamless operation in power systems with highly variable proportions of synchronous and converter-connected generation. In such systems, land-based grid codes and practices were less relevant than a need to simply make the systems "work". To do this, converter manufacturers have adopted voltage source approaches to converter control and effectively implemented grid forming solutions. This includes shipping / marine applications incorporating VSM in Italy [13].

B. Access to low cost stored energy

In the context of electrical propulsion, the main drive has a major capability of delivering Demand Response (DR) very quickly (including in the inertia timeline). This is effectively an ideal form of stored energy.

Equivalent for the five main European Synchronous Areas could have been delivered by DR facilities for inertia and other reserve facilities defined in the European Network Code Demand Connection Code (NC DCC), see [14]. In an earlier draft version of NC DCC use of thermal electrical demand, including domestic, was proposed to become mandatory.

Mandatory DR for suitable thermal demand could have, after about 10 years, delivered most of the reserve / response capability needed by Europe's power systems by autonomous DR means (measuring frequency locally), although in the main this may not have delivered Grid Forming advantages. Unfortunately, in the view of the first author, the mandatory element was strongly objected to and therefore dropped. This in spite of the basic simple design principle, that "everyone contributes for everyones' benefit" which avoids market complexities. This principle was complimented with a second principle of allowing no noticeable detriment to the primary function of the demand. The loss of the mandatory element of this proposal was in reality probably due to the campaign of vested interests by existing providers of ancillary services and also prospective new commercial providers, the emerging Aggregators of DR.

The slow progress with DR, in the absence of simple mandatory services, has opened up for such services from battery based storage, but at much higher societal cost.

C. Problems experienced to date with high penetration

1) Synchronous Areas including GB and EI+NI

In 2012 the GB system experienced problems relating to low inertia and consequential loss of generation equipped with Rate of Change of Frequency protection to identify islanding conditions. These protections mal-operated during a large import step change. Subsequently, costly market based actions in the form of substitution have been taken to increase inertia on the system, when necessary. Actions are in progress to make protections less sensitive to mal-operation as well as endeavoring to obtain a contribution to inertia from PEIPSs.

In Ireland & Northern Ireland a limit on non-synchronous generation has been operated for a number of years, increased from 50% to 55% and is aiming to get to 70%, see [15]. Costs of associated Ancillary Services (AS) for EI+NI have been predicted by EirGrid, (the TSO) to rise 5 fold between 2015 and 2020 from 5 to 25% of the total cost of electricity for end users

VIII. CONCLUSIONS & KEY OUTSTANDING QUESTIONS

As penetration of RES continues to rise, Power Systems are rapidly coming closer to 100% penetration under conditions of the highest RES production and relatively modest demand.

Analysis shows that it is necessary to prepare some power systems for operation without relying on support of services from synchronous generators. This includes GB and Ireland with Northern Ireland.

It is believed that some hybrid power systems have already been through this process and established workable solutions for stable operation.

To answer questions raised by converter manufacturers it would be helpful to establish what experience has already been gained in the world of Hybrid Systems, beyond that reported, regarding:

Q1:Operation close to 100% PEIPS. Evidence of success?

Q2: Does evidence exist of successful operation with TSI in per unit of H<1s?

Q3: Problems encountered in context of stability aspects?

Q4: What measures have been tried to overcome problems?

Has Grid Forming, e.g. VSM been part of this?
If so, how challenging was its introduction?
Time to develop?
% added cost to converters?
Are solutions transferrable to SAs?

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