PPM Hybrid SVC / STATCOM Workshop
September 20th 2013

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Agenda

10:00	Introductions
	Presentation by National Grid
	Presentation by Mick Barlow of S&C Electric Company
11:15	Coffee
	Open Floor Discussion
12:30	Lunch
	Cost and Timing Implications
14:00	Coffee
	Further Agreed Actions

Introductions - Invitees

- Zoltan Zavody – Renewables UK
- *Graham Stein & Richard Ierna – National Grid
- *Mick Barlow – S&C Electric
- Sagnik Murthy – CG Global
- Guy Nicholson – Element Power
- *Martin Lyster – American Super Conductor
- *Mick Chowns – RWE
- *Peter Jones & Anne Palesjo – ABB
- *Sridhar Sahukari – DONG
- Damien McCool – EDP Renewables
- *Mustafa Kayikci – TNEI
- Alan Mason – REPower
- Jason Hill – Senergy
- UK Energy
- David Meadows – Siemens

*Attended

National Grid

- Current Position as Agreed at the Grid Code Review Panel
- What is needed and why
  - Multiple DAR Events
  - Response to Operator Commands and Interaction Effects
  - Erosion of Reactive Reserves
  - Effects of high Penetration of Renewable Generation on Voltage / Dynamic instability
- Drivers for performance within given time frames
  - Example System Studies
  - System Event Timings
  - Short Circuit Ride Through
- Capacitor and Reactor Shutdown on Short Circuit
- Proportion of wind where changes become essential and must be implemented
- Summary of Requirements

National Grid’s Objectives

- National Grid aims to set its requirements based on current and “medium” term system need. As a consequence
  - Developers are not over burdened by longer term concerns
  - Developers and manufactures may find requirements change with time and installed capacity
- National Grid has obligations to
  - Facilitate competition and access to the networks
  - Maintain transmission system performance and security
  - Keep its technical requirements under review
  - To demonstrate solutions are economic and efficient
- In the 2020 and 2030 scenario’s the control room must manage a wide range of generation and demand profiles, with a very high dependence on renewable sources for reactive reserve
  - Considerable uncertainty over the generation pattern we might see
- Increased generation at the coast and very high north south power flows result in considerable difficulties relating to voltage control and may impact dynamic/synchronous stability
- National Grid is not seeking to restrict the use of Hybrid SVC / STATCOM’s
  - We are seeking better performance for future projects in order to manage higher penetration of renewables and more demanding and variable scenarios.

Typical Hybrid SVC / STATCOM Operating Ranges

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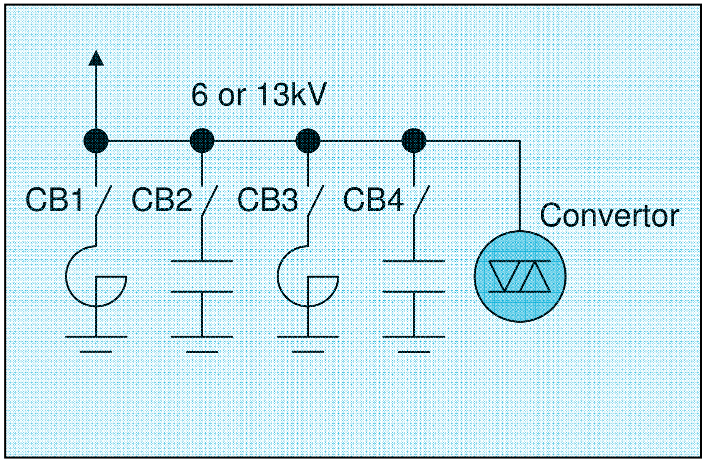
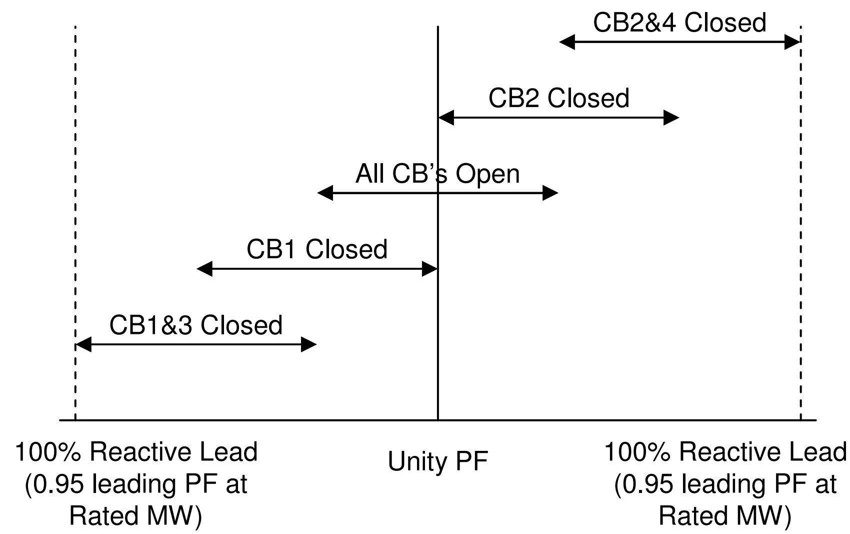
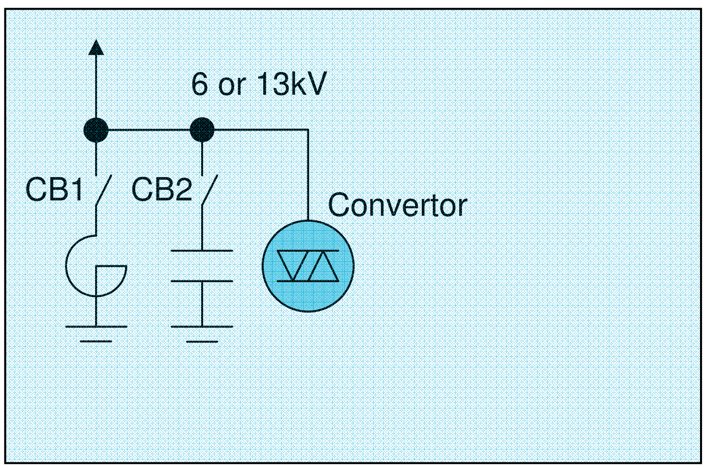
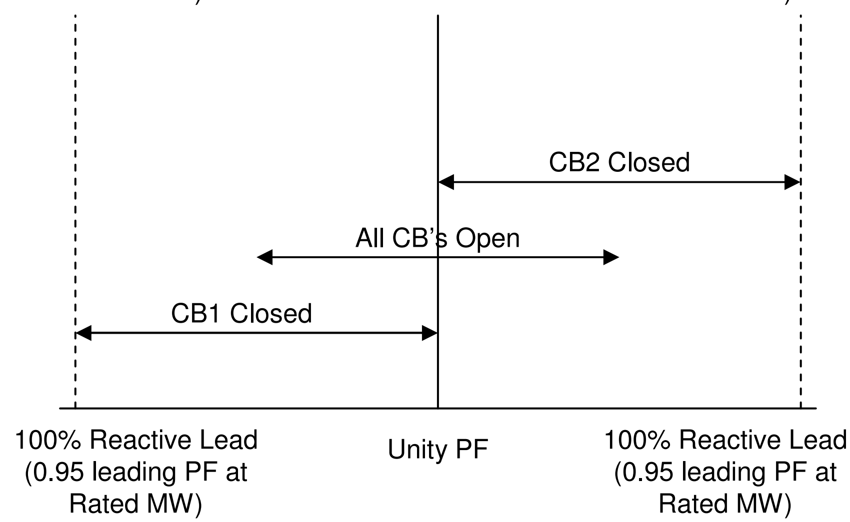
Double switched capacitor / reactor



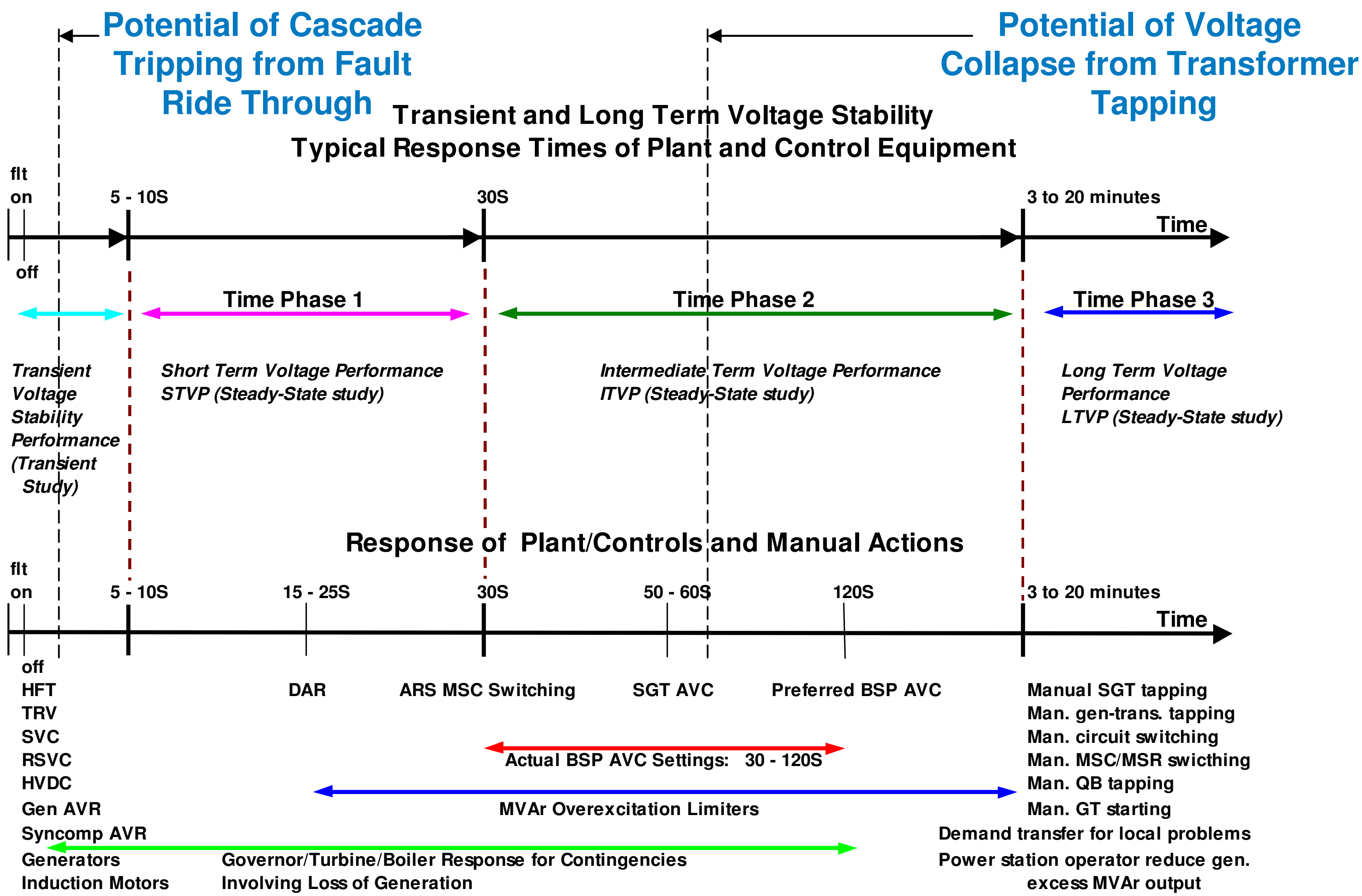




Single switched capacitor / reactor



Transient & Long-Term Stability: Time Phases



Current Position:

National Grid's position:

Hybrid SVC / STATCOM's that have a performance such that switch recharge time (close-open-close) less than 15 seconds and capacitor discharge time less than 2 seconds will be accepted.

We believe this position should be maintained. Hybrid SVC / STATCOM's can be used provided they provide repeatable performance without delay. We would like to see further improvements beyond 15seconds ensuring the steady state requirement of 5 seconds is met under any circumstance.

DAR Operation

DAR Operation:

1. DAR will automatically reclose tripped circuit breakers after the ‘Dead Time’ has expired, typically 3-20seconds. Dead time allows ionized gas to blow away or ash to fall away.
2. On re-establishing the circuit a second timer starts, this period is known as the ‘Reclaim Time’. Faults during this period will cause a second trip which will lock out the breaker. This period typically lasts 10-20seconds. The Reclaim Time allows the insulation medium in the breaker (Oil / SF6) time to recover.
3. If faults repeatedly occur after the Reclaim Time, operator intervention is required to lock the line out. In this scenario, further operator interventions i.e. switching operations, may require additional actions from the Hybrid SVC / STATCOM’s.

Scenarios which cause DAR Operation include:

- Lightning Storm Travelling up a Line
- Debris on the line e.g. Polythene sheet
- High winds causing conductor clashing

Multiple Circuit Trip Examples

Burns Day Storm 1990 (paper records prior to 97 – only example used) – **261 trips 80 faulted circuits in 24hours**.

Wednesday/Thursday 24th/25th Dec 1997 – **33 circuits tripped in 5 Hours**.

Saturday 26th Dec 1998 – High Winds – **Approx 20 trips, including 4 DAR restorations on same line in 4mins**.

Tuesday 27th Feb 2001 – Snow & High Winds - **Multiple trips on Scot. Interconnector. 600MW generation lost**.

Tuesday 3rd Aug 2004 – Lightning – 6 Circuit Trips (5 DAR Restoration's) in 3.25Hrs

Wednesday 18th Aug 2004 – Lightning - 10 Circuit Trips in 5 Hours including **3 DAR restorations in 3mins.**

Saturday 8th Jan 2005 – Gales - **32 faults on the NG System including 6 in 18, 7 in 21, 5 in 22 and 5 in 24mins**, most of which were restored by DAR

Wednesday 31st Aug 2005 – Lightning – 11 Trips in 2hrs 21mins including **6 in 27minutes** in the same area. All recovered by DAR.

Friday 15th Jun 2006 – Lightning – 9 trips in 3 hours, several within a few minutes of each other.

Sunday 2nd Jul 2006 – Lightning - 8 trips in approx. 1.5 hours including **4 trips in 17minutes and 2 trips in 2mins**.

Wednesday 11th Oct 2006 – Lightning - 6 trips in approx. 6 hours in the Taunton area.

Thursday 18th Jan 2007 – **137 Protection operations – 51 DAR Sequences** – 3 Conductor Failures resulting in permanent loss of circuits. A further 14 trips in 4 hours including sequences of **4 trips in 40mins, 4 trips in 8mins, and 3 trips in 10mins**. Most restored by DAR.

Sunday 1st Jul 2007 – Lightning – **5 trips in a localised area in 1/2 hour 4 of which auto reclosed or where restored manually**.

Wednesday 1st Jul 2009 – Lightning – **4 trips/events over a period of 25 minutes**

Monday 15th Jun 2009 – Lightning – 8 trips and restorations (i.e. 16 in total) in 3 hours including **4 in London area in 27 minutes**.

Thursday 28th Jun 2012 – Lightning – 9 trips at various places in UK and Scotland. At about 1 hour or half hour intervals.

Can Interaction Cause Lock Out?

- Interaction occurs as follows:
  - Volts change and plant A switches reactive elements to recover volts.
  - Volts are not fully recovered (plant A is at the limit of its capability)
  - Plant B then switches reactive elements and recovers volts.
  - Plant A is now required to switch elements back to previous state but has to observe its designs timing limitations and can not switch.
- Is it conceivable interaction could cause lock out of reactive capability due to timing difference between different manufacturers plant?
- If interaction occurred in combination with DAR the capability is lost earlier and takes less DAR operations.
- Interaction events can also occur when generation or other plant trip in quick succession with line trips.
- If the operator takes further actions they will expect the plant to operate in a timely manor without delay e.g. if they disconnection or reconnect plant after an event.
- The risk of unpredictable behaviour increases with the number of devices applied to the system and uncertainty of fast repeatable performance

Erosion of Reactive Reserve

- Synchronous Generators provide continuous reactive support from 0.95PF Lead to 0.85PF Lag at the generator terminals i.e. available at the POC (Point of Connection) less transformers losses
- This range is similar for asynchronous generators to $\pm$0.95PF but at POC (Point of Connection)
- Synchronous Generators provide short term extended reactive capability when volts are depressed due to forcing of DC field, typically a PF of 0.6
- Many of the current Hybrid SVC / STATCOM's provide reduced capability after a number of operations – recharging of switch control circuits and discharging of capacitors can delay operating times for up to 10mins
- PWM convertors typically maintain reactive output within the limits of the semiconductors at lower voltages
- Response from mechanical or thyristor switched capacitors and reactors is less desirable as Reactive Power is a function of V^2 resulting in reduced capability at low volts with increased risk of voltage collapse
- Some Hybrid SVC / STATCOM's switch capacitors off during a short circuit further reducing reactive capability at critical times
- After multiple switching events, time delays are so long the operator could manually intervene, assuming that the equipment is not working and make the wrong decision e.g. request a reference change because the volts are incorrect, minutes later switches operate with further consequences.
- National Grid SVC / STATCOM's are required to deliver 90% of their capability in 100ms.

Comparison of Operating Scenarios – 2012, 2020 & 2030

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2012 Maximum Renewable Generation as percentage of total demand $\simeq$25% high case

- At night where $\simeq$5GW of generation supplies $\simeq$20GW of demand, the other 75% being supplied by synchronous machines

2020 Maximum Renewable Generation as Percentage of total demand could be greater than 75%

- Peak Demand 57.5-59.7GW (UK Future Energy Scenario)
- Wind On and Offshore 17.6-26.3GW (UK Future Energy Scenario)
- Solar 3.4-6.9GW (UK Future Energy Scenario) but possibly 8GW at current growth rate

2030 Maximum Renewable Generation as Percentage of total Demand could exceed 100%

- Peak Demand 56.7-62.7GW (UK Future Energy Scenario)
- Wind On and Offshore 34.4-57GW (UK Future Energy Scenario)
- Solar 6.1-15.8GW (UK Future Energy Scenario)

NB Range indicates “Slow Progression” – “Gone Green” Scenario’s

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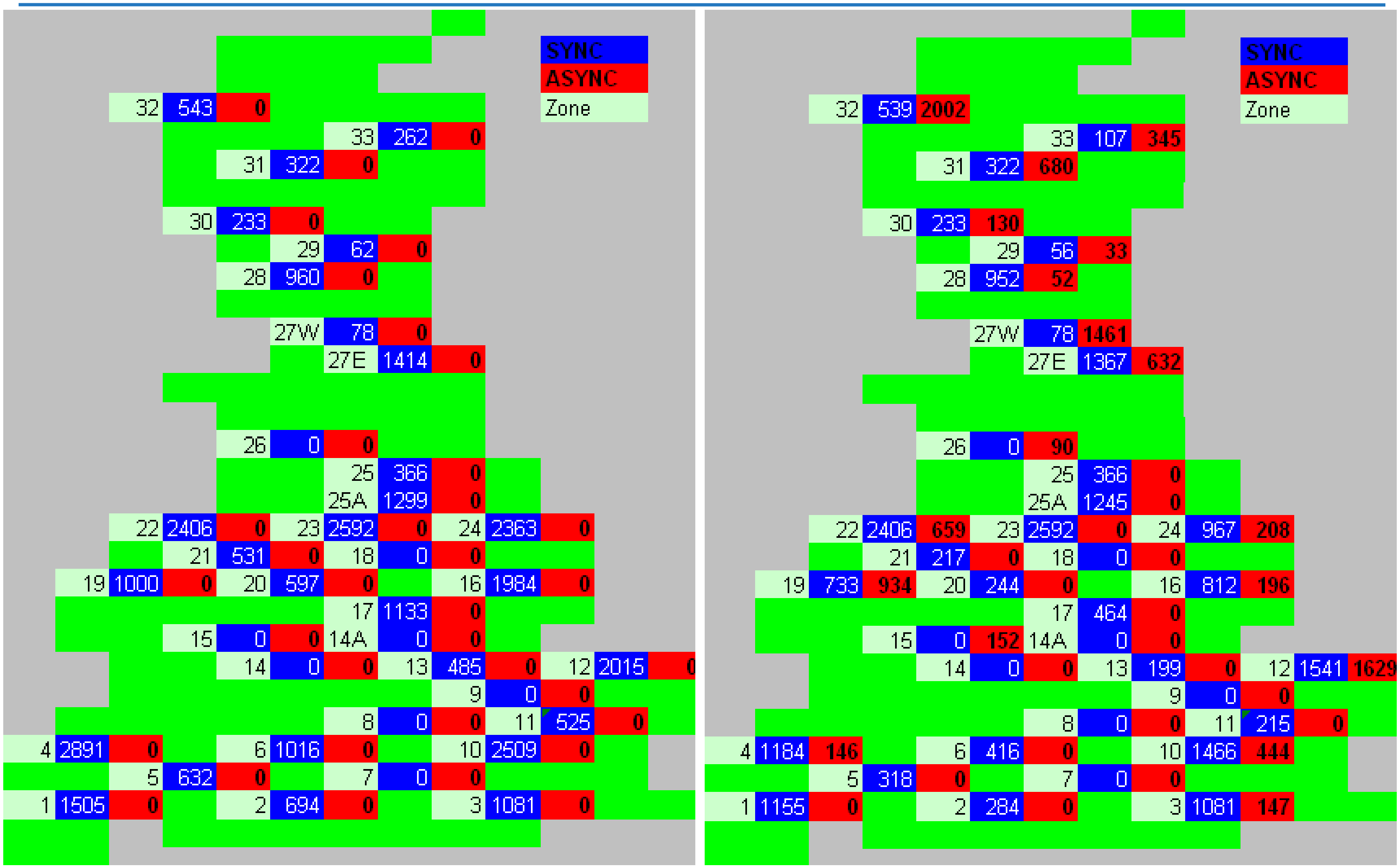
2020 30GW Demand No and 70% Renewables



2020 20GW Demand 50% Renewables (Wind Avail)

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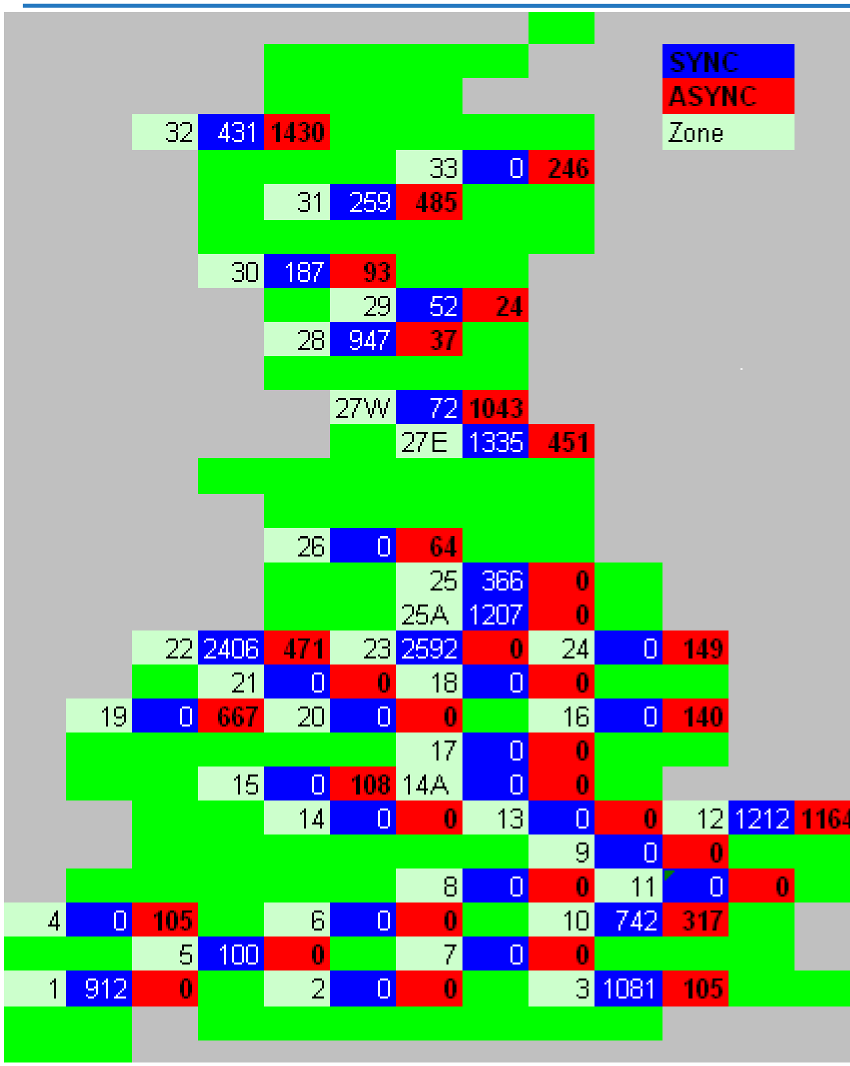
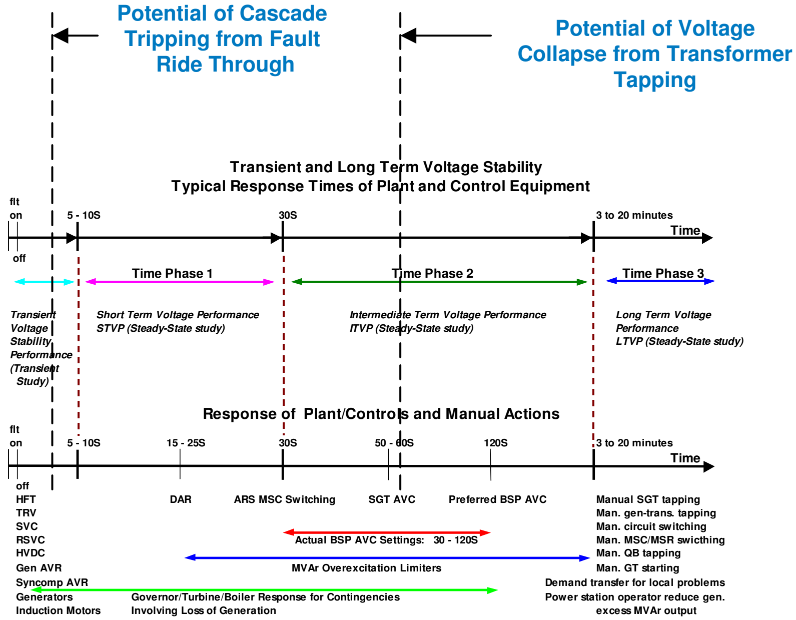


- In 2020 and beyond generation frequently moves to the edge of the system with largely embedded solar and wind in central regions
- In addition high North South transfers occur
- Securing for voltage and transient stability is made more difficult
- Limited reactive range would further compounds these difficulties
- Voltage stability is sensitive to circuit topology of the area in question and the operating scenario which in practice may change with many factors including weather, outages, new connections etc

NB Only the Transmission System Generation is displayed. It is anticipated there will be approx. 4-11GW of embedded Solar and Wind in addition to that shown.

Transient & Long-Term Stability: Time Phases

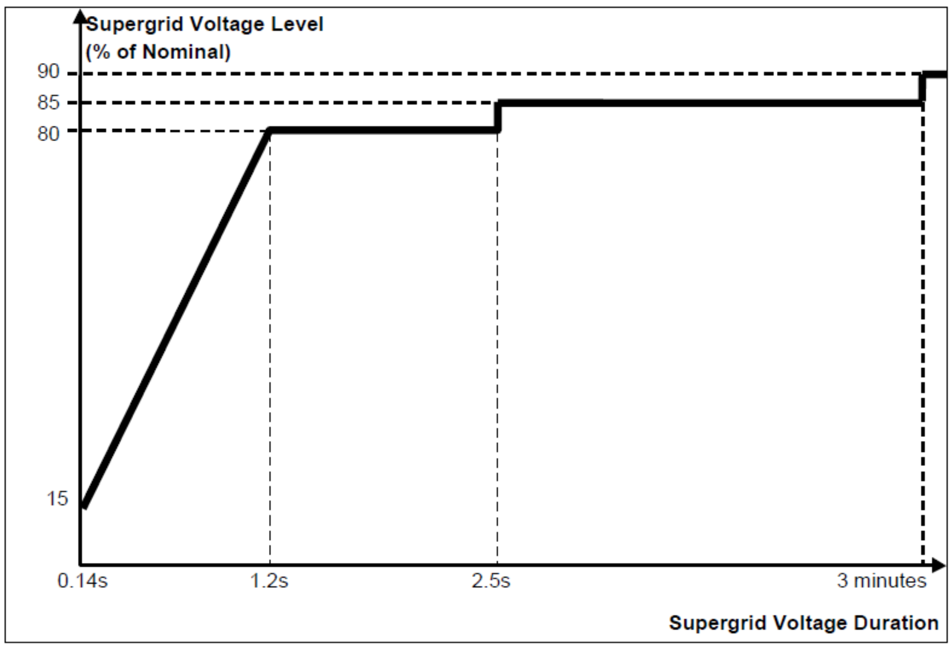


Desirable Outcome:

- Initial Response as per Current Grid Code Requirement as defined currently in CC.A.7.2.2a, CC.A.7.2.3.1, CC6.3.2 and CC.A.7.2.2
- All subsequent switching actions are faster than DAR $\leq$5 seconds ensuring requirement CC.A.7.2.2.5 or CC.A.7.2.3.1(ii) is always met within 5 seconds and all other aspects of CC.A.7.2.2a, CC.A.7.2.3.1, CC6.3.2 and CC.A.7.2.2 are met there after
- All Actions are Repeatable, Consistent, Predictable and Continuously Available including switching.
- 30 seconds after the last switching event performance returns to requirements defined in CC.A.7.2.2a, CC.A.7.2.3.1, CC6.3.2 and CC.A.7.2.2

Post Fault Condition

CCA.4A.3 **SUPERGRID VOLTAGE** DIPS ON THE **ONSHORE TRANSMISSION SYSTEM** GREATER THAN 140MS IN DURATION – This allows generators to trip after 2.5seconds if the voltage falls below 85%. As a consequence failure to support the volts to within 85% could result in cascade tripping.



Studies on 2012 contracted position

- These studies show effects of limited reactive capability on renewable generation as contracted in 2012
- The generator models were replaced by generic models which are not representative of the real plant at these sites – THESE ARE STUDIES ILLUSTRATIVE AND ARE NOT A REFLECTION OF ANY SPECIFIC GENERATORS PERFORMANCE.
- The studies were performed on and using the 2012 MVA ratings of the following sites:
  - Spalding North, Bicker Fen, Walpole Single Circuit Trip / DAR
  - Southern Coastal Region (Rampion, London Array and Thanet) – Voltage Collapse
  - Hedon Multiple Circuit Trips and DAR's

1. Spalding North, Bicker Fen, Walpole Circuit Trip / DAR Operation

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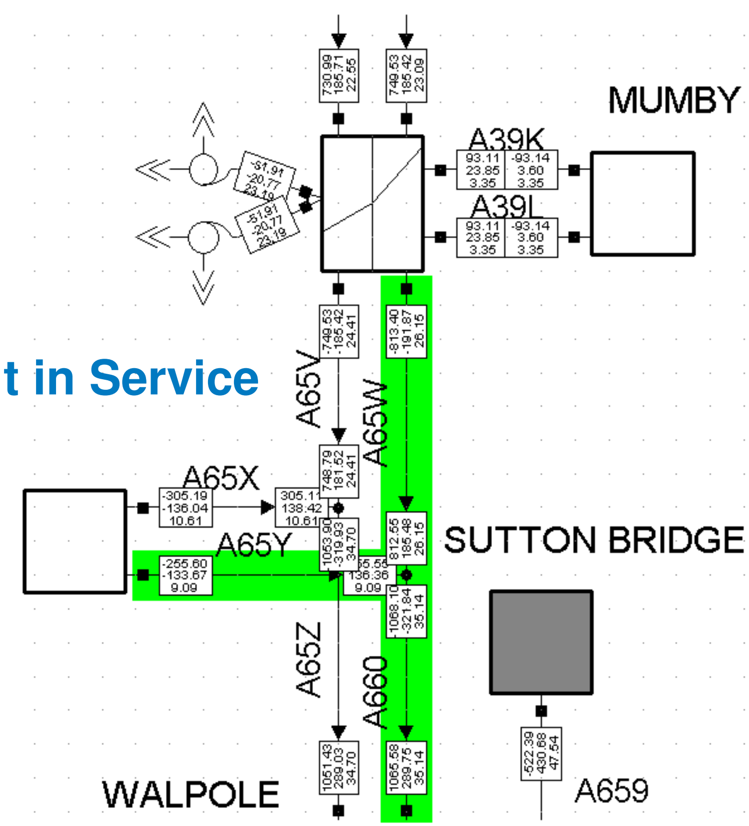
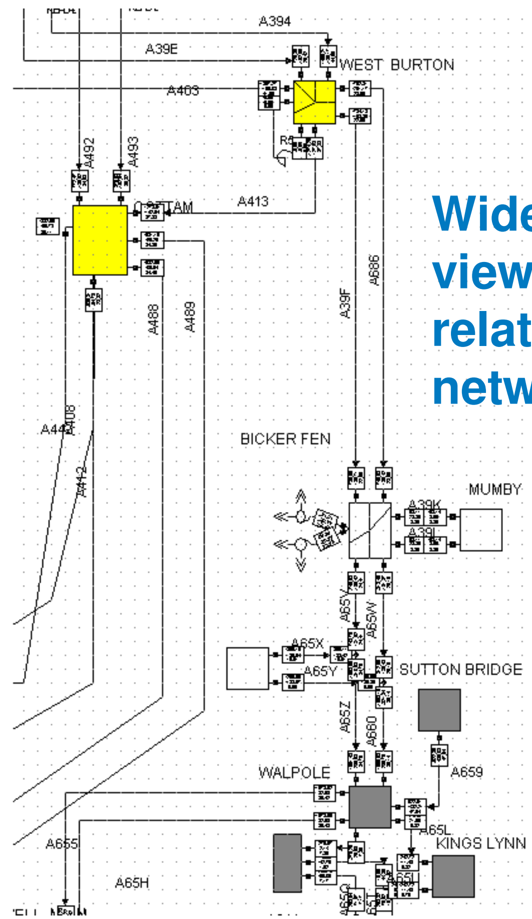
Before the trip of the circuit containing A65W A65Y and A660 the Wind Farm at Mumby has both 150MVA Power Park Modules connected producing 2 x 93MW and 2 x -3.6MVAr

Circuit in Service





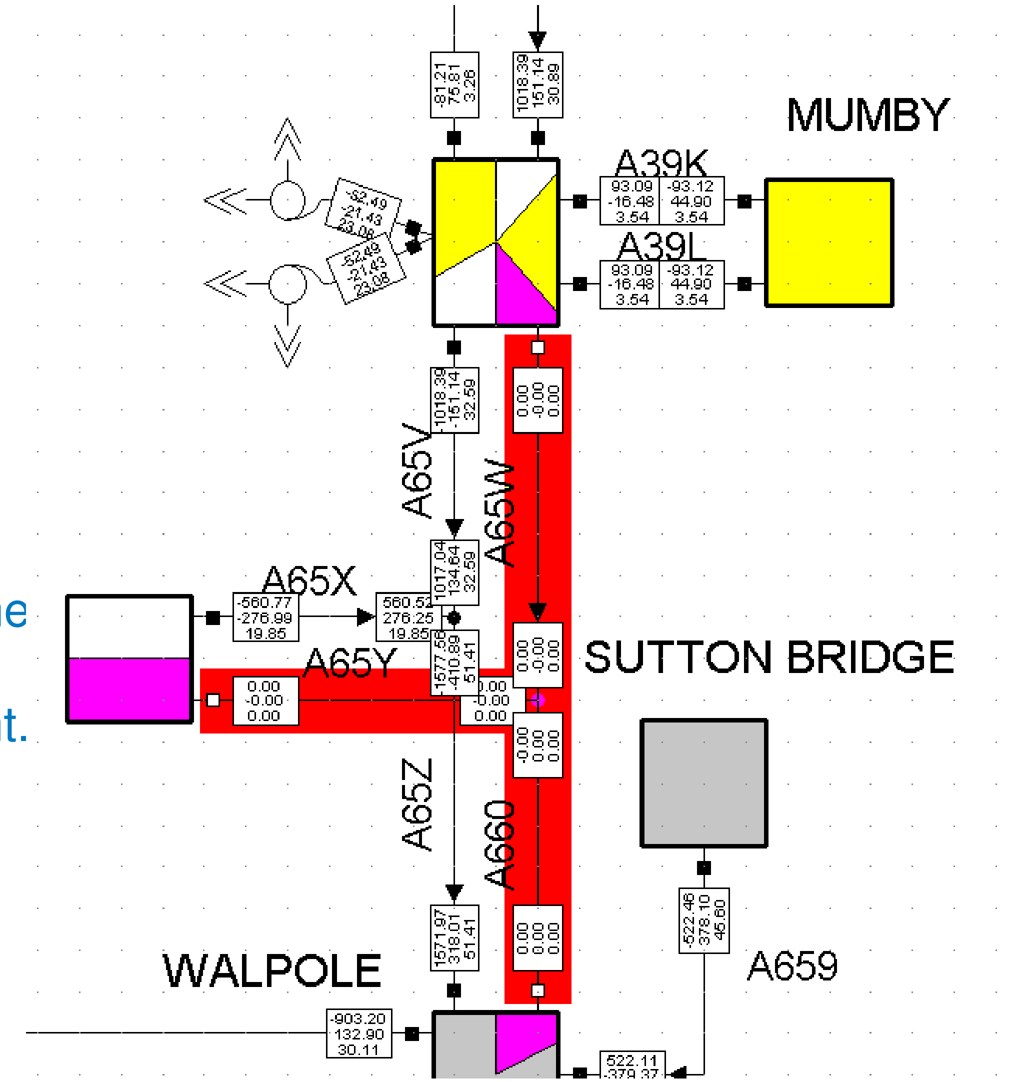
Wider view of related network

Post Line Trip / Pre restoration

After the trip of the circuit containing lines A65Y, A65W and A660, Mumby incurs a 41.3MVAr swing on an SVC rating of 49.34MVAr (or 83.7% of Rated Capacity of each Power Park Module).

This results in capacitor and / or reactor switching depending on the Hybrid SVC / STATCOM configuration and voltage set point.

Multiple DAR’s on this circuit alone, would require multiple operations of the Hybrid SVC / STATCOM capacitor and reactor switches.



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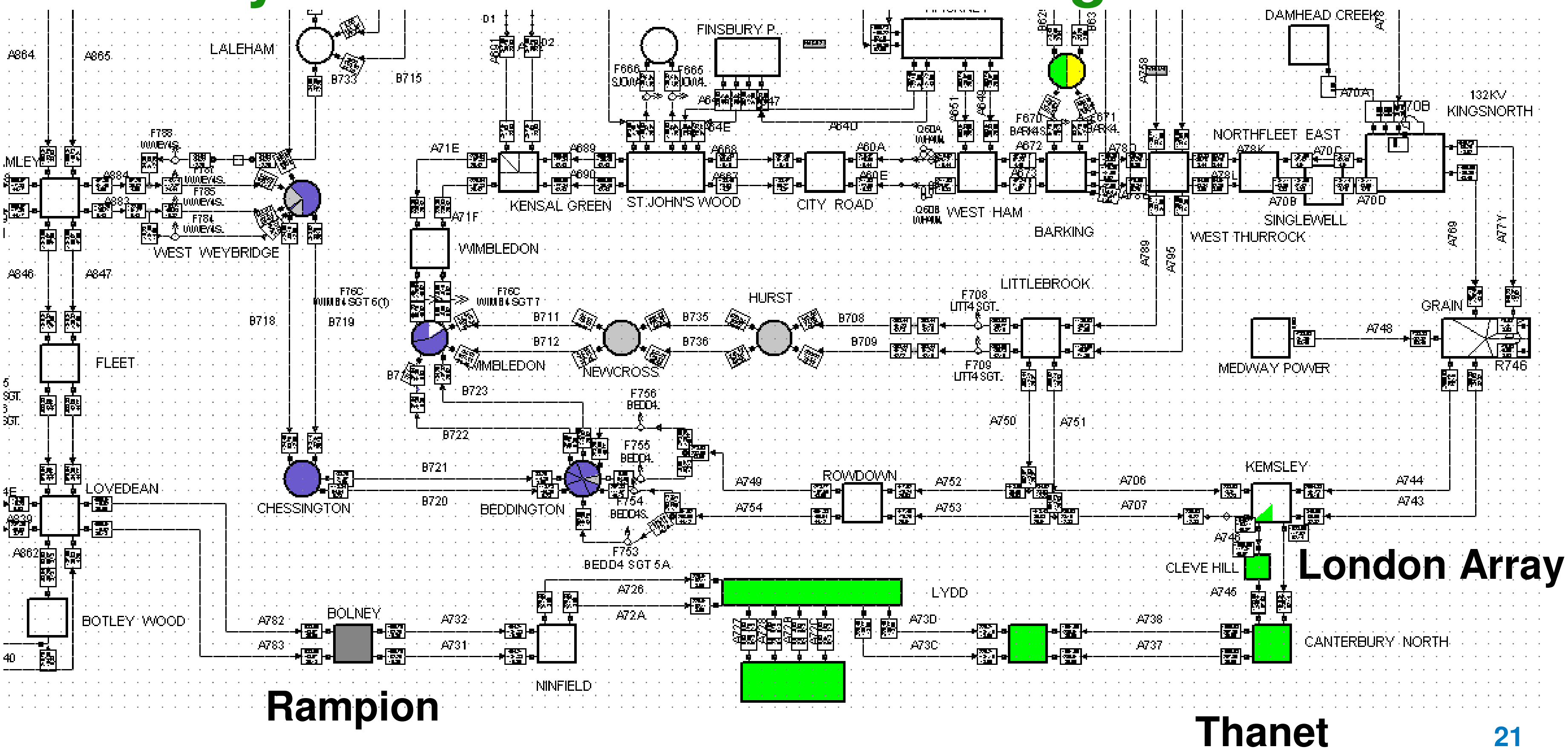
2. Voltage Collapse – On the South Coast 2018

Situation Before Double Circuit Fault from Kemsley to South Coast – All voltages within 2.5%



Scenario

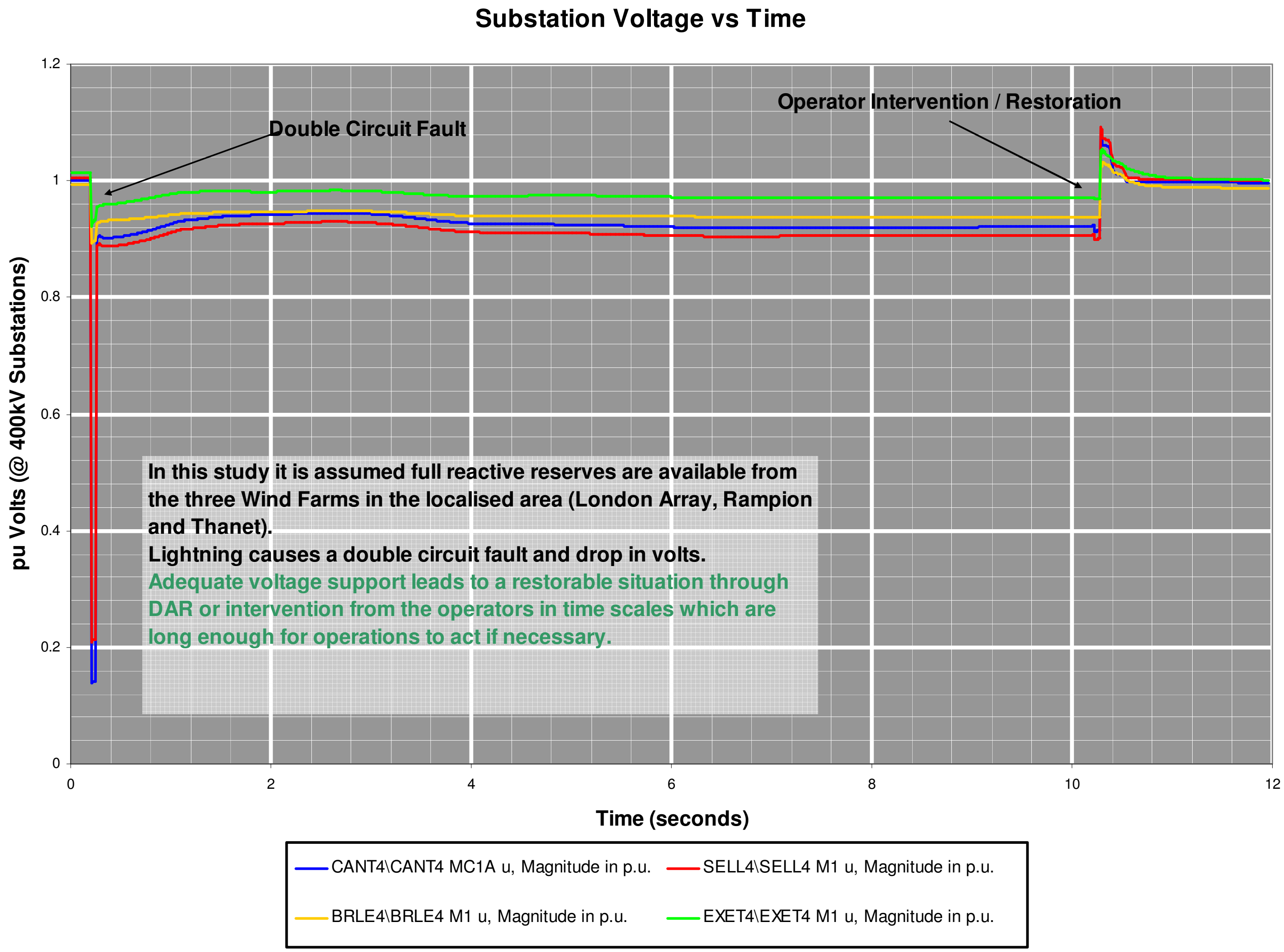
Three Wind Farm's, Thanet, Rampion and London array (as currently contracted for this area) provide 39.6% of the support available in the area. For the purpose of this study it is assumed these Wind Farms are fitted with Hybrid SVC / STATCOM's. Network operations perform studies and set the system up to cover for a double circuit fault.

Lightning causes DAR operations and Hybrid SVC / STATCOM capacitor and reactor switching and deplete the reactive reserves available from the Wind Farms.

A double circuit fault occurs a Kemsley and within a few seconds generators start to trip in timescales which are too fast for operations to take evasive action. This ultimately leads to disconnection of load.

The following graphs show the effect on system voltage with the wind farm providing the appropriate response where the system recovers and as described above where there is load disconnection due to voltage collapse.

Dynamic Performance with Full Reactive Capability



Dynamic Performance with Limited Reactive Capability

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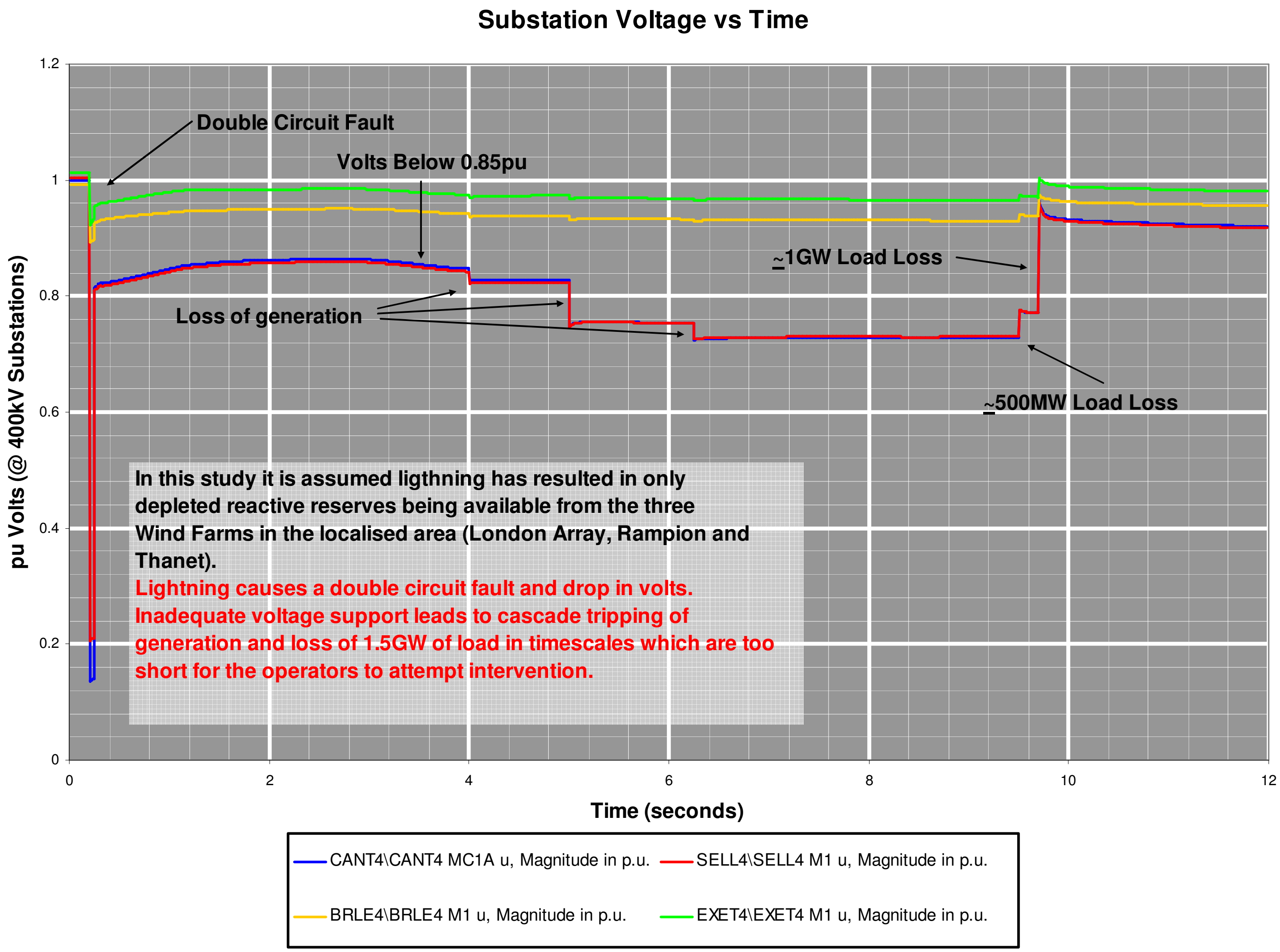
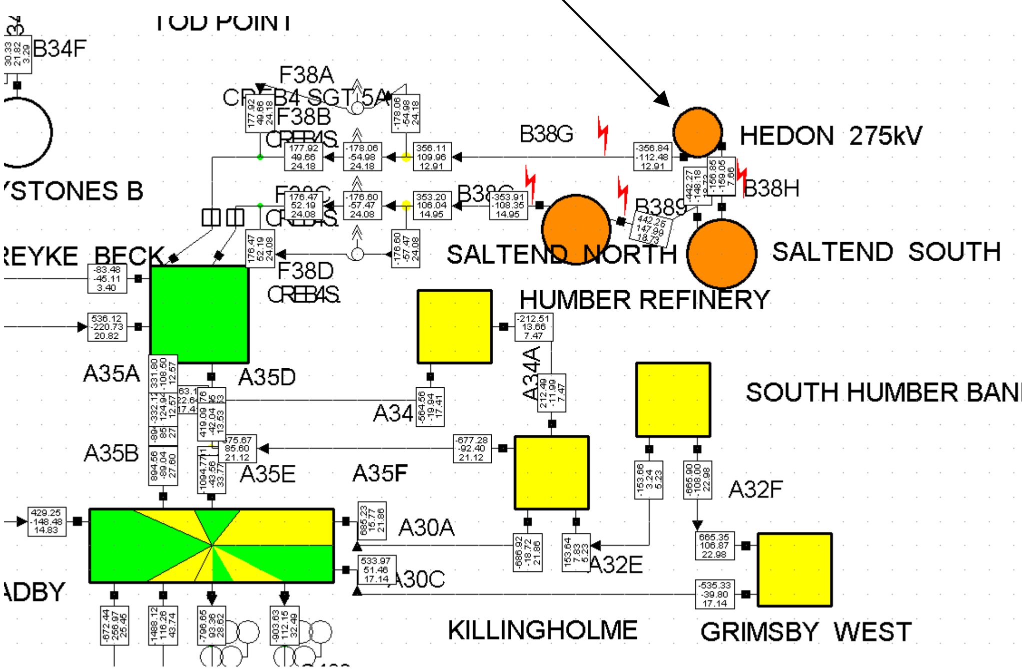
Loss of generation



3. Hedon Circuit Trip and DAR's

400MVA of Wind Generation at Hedon provides 124.9MVAr Support. Pre fault condition sees the WF producing -31MVAr and 200MW



In this Scenario lightning in the Saltend area results in trips and DAR's on lines B38G B38C B389 and B38H.

MVAr WF Output for various line trips:

No Trips =>	-31MVAr
B38G =>	-63.16MVAr
B38H =>	+47.9MVAr
B389 =>	-68.42MVAr
B38C =>	-60.05MVAr
B389 & B38H =>	+72.2MVAr

Multiple capacitor and reactor switching is likely.

4. Demonstration of Potential Effects on Dynamic Stability

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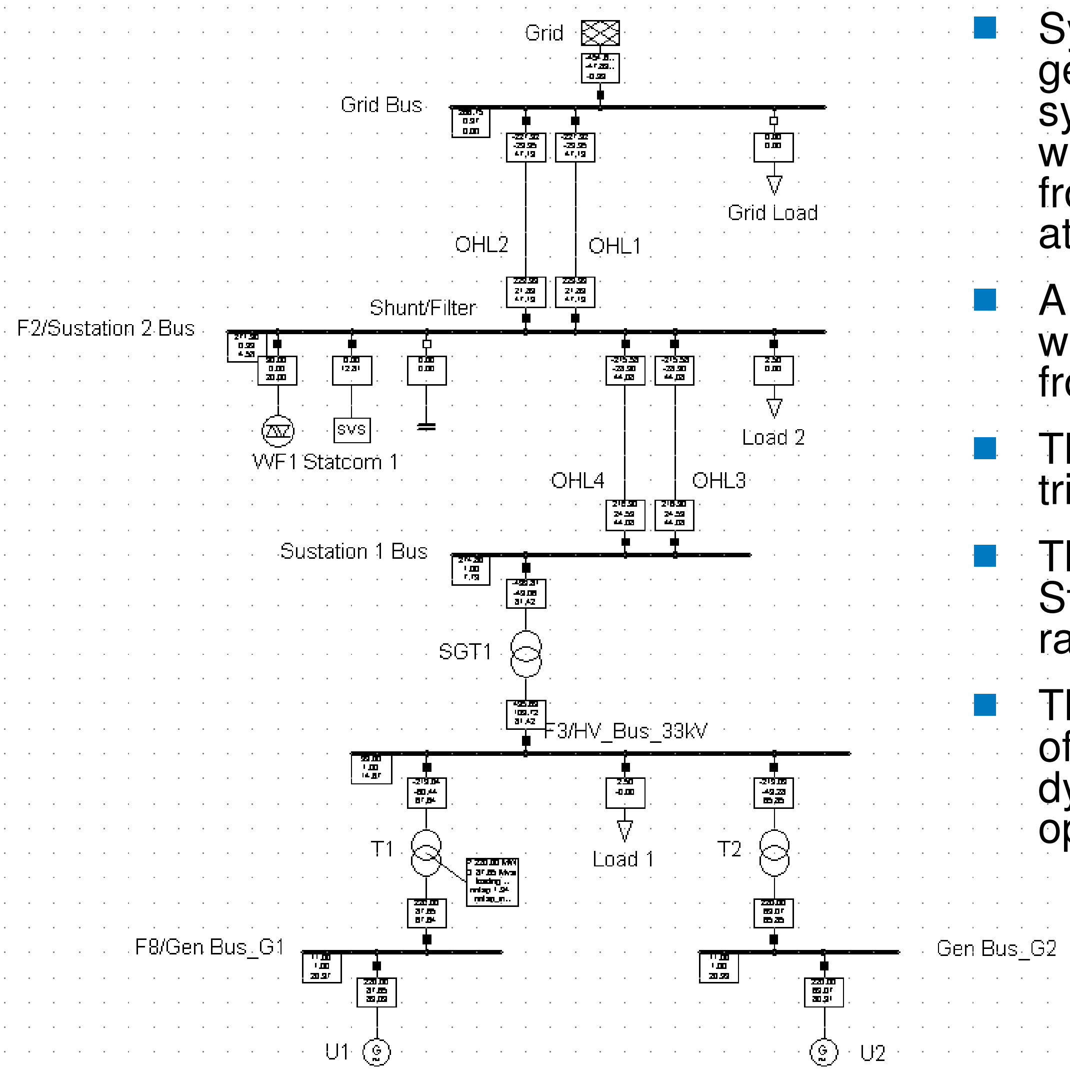
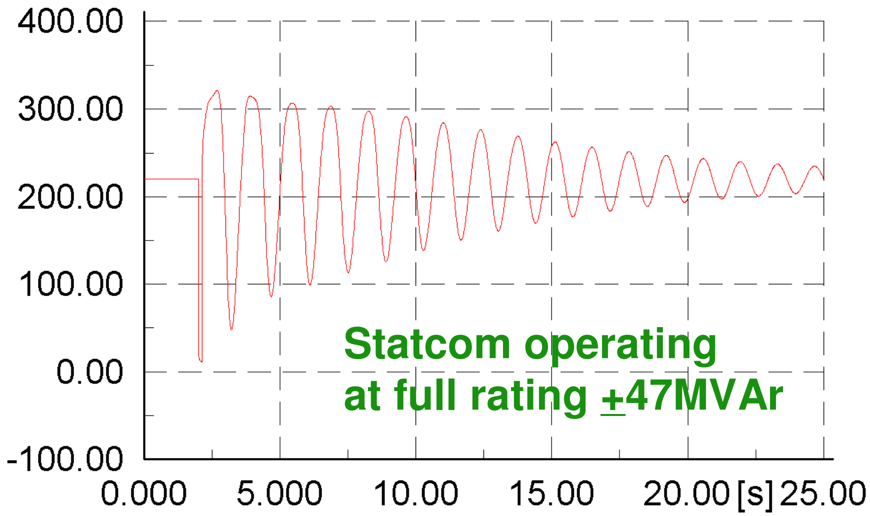
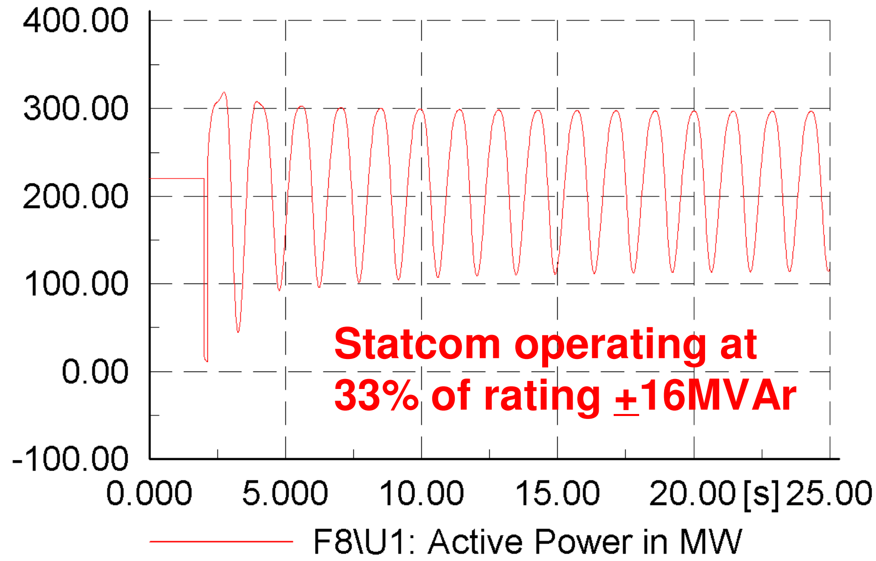
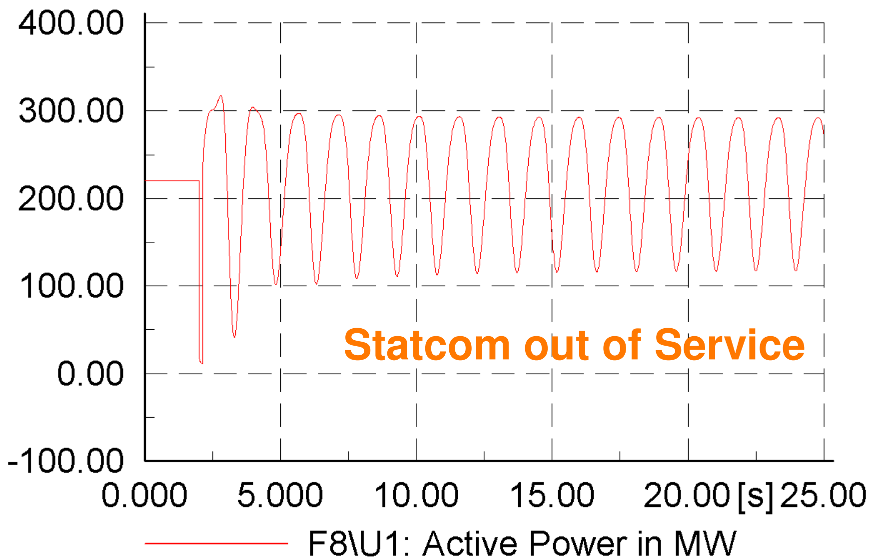


- System comprises of ~400MW of generation connected to a grid system via 60km and 80km of OHL with a 150MW WF connected 60km from the Power Station and operating at 21% of it full rating.
- A short circuit is applied to OHL 1 with full reactive capability available from the WF via Statcom 1.
- The fault on the line is cleared by tripping OHL 1 after 140ms.
- The study is then repeated with the Statcom output limited to 33% of its rating.
- The following slide shows the effect of limiting reactive capability on dynamic stability for the above operating conditions.

Results of Dynamic Stability Study – Power Flow from Synchronous M/C’s







This study demonstrates how limiting the reactive capability of dynamic voltage support can effect:

- **Dynamic Stability of Synchronous Generation on the System and therefore…**
- **The transfer capability of a transmission system**

MSC Shutdown During Faults

Some Hybrid STATCOM / SVC’c switch out the capacitors during a fault condition further reducing reactive support.

This increases the risks from voltage depression after a fault and increases the risk of post fault voltage depression and cascade tripping.

National Grid doesn’t switch its own capacitors out during fault conditions.

We would like to understand why is it necessary for some Hybrid STATCOM / SVC’s to disconnect capacitors during faults?

Fault Ride Through Capability
Voltage Dip Propagation - The Wash

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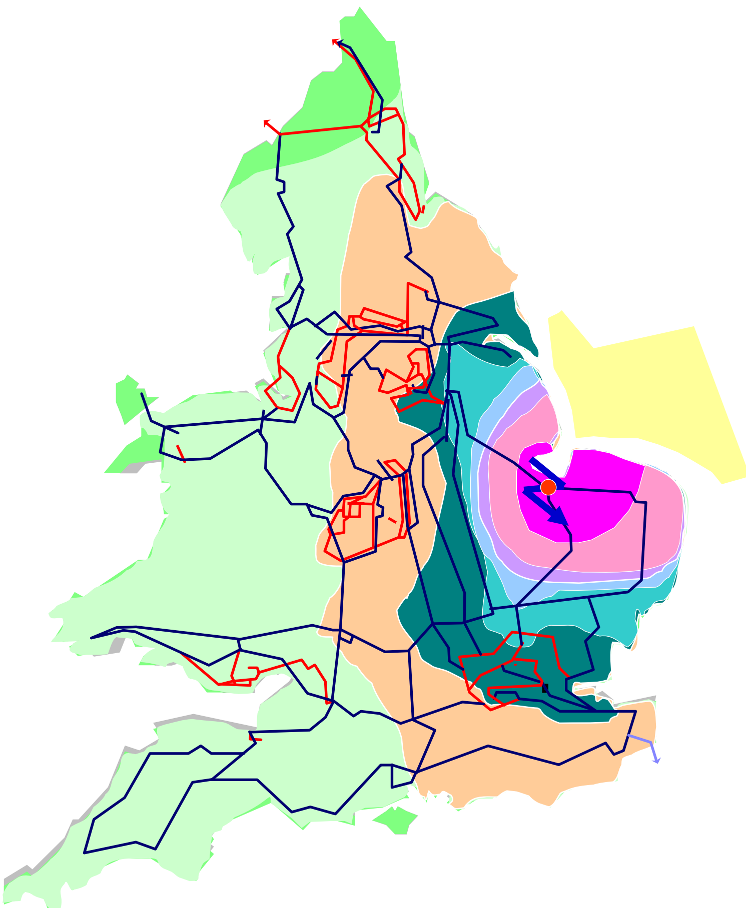

3 phase fault applied at Walpole 400 kV substation

- Fault Location 0 % Volts
- 0 - 15 % Volts
- 15 - 30 % Volts
- 30 - 40 % Volts
- 40 - 50 % Volts
- 50 - 60 % Volts
- 60 - 70 % Volts
- 70 - 80 % Volts
- 80 - 90 % Volts

Typical Arrangement England Wales & Scotland

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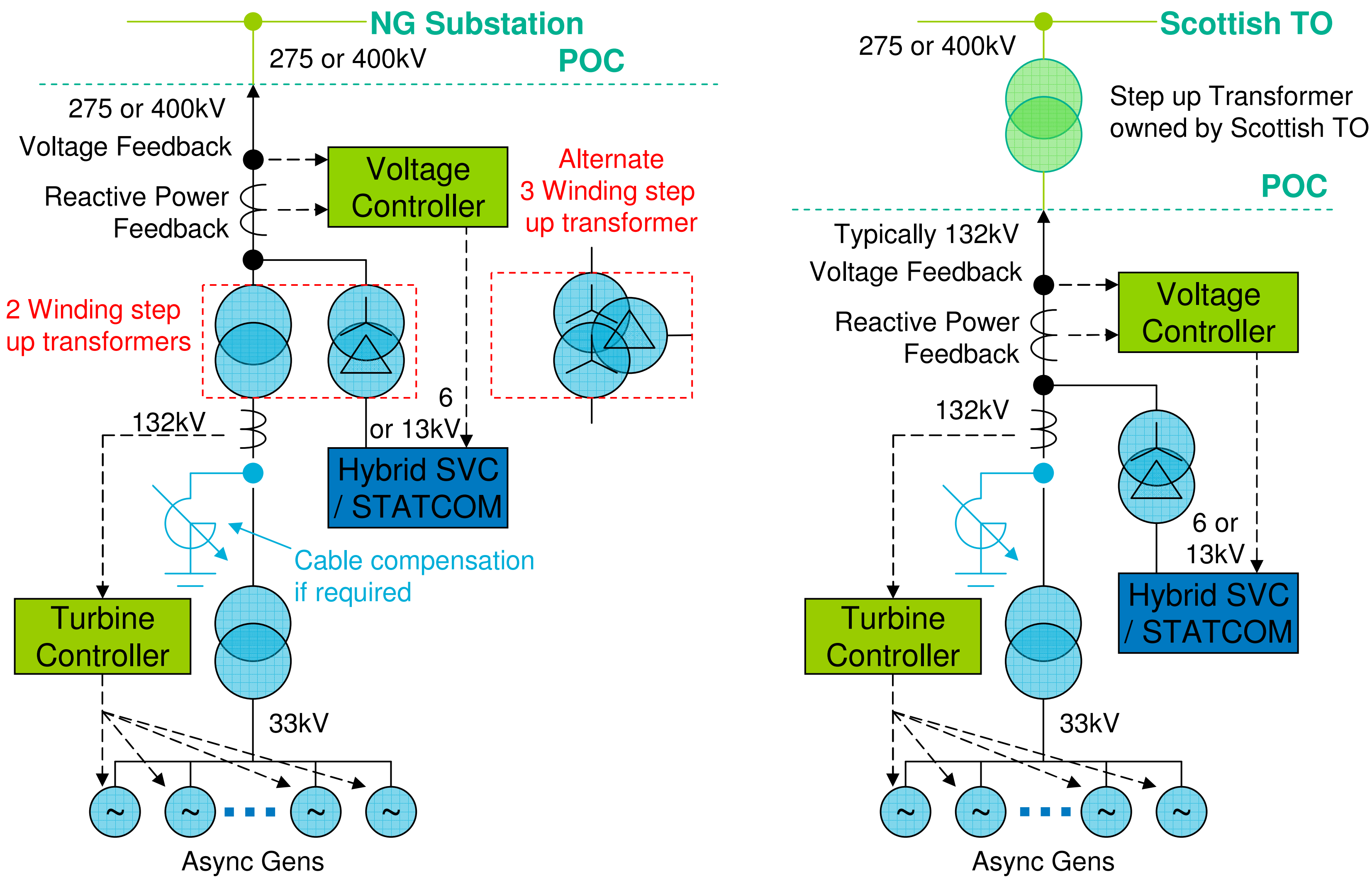

When is Improvement Required

National Grid would like see improvement ASAP but believe the situation is currently manageable. This therefore allows time for any changes to be implemented.

Currently installed equipments will not be affected by any changes agreed.

There is a need to identify the performance of the equipment which is currently planned for installation.

As penetration of renewable generation increases the level of risk also increases and National Grid will need to assess Generator applications on their merits, considering the effects of limited reactive reserve in the specific geographic area.

National Grid understand manufacturers will need time to implement and test any design changes.

Manufacturers need to advise when any agreed changes could be achieved. National Grid would like feedback on the cost and timing implications of any changes.

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Point on Wave Switching

1. Hybrid SVC / STATCOM’s could to be fitted with point on wave switching (open and close) or fast capacitor discharge to achieve repeatable continuously available switching operations

2. In practice the requirement to switch on multiple occasions would probably only occur on rare occasions but the availability should be continuous.

4. If capacitors switch off at the peak and on when the voltage across the switch is zero, the need to discharge capacitors is avoided. This allows repeated switching, minimizes switching transients and the effects of switching timing errors. Alternatively the switch could open when the capacitor is discharged.

5. Similar switching strategies can be adopted for reactors to by monitoring current and volts, ensuring matched performance for leading Power Factors.

6. Electronic elements of the SVC / STATCOM should step change in sympathy to ensure the output changes linearly from min to max or visa versa, with any steps being eliminated at the point of connection.

Conclusions

Current levels of system performance can be maintained provided:

1. Hybrid SVC / STATCOM's are capable of fast continuously repeatable switching operations within DAR timescales i.e. ensuring steady requirement CC.A.7.2.2.5 is met under all circumstances or if this is not achievable (or CC.A.7.2.3.1(ii) is met within 5 seconds).

2. Hybrid SVC / STATCOM's are fitted with a convertor element which is capable of supplying at ±33% to ±50% of full reactive capability, amount to be specified in the BCA (Bilateral Connection Agreement).

3. Capacitors are not switched out during voltage dips.

4. The BCA does not specifically preclude the use of a Hybrid SVC / STATCOM at specific sites for system reasons or specify a requirements in excess of the above (CC.A.7.1.2).

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Summary

1. Hybrid SVC / STATCOM’s could to be fitted with point on wave switching or fast capacitor discharge and good quality switches to achieve repeatable continuously available switching operations

2. Requirement to switch on multiple occasions occurs infrequently

3. If continuous and repeatable switching capability can not be provided, the risk of customer disconnection increases inline with increases in proportion of renewable generation.

4. Hybrid SVC / STATCOM Performance Improvements:

A. Reduce the number of studies required to determine suitability.

B. Potentially increase the number of potential applications both in renewable generation and else where.

C. Allow higher market penetration.

D. Reduce the risk of a major event on the system.

Questions




Appendix 1.0 – Grid Code Requirements

Control Arrangements CC.6.3.6 (b)

Each:

(i) **Onshore Generating Unit**; or,

(ii) **Onshore DC Converter** (with a **Completion Date** on or after 1 April 2005 excluding current source technologies); or

(iii) **Onshore Power Park Module** in England and Wales with a **Completion Date** on or after 1 January 2006; or,

(iv) **Onshore Power Park Module** in Scotland irrespective of **Completion Date**; or,

(v) **Offshore Generating Unit** at a **Large Power Station**, **Offshore DC Converter** at a **Large Power Station** or **Offshore Power Park Module** at a **Large Power Station** which provides a reactive range beyond the minimum requirements specified in CC.6.3.2(e) (iii),

must be capable of contributing to voltage control by continuous changes to the **Reactive Power** supplied to the **National Electricity Transmission System** or the **User System** in which it is **Embedded**.

Existing Grid Code Requirements

- APPENDIX 7 - PERFORMANCE REQUIREMENTS FOR **CONTINUOUSLY ACTING AUTOMATIC VOLTAGE CONTROL SYSTEMS**
- CC.A.7.2.2.1 The Onshore Non-Synchronous Generating Unit, Onshore DC Converter, Onshore Power Park Module or OTSDUW Plant and Apparatus **shall provide continuous steady state control of the voltage** at the Onshore Grid Entry Point (or Onshore User System Entry Point if Embedded) (or the Interface Point in the case of OTSDUW Plant and Apparatus) with a Setpoint Voltage and Slope characteristic as illustrated in Figure CC.A.7.2.2a…

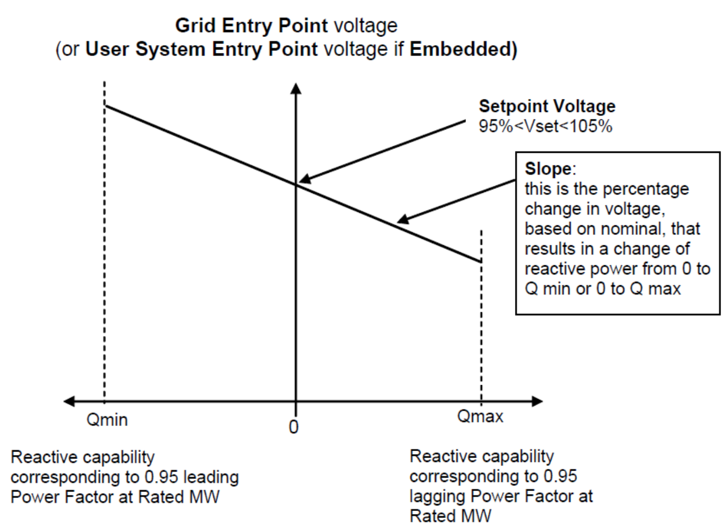


Figure CC.A.7.2.2a

- CC.A.7.2.2.5 Should the operating point of the Onshore Non-Synchronous Generating Unit, Onshore DC Converter, OTSDUW Plant and Apparatus or Onshore Power Park Module deviate so that it is no longer a point on the operating characteristic (figure CC.A.7.2.2a) defined by the target Setpoint Voltage and Slope, **the continuously acting automatic voltage control system shall act progressively to return the value to a point on the required characteristic within 5 seconds**.

Existing Grid Code Requirements

- CC.A.7.2.3.1 **For an on-load step change** in Onshore Grid Entry Point or Onshore User System Entry Point voltage, or in the case of OTSDUW Plant and Apparatus an on-load step change in Transmission Interface Point voltage, the continuously acting automatic control system shall respond according to the following minimum criteria:
  - (i) **the Reactive Power output response** of the Onshore Non-Synchronous Generating Unit, Onshore DC Converter, OTSDUW Plant and Apparatus or Onshore Power Park Module **shall commence within 0.2 seconds of the application of the step. It shall progress linearly although variations from a linear characteristic shall be acceptable provided that the MVAr seconds delivered at any time up to 1 second are at least those that would result from the response shown in figure CC.A.7.2.3.1a.**

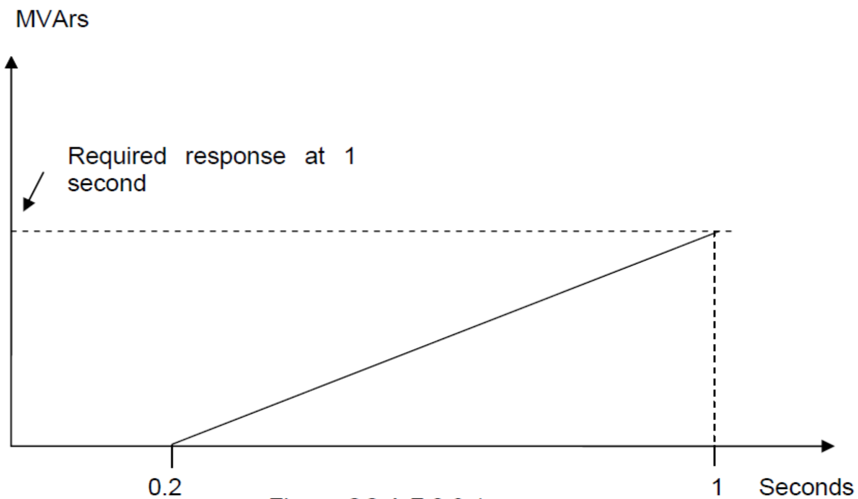
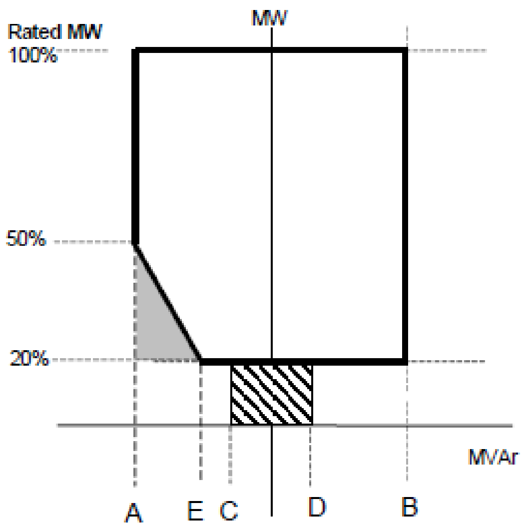


Figure CC.A.7.2.3.1a

  - (ii) the response shall be such that, for a sufficiently large step, **90% of the full reactive capability** of the Onshore Non-Synchronous Generating Unit, Onshore DC Converter, OTSDUW Plant and Apparatus or Onshore Power Park Module, as required by CC.6.3.2 (or, if appropriate, CC.A.7.2.2.6 or CC.A.7.2.2.7), **will be produced within 1 second**.
  - (iii) **the magnitude of the Reactive Power output response produced within 1 second shall vary linearly in proportion to the magnitude of the step change**.
  - (iv) **the settling time shall be no greater than 2 seconds** from the application of the step change in voltage and the peak to peak magnitude of **any oscillations shall be less than 5% of the change in steady state** Reactive Power within this time.
  - (v) following the transient response, the conditions of CC.A.7.2.2 apply.

Existing Grid Code Requirements



Point A is equivalent (in MVAr) to: 0.95 leading **Power Factor** at **Rated MW** output

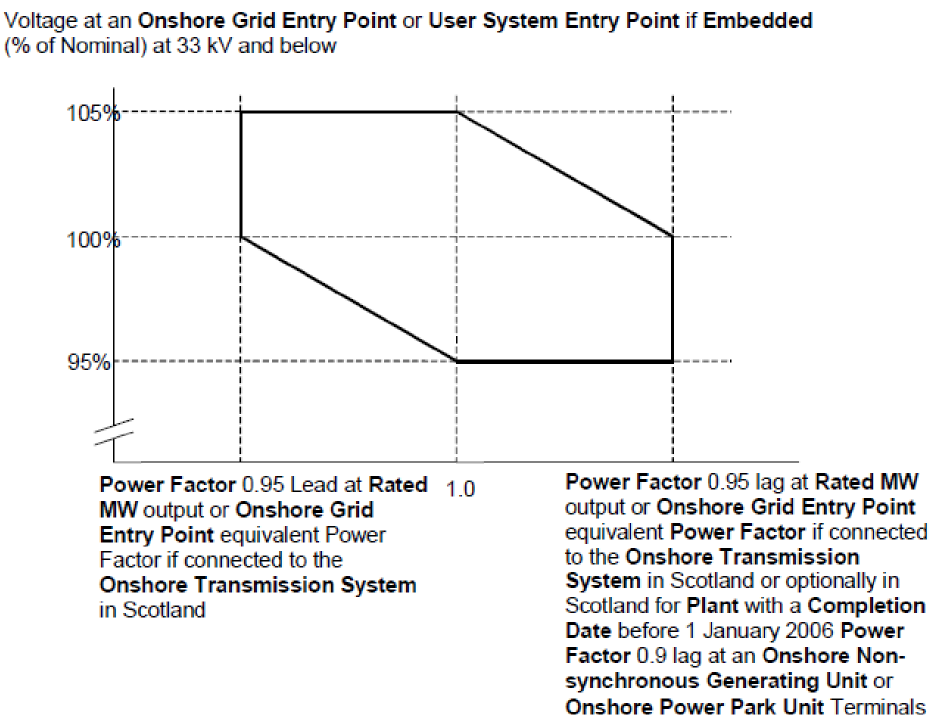
Point B is equivalent (in MVAr) to: 0.95 lagging **Power Factor** at **Rated MW** output

Point C is equivalent (in MVAr) to: -5% of **Rated MW** output

Point D is equivalent (in MVAr) to: +5% of **Rated MW** output

Point E is equivalent (in MVAr) to: -12% of **Rated MW** output

CC 6.3.2 – Reactive Capability Chart For Asynchronous Generation



CC 6.3.4 – Reactive Capability vs Volts

Reactive Slope Set Point

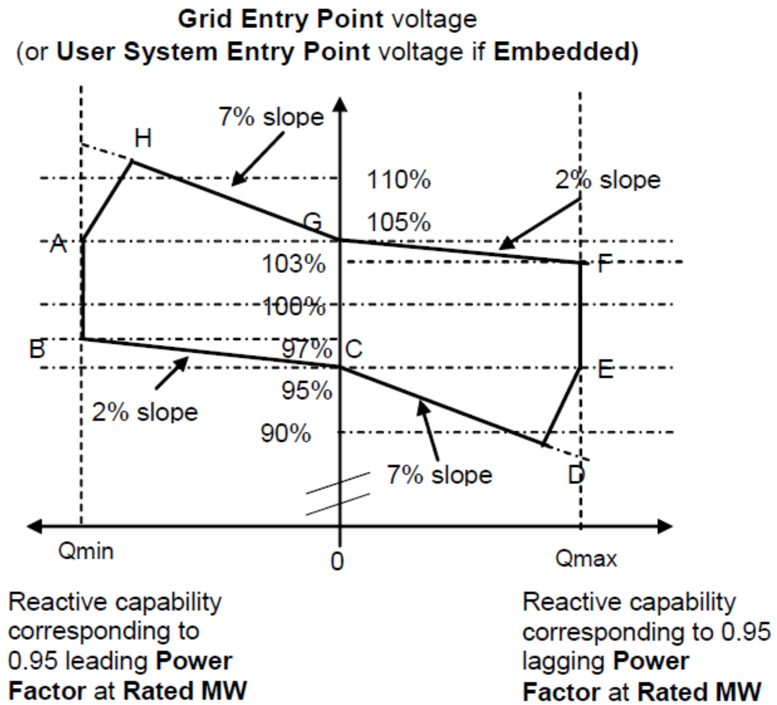


Figure CC.A.7.2.2b

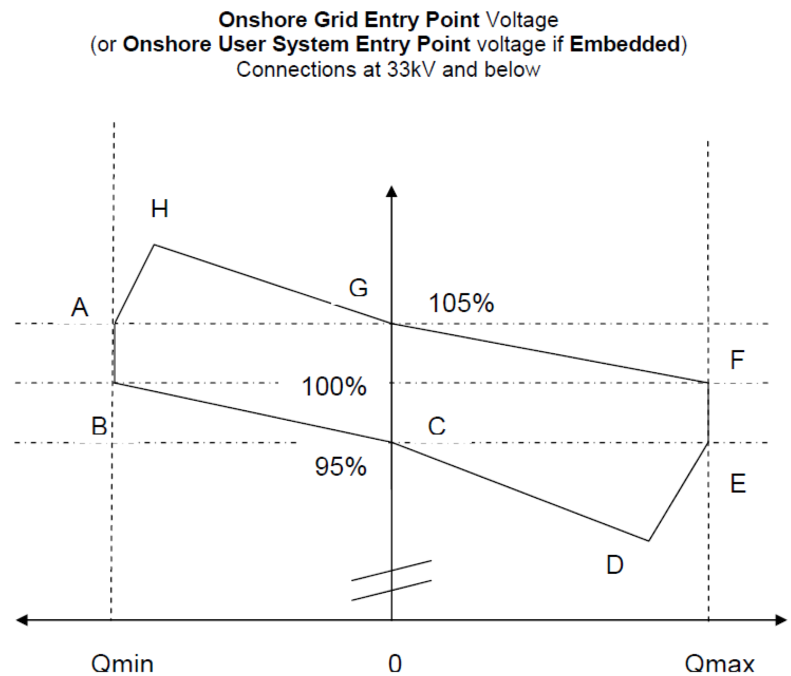


Figure CC.A.7.2.2c

Grid code CC.A.7.2.2 specifies that the Voltage vs Reactive Power slope can be set between **2 and 7% irrespective of whether it is transmission connected or embedded**. However for embedded connections the system operator (National Grid) must agree the settings with the DNO first.

The default setting is 4% however the **worst case from the Hybrid SVC / Statcom's perspective is 2%** as this produces a wider swing in reactive power for a small swing in volts.

The **system operator can specify a new slope setting at any time** and the generator is required to comply within 2 weeks.