Session 3

Managing Voltage Control on a Power System with High Renewable Penetration

Simon Tweed
Tony Hearne
Andrew Keane
Steve Gough
Douglas Cheung

Managing Voltage Control on a Power System with High Renewable Penetration

PROBLEM DESCRIPTION

Simon Tweed
Tony Hearne

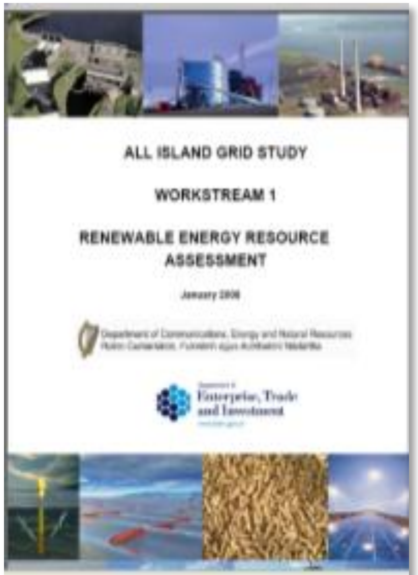
Session 3: Managing Voltage on a Power System with High Renewable Penetration - TSO Issues

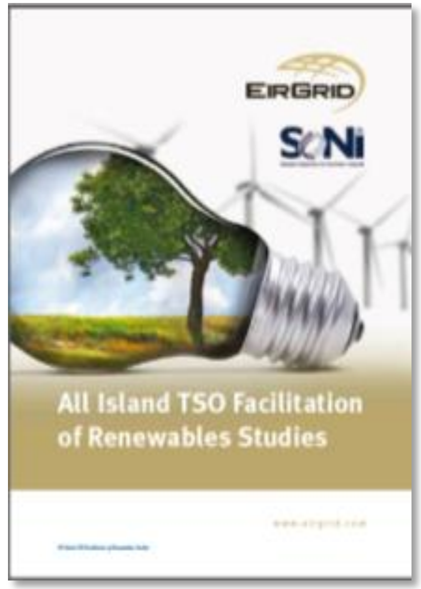
Simon Tweed, EirGrid

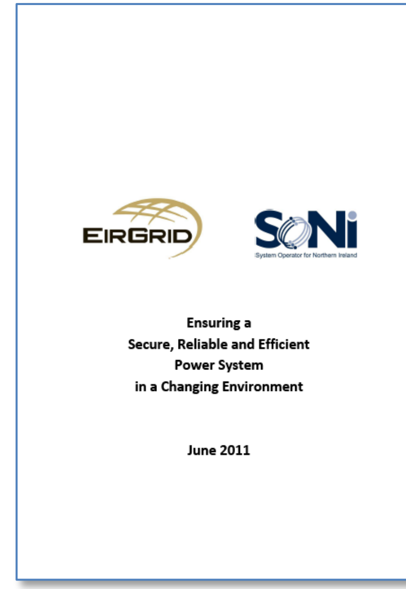
CIGRE Ireland Training Day

2nd December 2013

Technical Analysis of the Issues



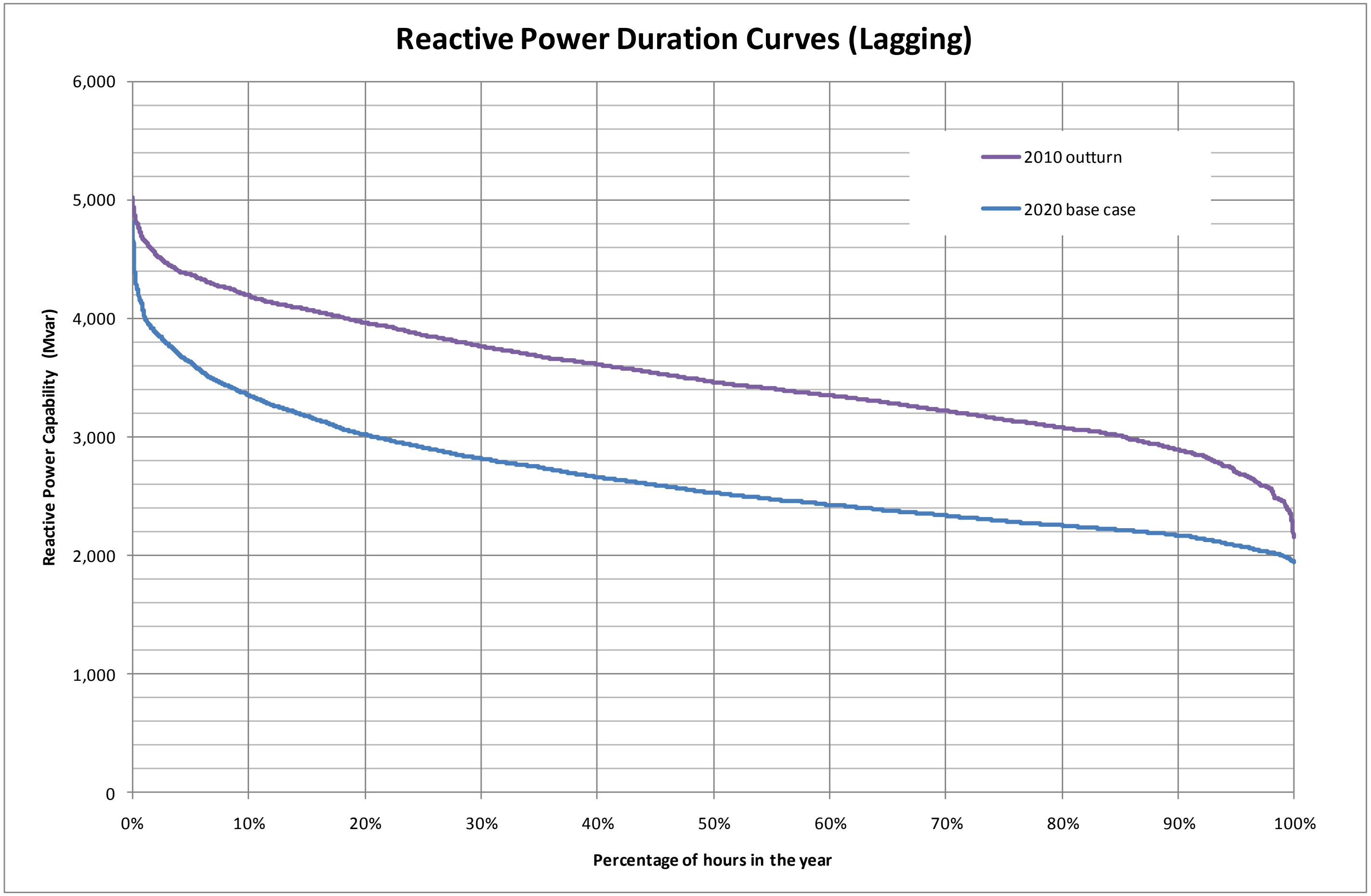




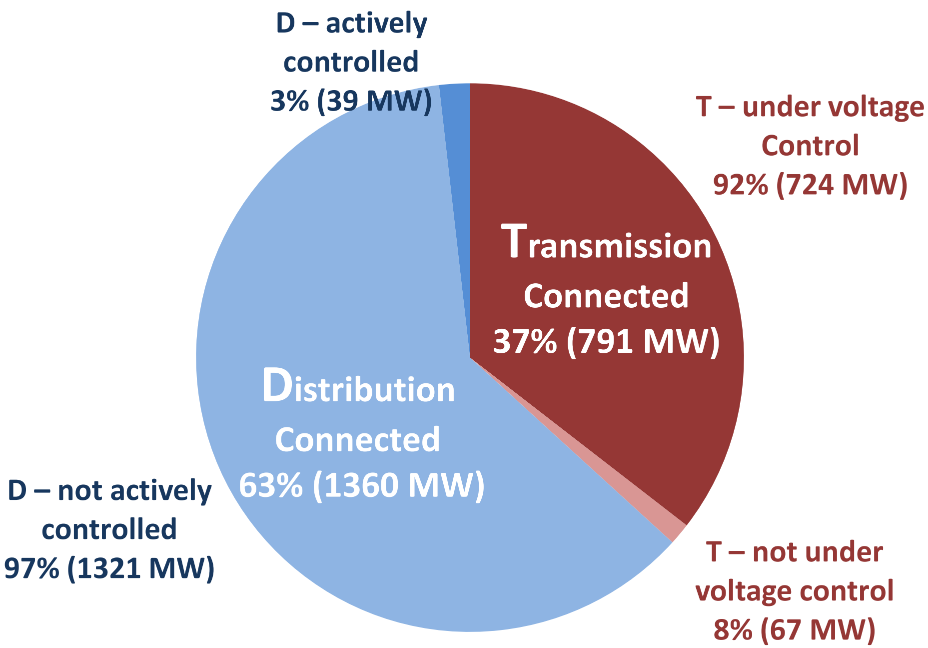
Detailed Technical Analysis

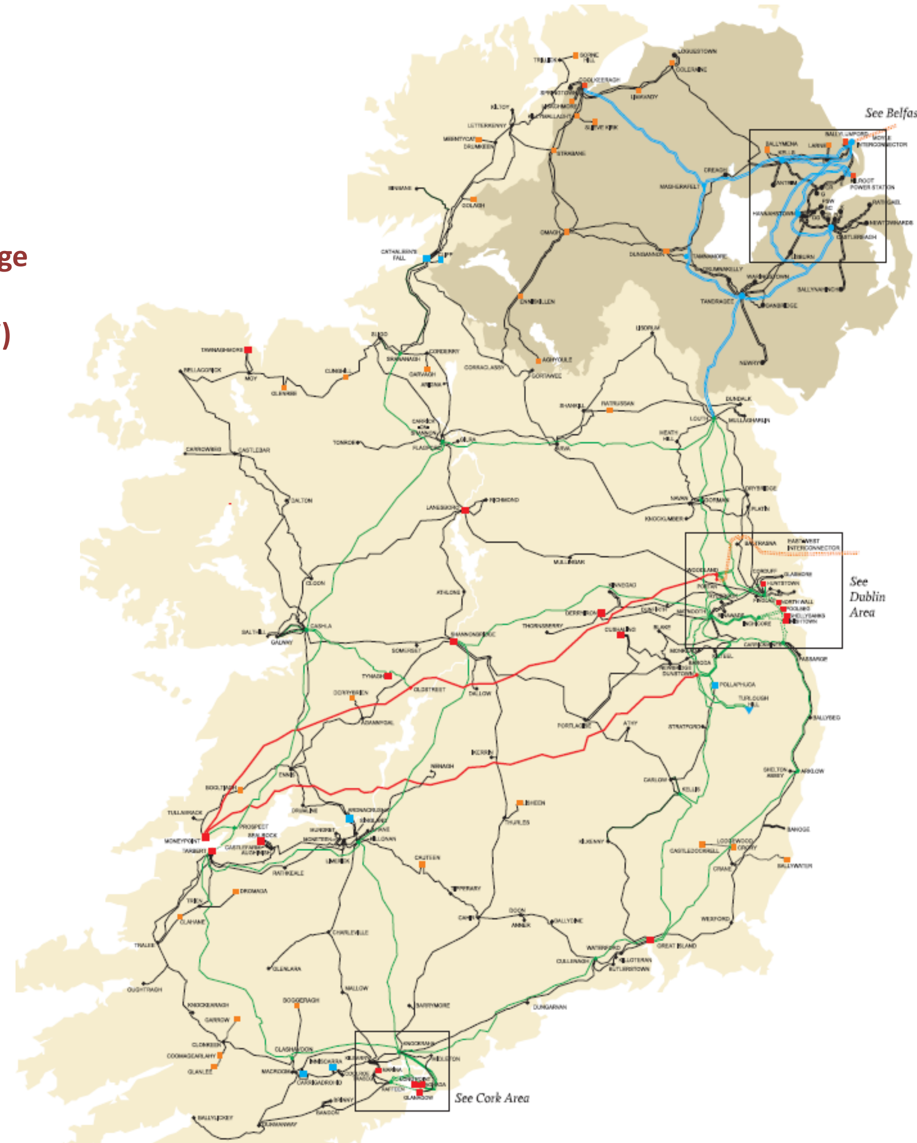
2008 - All Island Grid Study
2010 - Facilitation of Renewables
2011 - Ensuring a Secure Sustainable System

Issue: Reactive Power Availability (Sync)



Issue: Wind Farm Location & Reactive Controllability

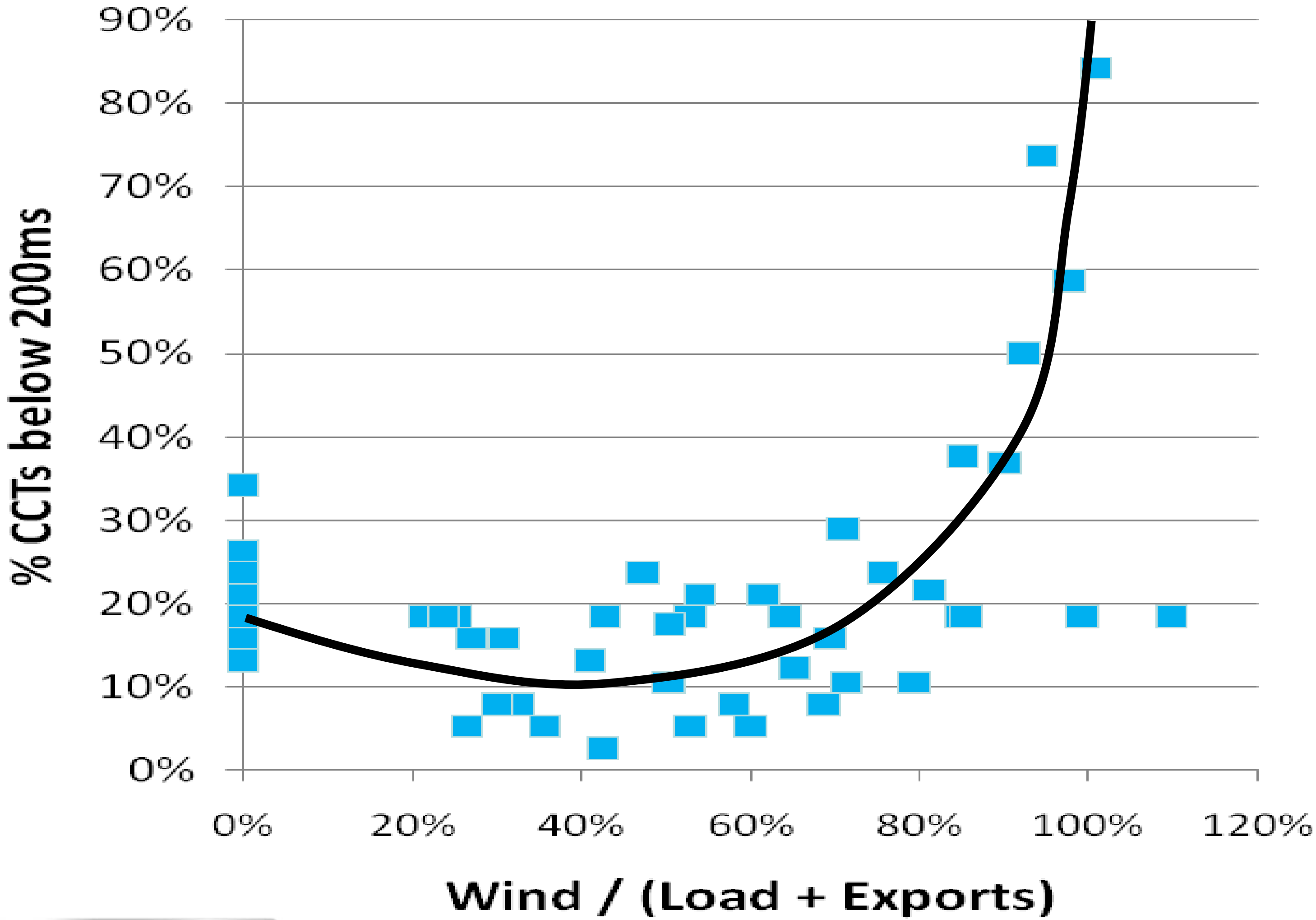




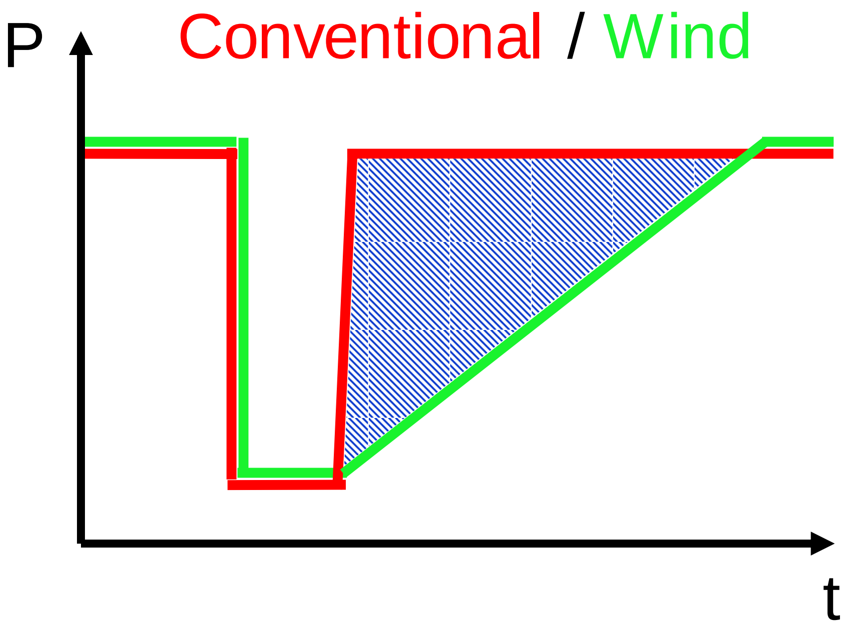
(2013 Data)

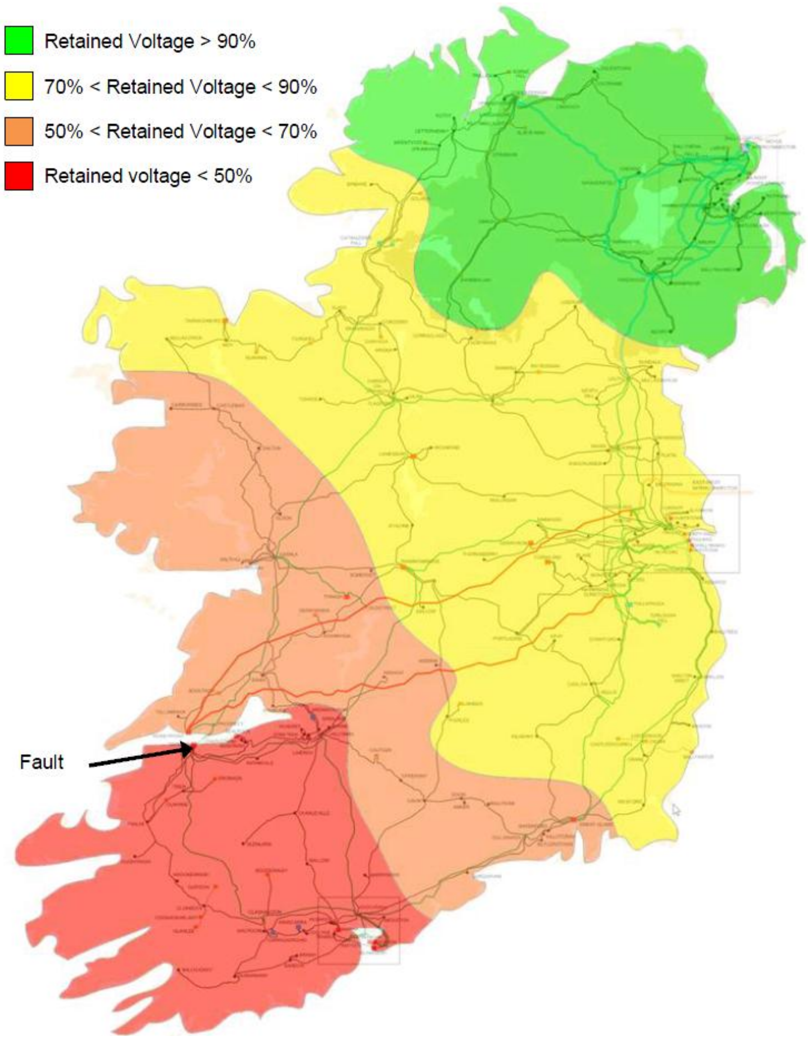
EIRGRID semo SONi

Issue: Dynamic Stability



Issue: Voltage Dip-Induced Frequency Dip





Managing Voltage Control on a Power System with High Renewable Penetration

Problem Description: DSO Perspective

Tony Hearne,

Manager IVADN Project, ESB Networks

Presentation Structure

What makes Distribution Connection different

Degrees of embedding within Distribution System

Traditional voltage-rise

New tools at our disposal

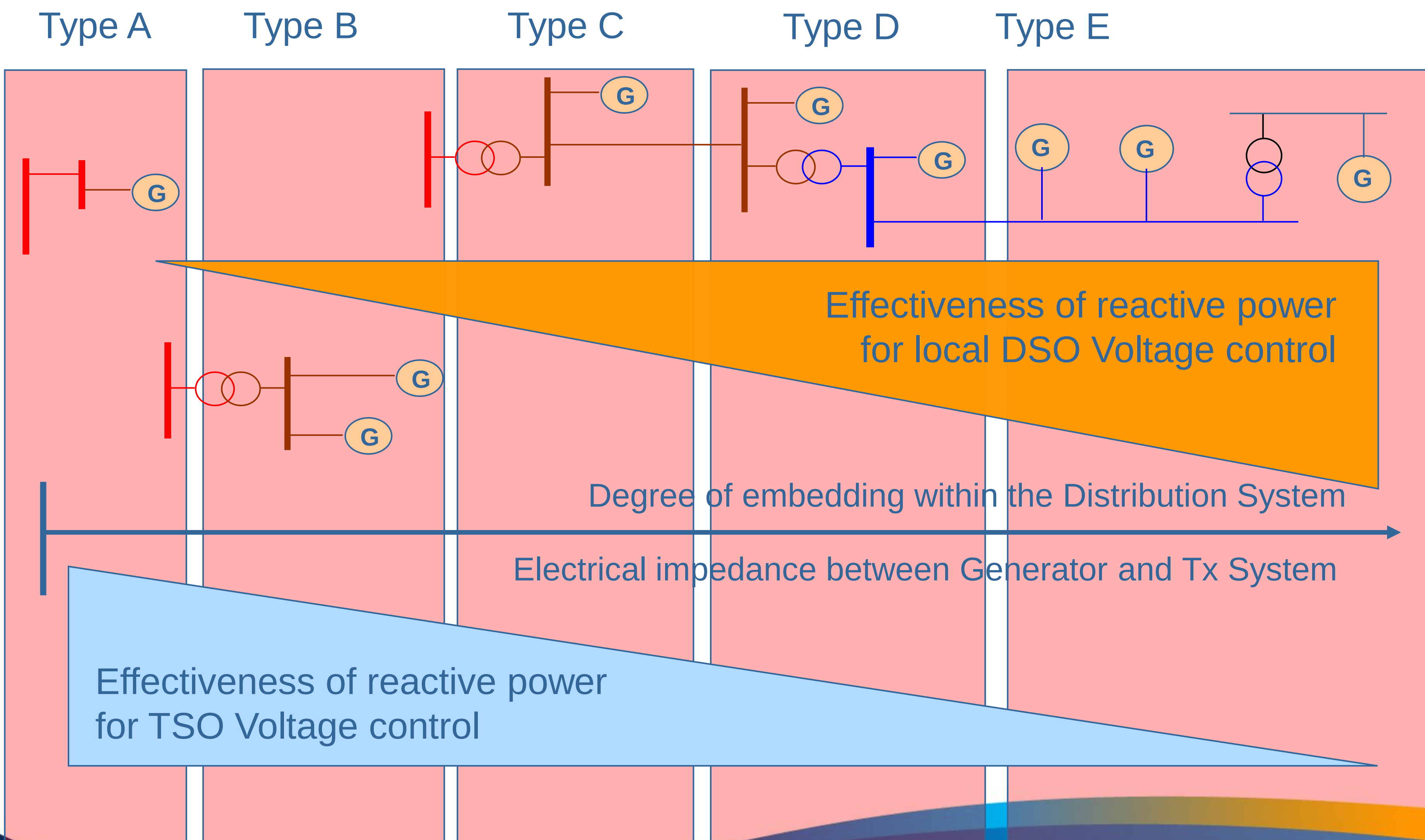
Reactive Range and visibility

Example of inter-windfarm interaction for Cluster scenario

What makes Distribution Connection different

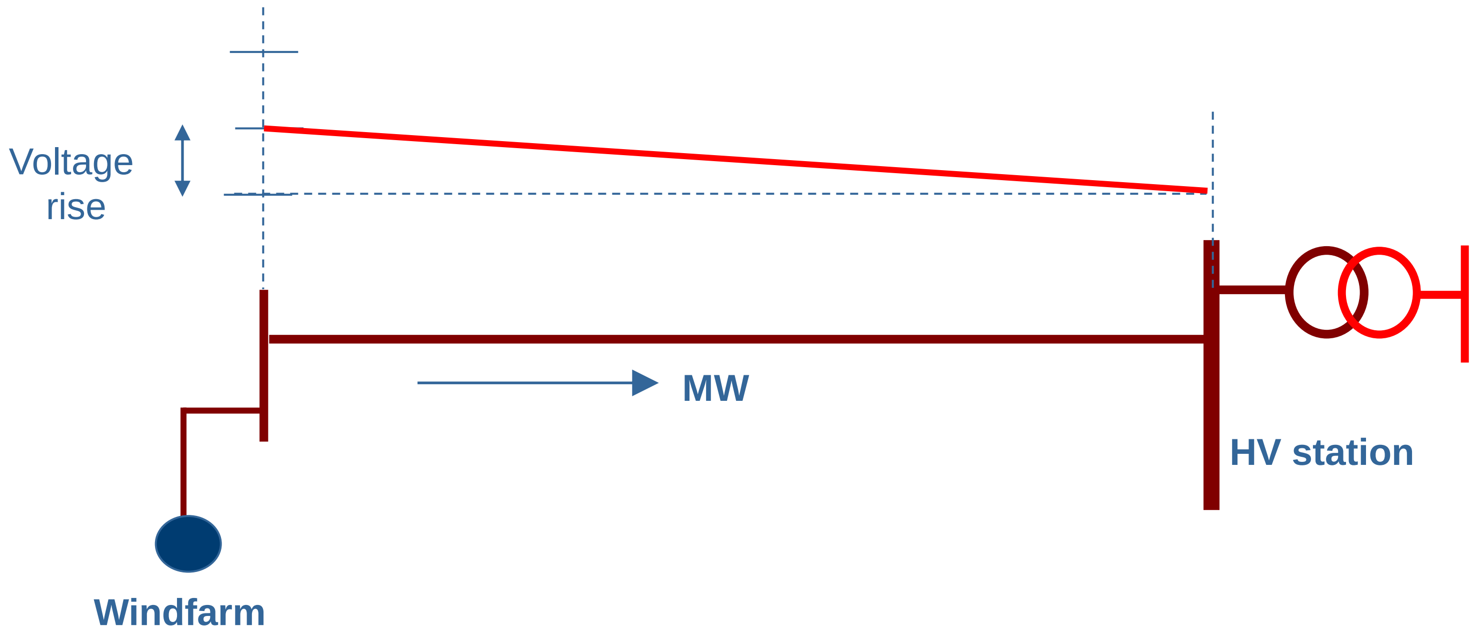
- **DSO License obligations**
  - Must keep all customers terminal voltage within limits [EN 50160] at all times
  - Must keep all network voltages within operational limits
  - Must minimise distribution network losses
- **Varying degrees of embedding in Distribution System**
- **Varying topologies**
- **Interaction with existing Distribution Plant**
- **Interaction with demand**
- **Voltage Range differences**

Varying degrees of embedding in Distribution System



“Traditional” Voltage Rise

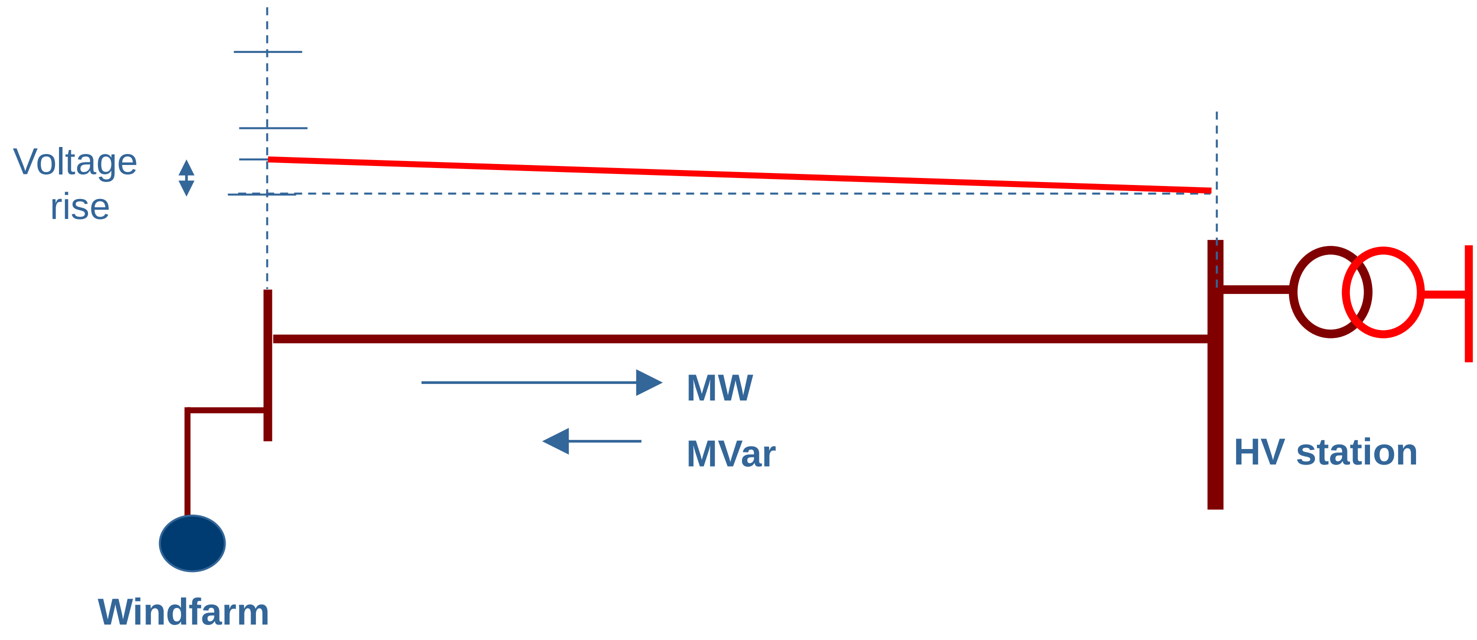
Traditional Voltage Rise



If Windfarm operates at unity Power Factor

– there is voltage rise along the feeder

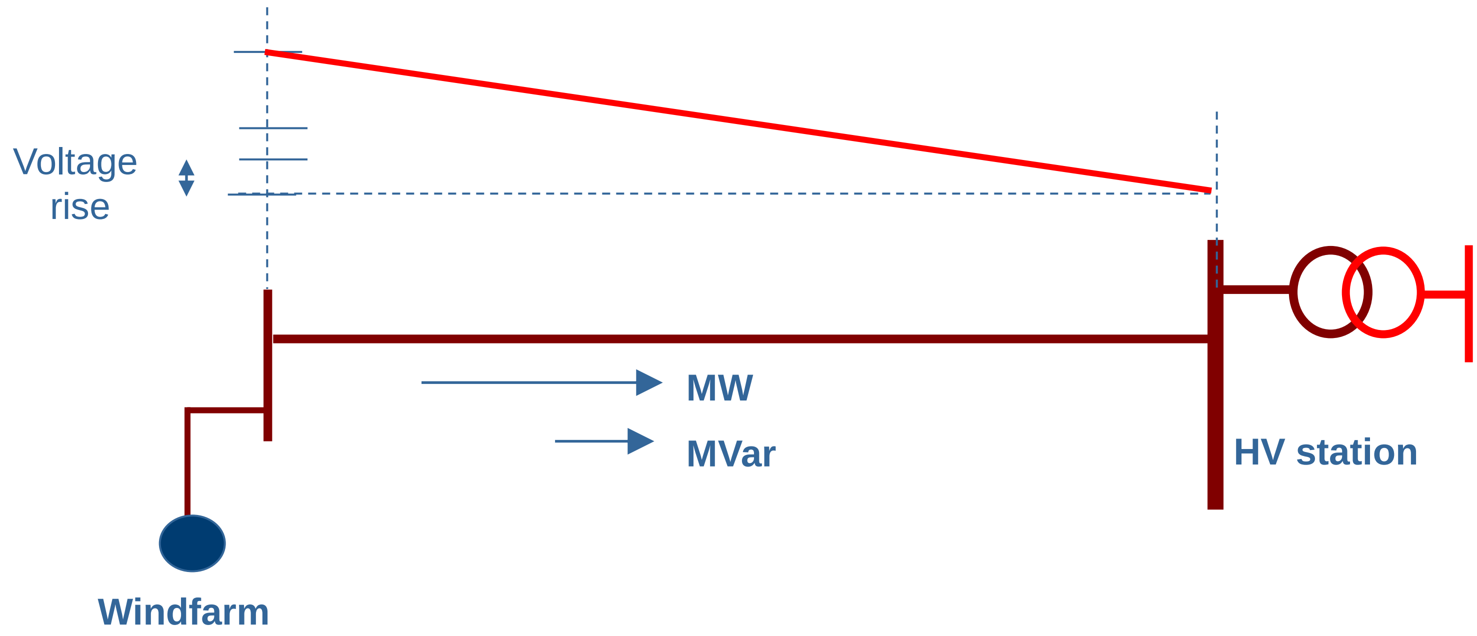
Traditional Voltage Rise



If Windfarm operates such as to import VArs

– Voltage drop due to MVAr offsets voltage rise due to MW

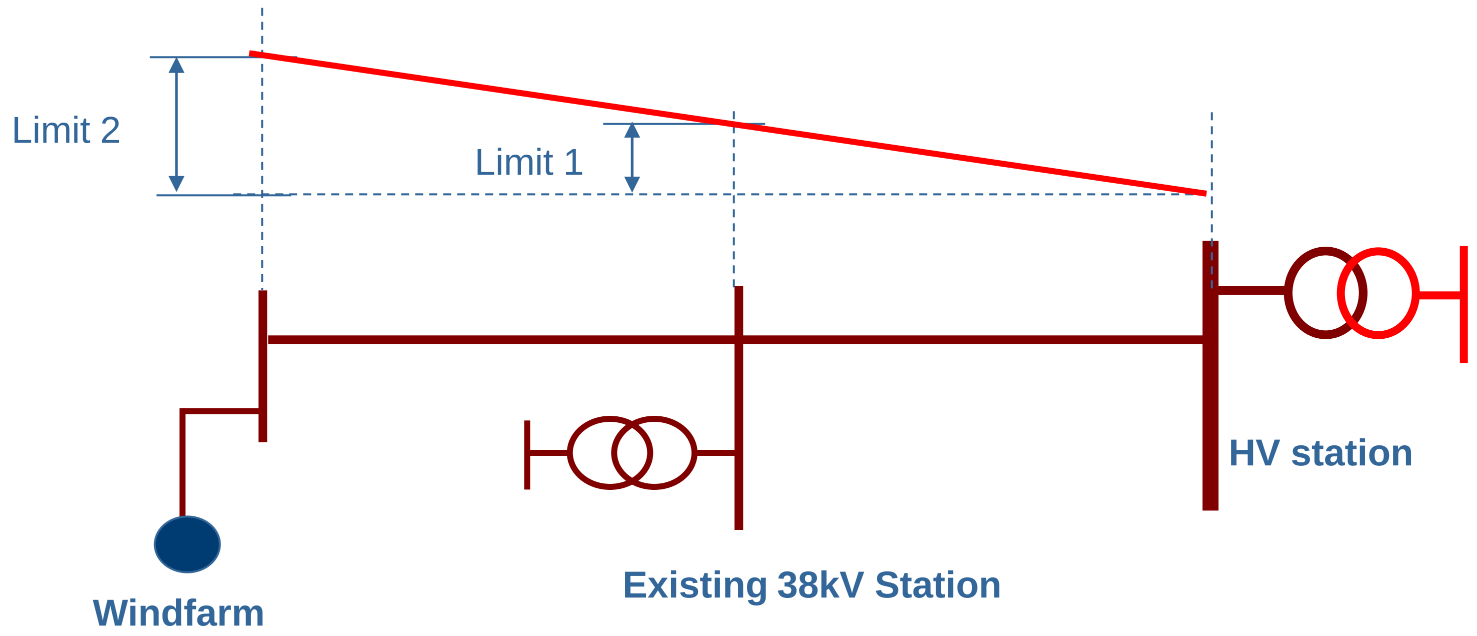
Traditional Voltage Rise



If Windfarm operates such as to export VArs

– Voltage rise due to MVAr adds to voltage rise due to MW

Traditional Voltage Rise



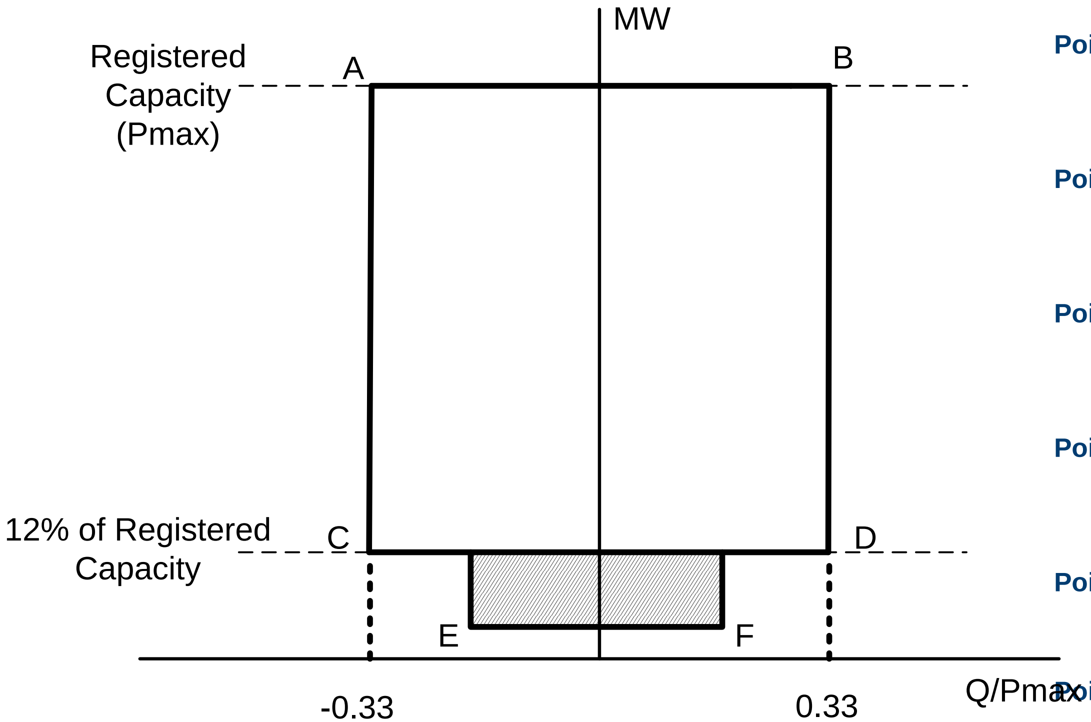
Limit 1 at load station dictated by tapping range on transformers

Limit 2 at Windfarm location can be higher

New tools at our disposal

Now and being contemplated for future use

Grid / Distribution Code Changes : Capability



Referring to *Figure WFPS1.4:*

Point A represents the minimum Mvar absorption capability of the Controllable WFPS at 100% Registered Capacity and is equivalent to 0.95 power factor leading;

Point B represents the minimum Mvar production capability of the Controllable WFPS at 100% Registered Capacity and is equivalent to 0.95 power factor lagging;

Point C represents the minimum Mvar absorption capability of the Controllable WFPS at 12% Registered Capacity and is equivalent to the same Mvar as Point A;

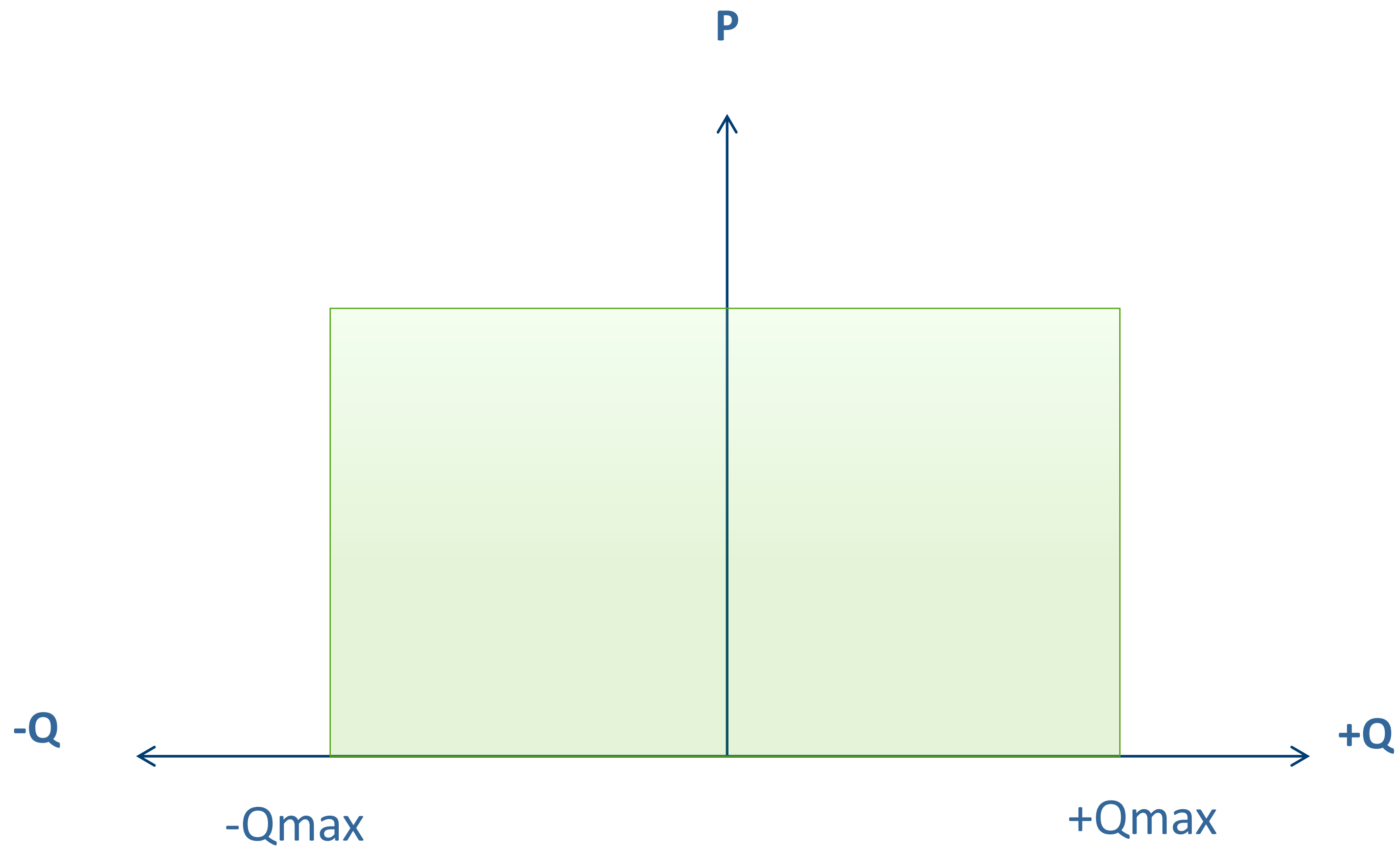
Point D represents the minimum Mvar production capability of the Controllable WFPS at 12% Registered Capacity and is equivalent to the same Mvar as Point B;

Point E represents the minimum Mvar absorption capability of the Controllable WFPS at the cut-in speed of the individual WTGs;

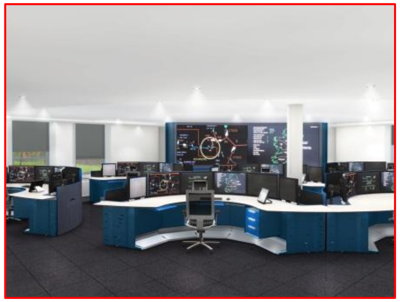
Point F represents the minimum Mvar production capability of the Controllable WFPS at the cut-in speed of the individual WTGs;

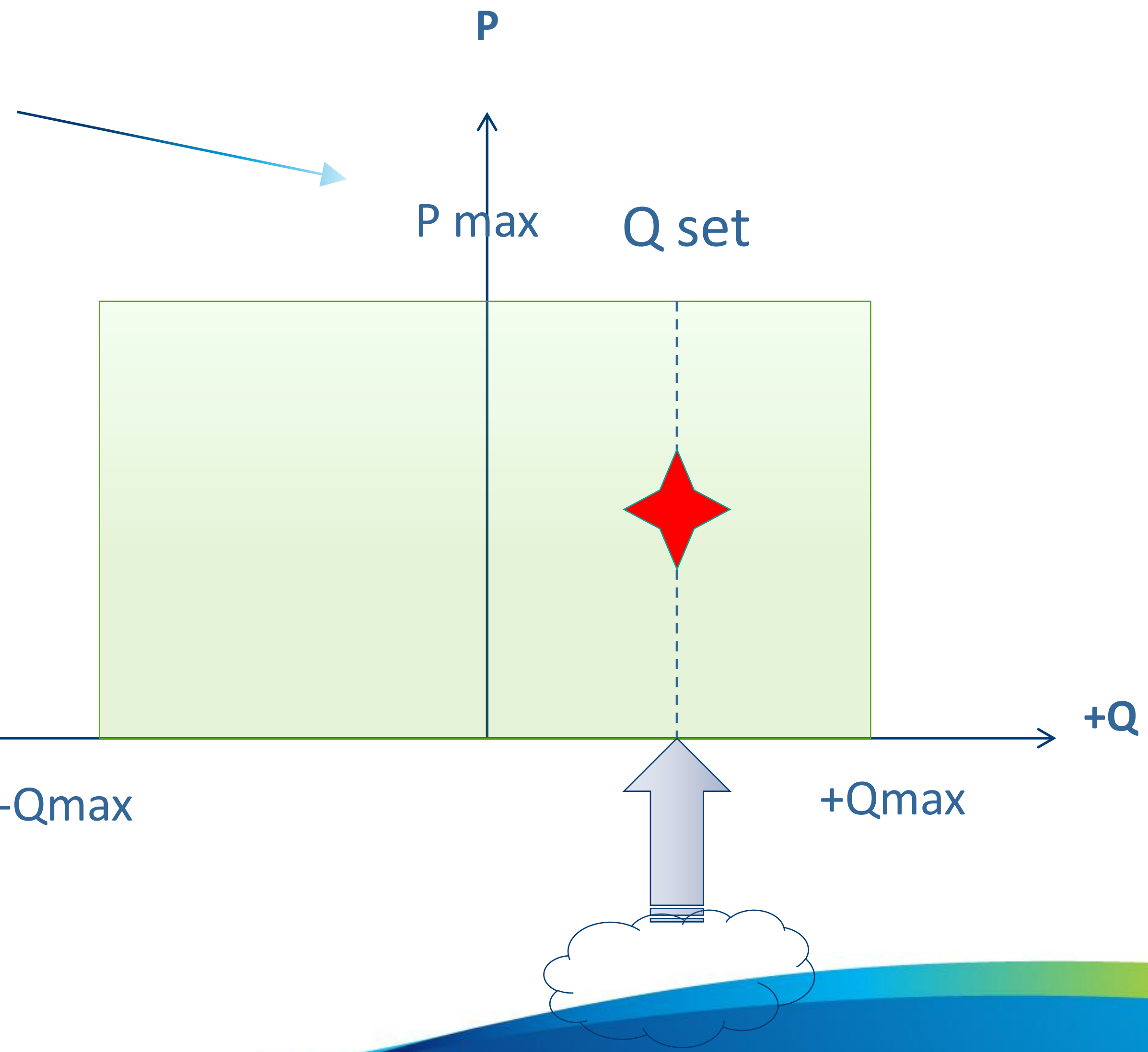
The TSO accepts that the values of Points E and F may vary depending on the number of WTGs generating electricity in a low-wind scenario;

Changes pending: Control modes

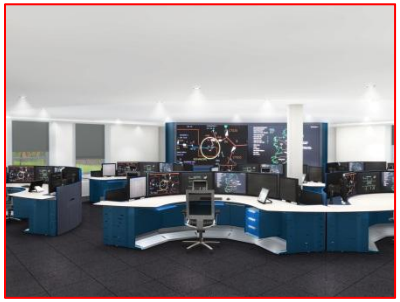


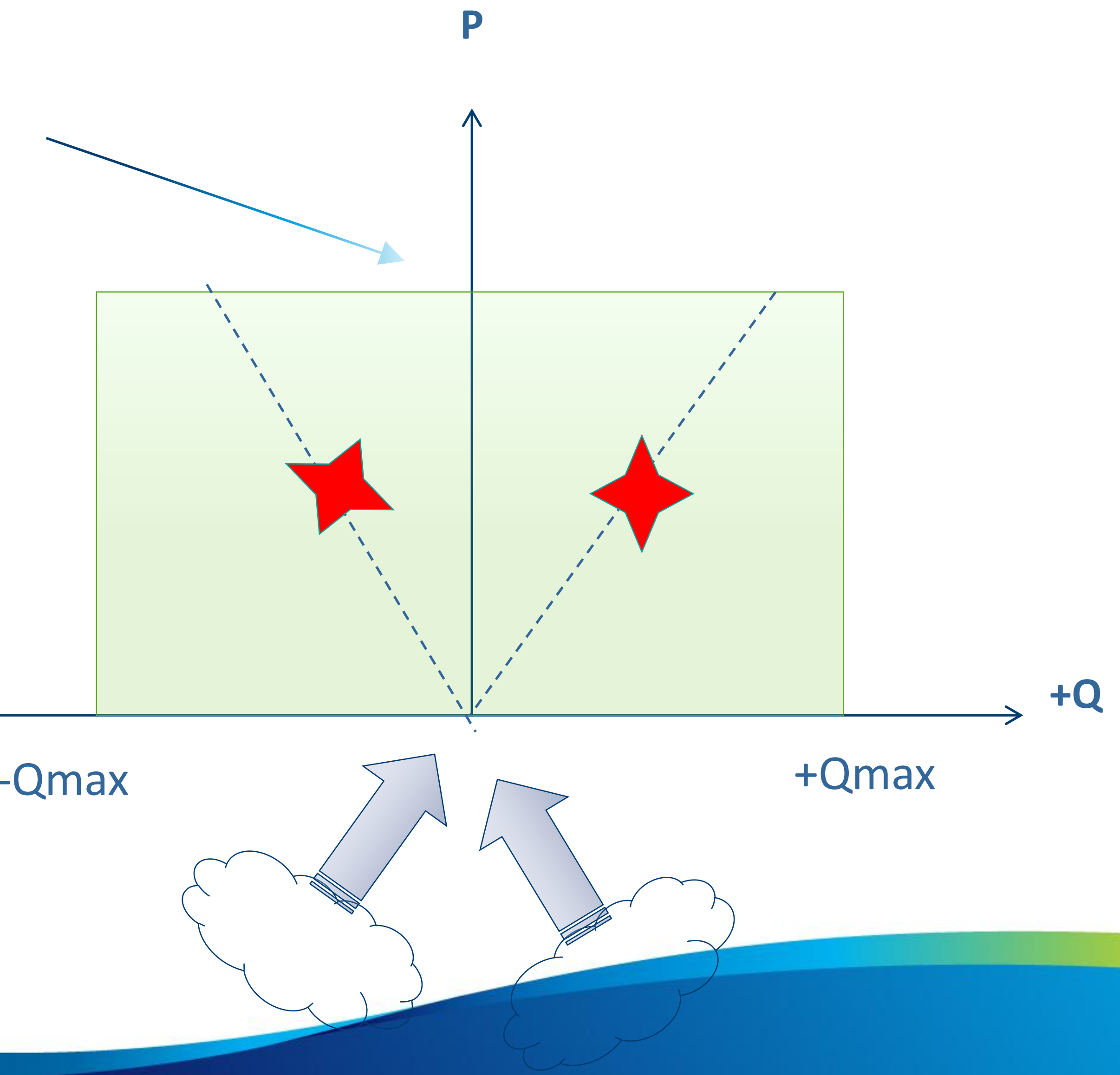
Q mode



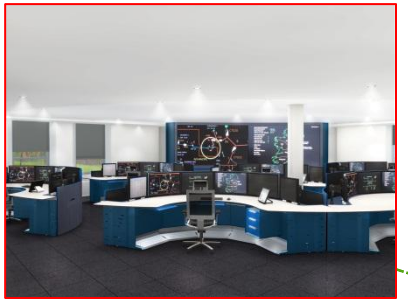


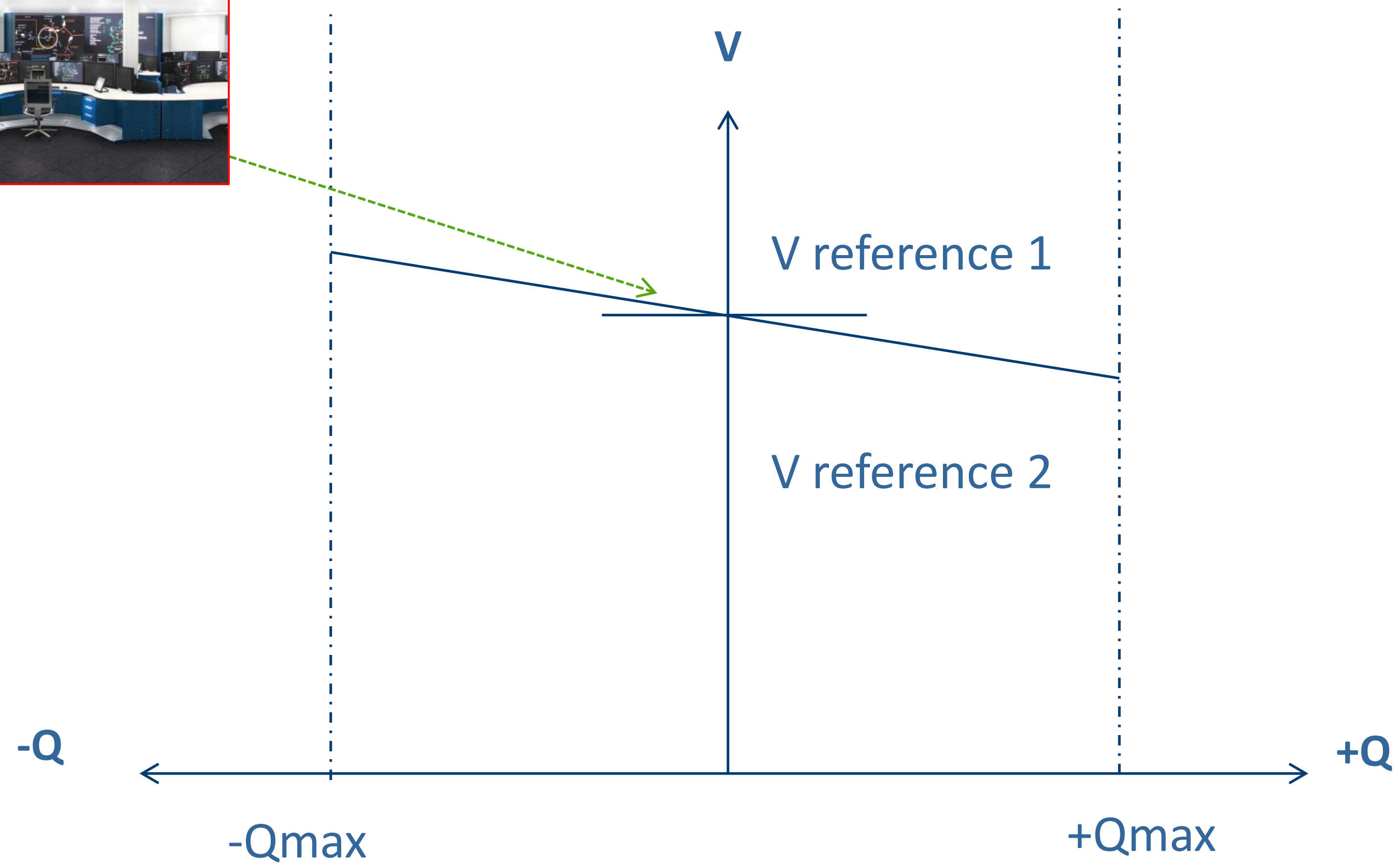
Power Factor mode

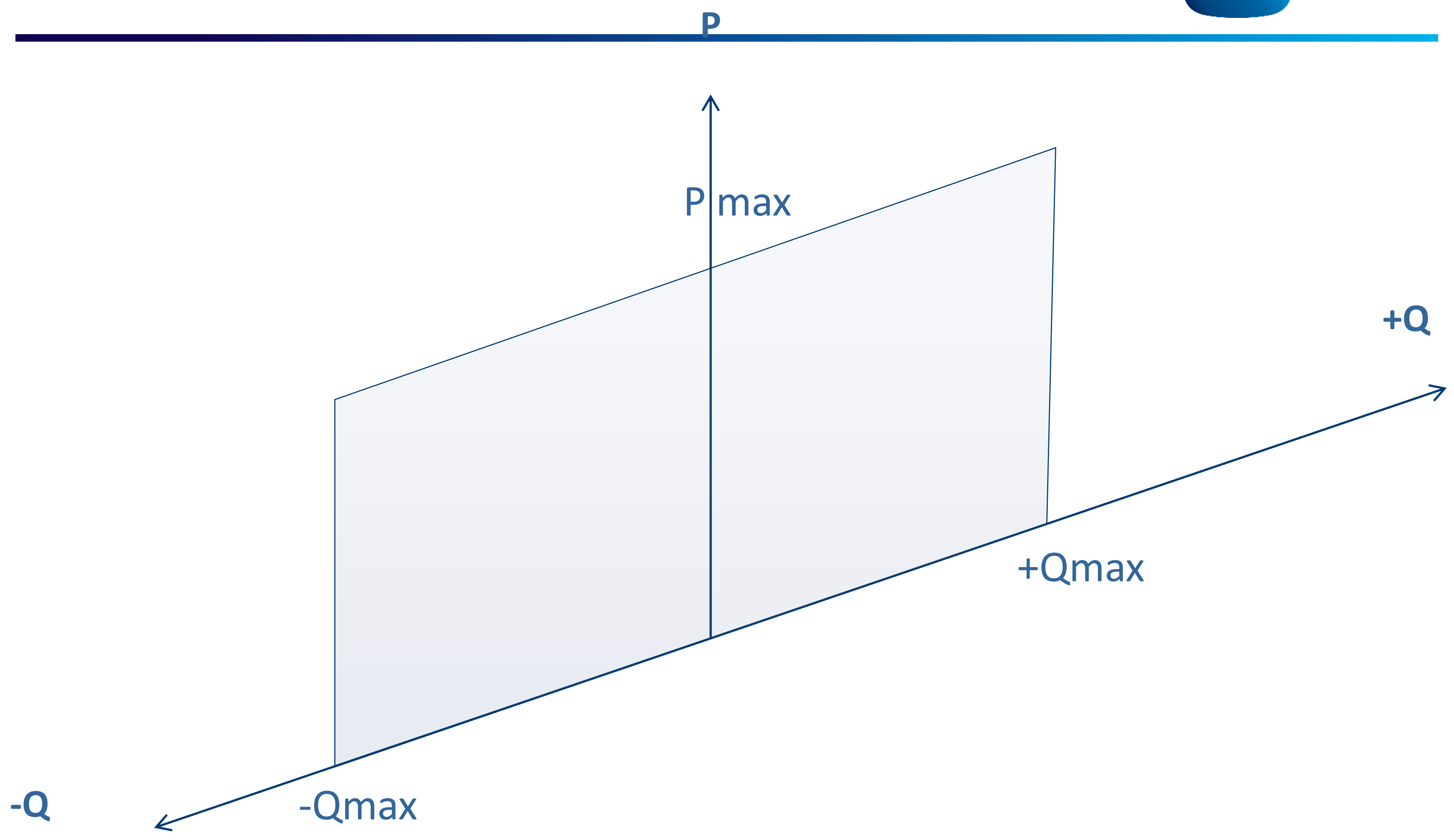


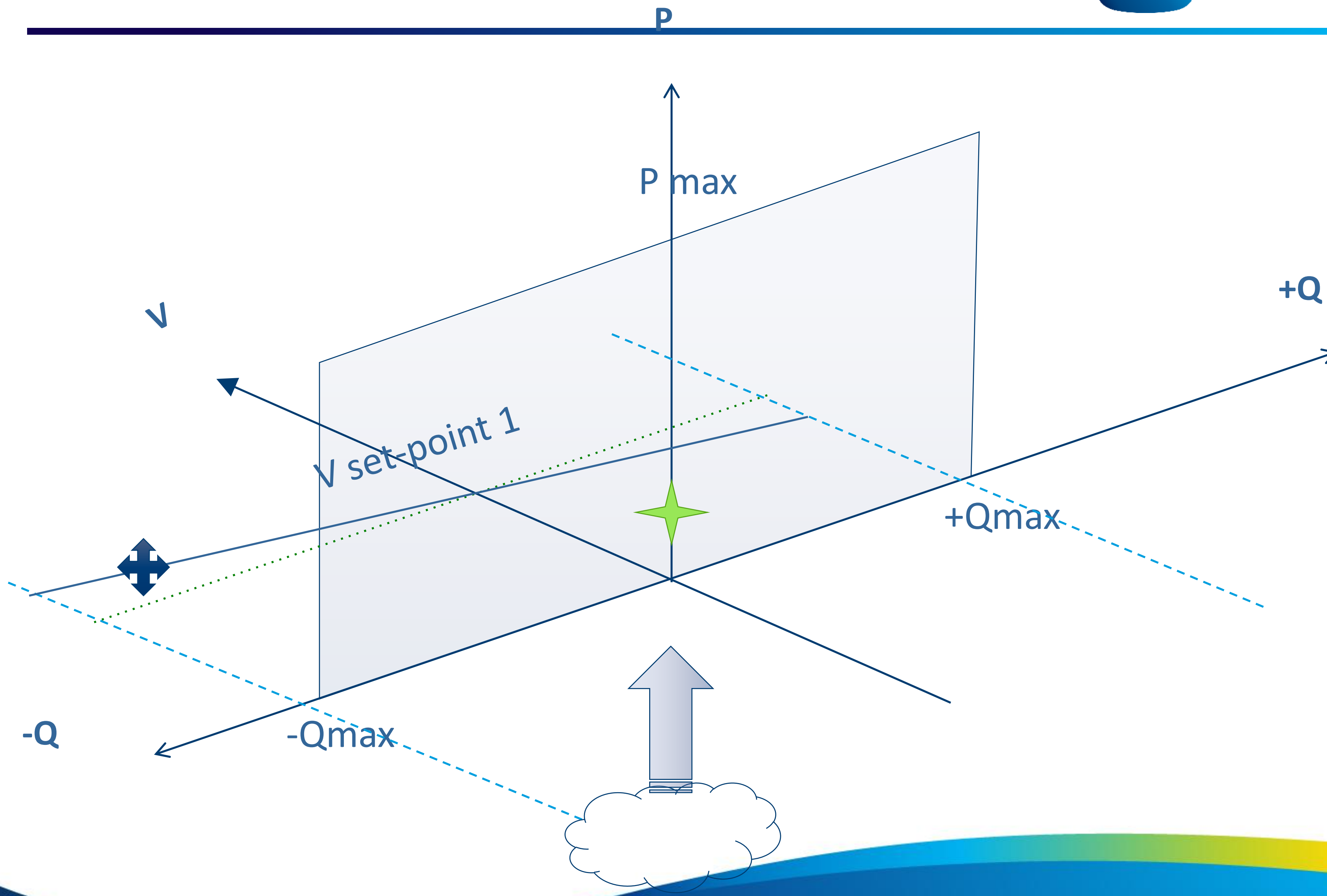


Voltage Control





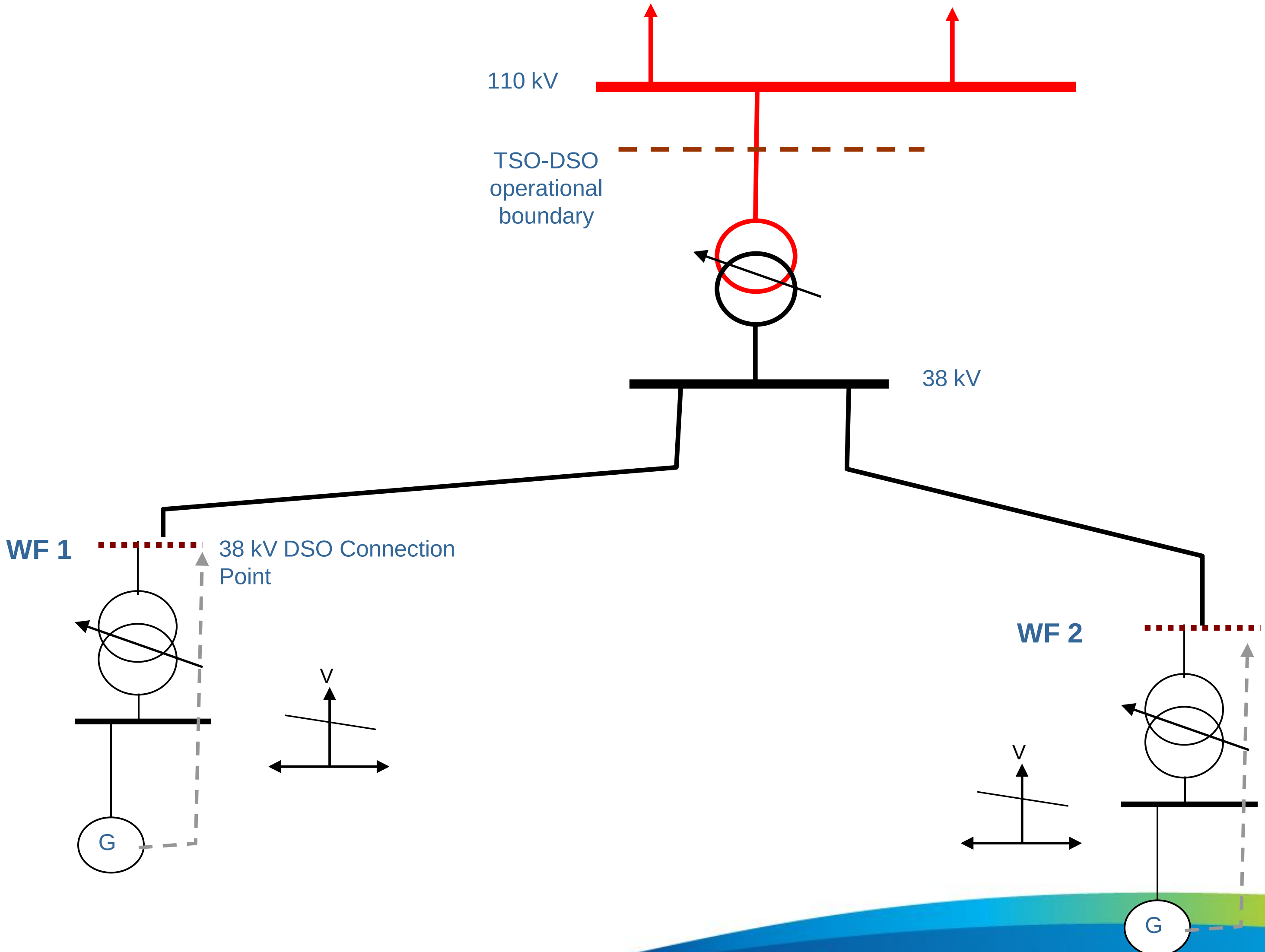

P
P max
+Q
+Qmax
-Q
-Qmax


P
P max
+Q
V
V set-point 1
+Qmax
-Q
-Qmax

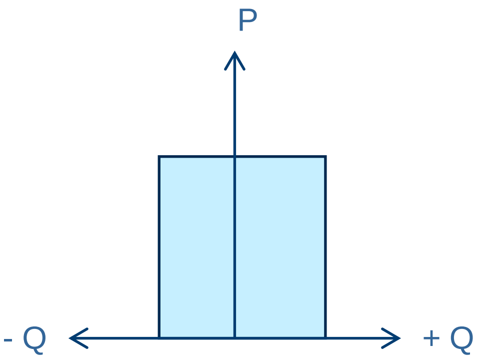
Reactive Range and visibility

Can this be applied to a distribution wind cluster?

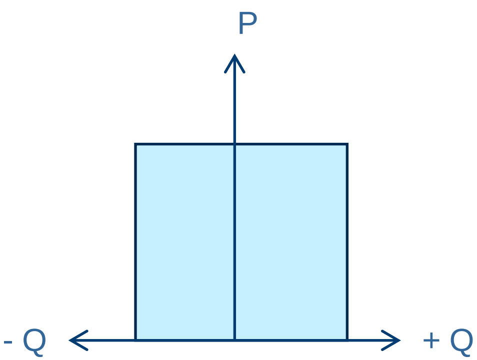
ESB NETWORKS



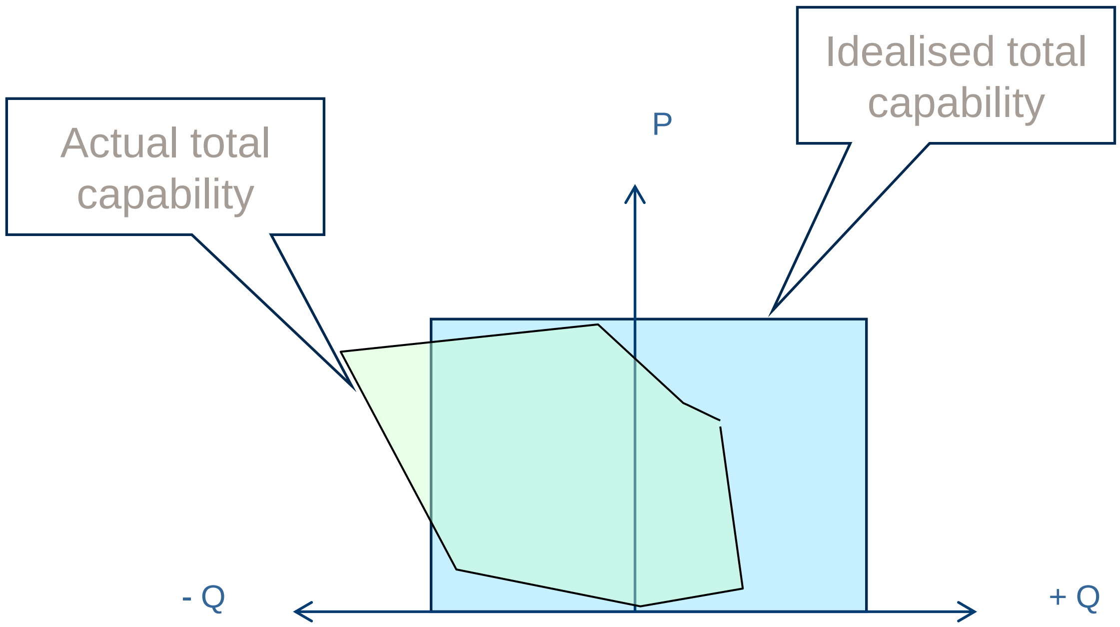
2 + 2 may not equal 4



WF 1

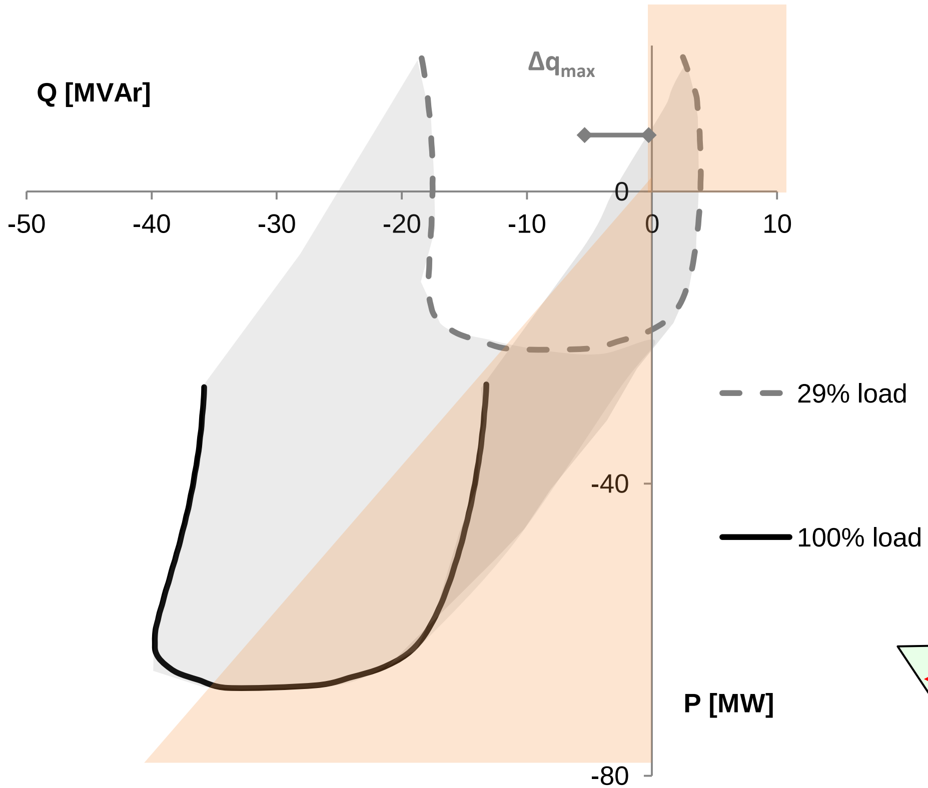


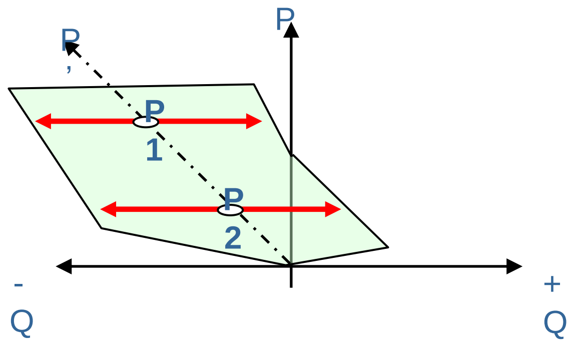
WF 2



Composite at TSO-DSO Interface

Interaction with Demand Load





Voltage Range differences

Tap 1

Tap 9

Tx KV %	TX KV
112	123.2
111	122.1
110	121
109	119.9
108	118.8
107	117.7
106	116.6
105	115.5
104	114.4
103	113.3
102	112.2
101.5	111.65
101	111.1
100.5	110.55
100	110
99.5	109.45
99	108.9
98.5	108.35
98	107.8
97	106.7
96	105.6
95	104.5
94	103.4
93	102.3
92	101.2
91	100.1
90	99
89	97.9
88	96.8
87	95.7
86	94.6
85	93.5
84	92.4
83	91.3
82	90.2
81	89.1
80	88
79	86.9
78	85.8
77	84.7

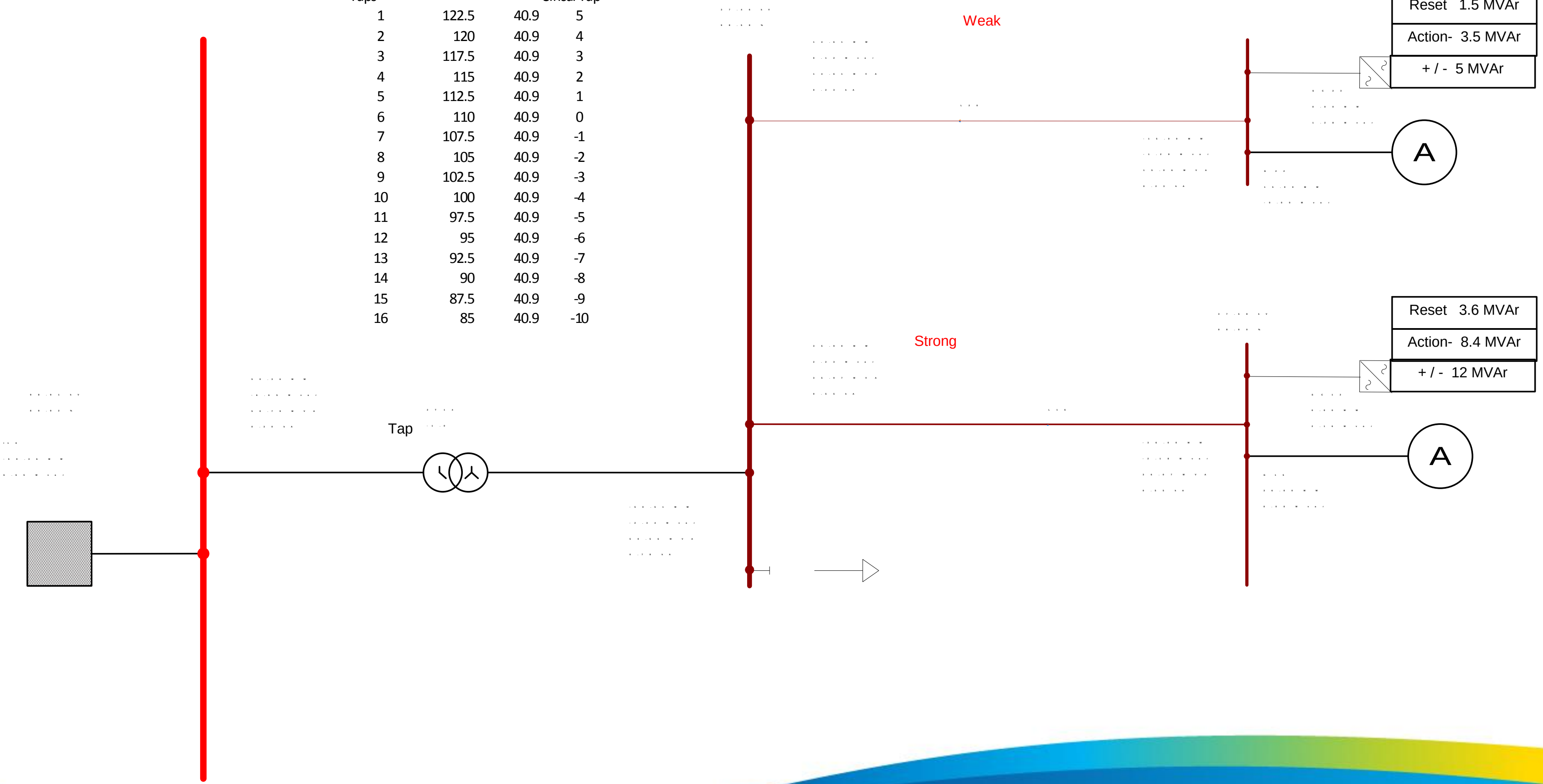
MV KV %	MV KV
113	22.6
112	22.4
111	22.2
110	22
109	21.8
108	21.6
107	21.4
106	21.2
105	21
104	20.8
103	20.6
102	20.4
101	20.2
100	20
99	19.8
98	19.6
97	19.4

Example of inter-windfarm interaction for Cluster scenario

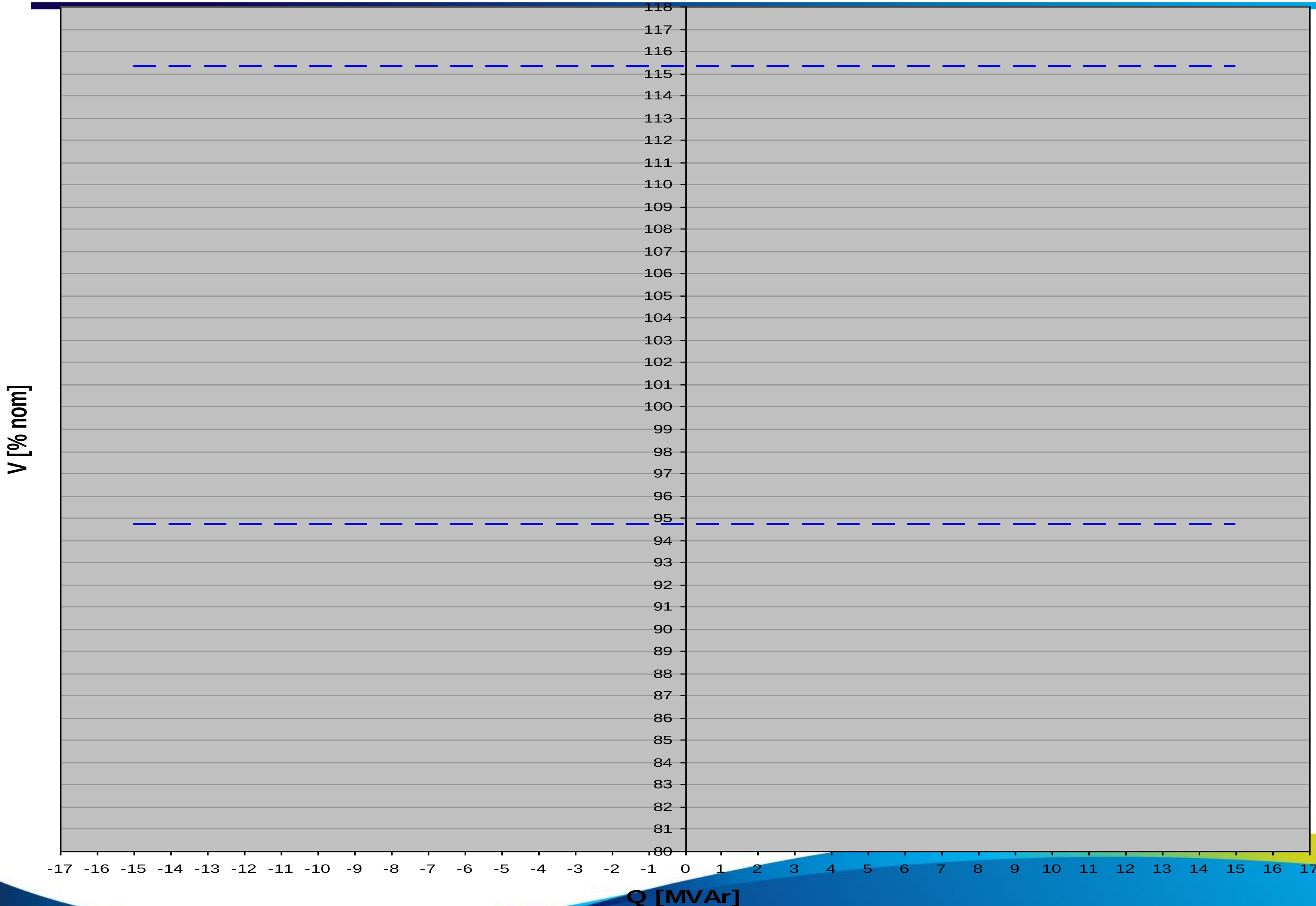
Case 3: Strong and weak on same trafo

110kV/38kV trafo Standard

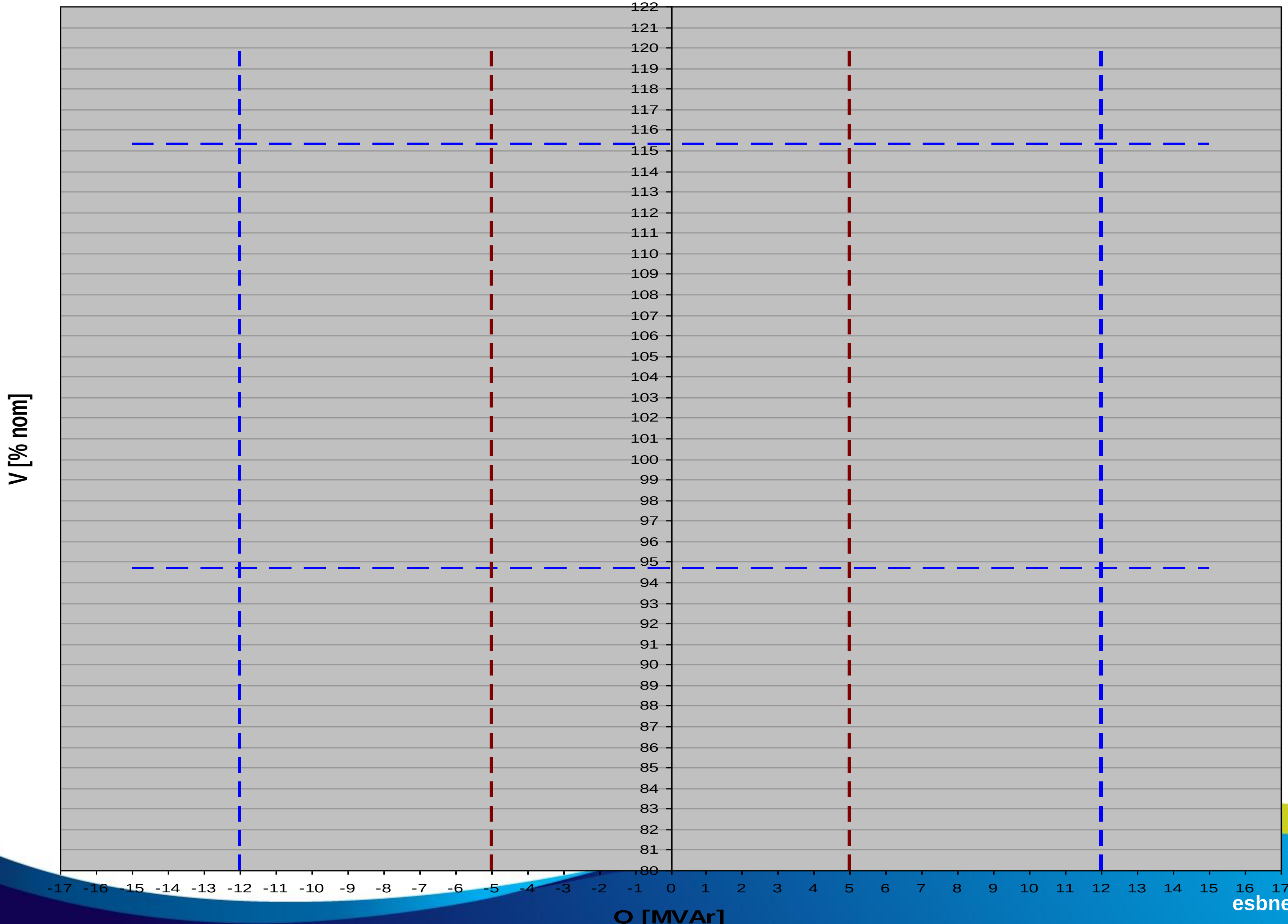
Taps			Sincal Tap
1	122.5	40.9	5
2	120	40.9	4
3	117.5	40.9	3
4	115	40.9	2
5	112.5	40.9	1
6	110	40.9	0
7	107.5	40.9	-1
8	105	40.9	-2
9	102.5	40.9	-3
10	100	40.9	-4
11	97.5	40.9	-5
12	95	40.9	-6
13	92.5	40.9	-7
14	90	40.9	-8
15	87.5	40.9	-9
16	85	40.9	-10



Case 3: Strong and weak on same trafo



Case 3: Strong and weak on same trafo



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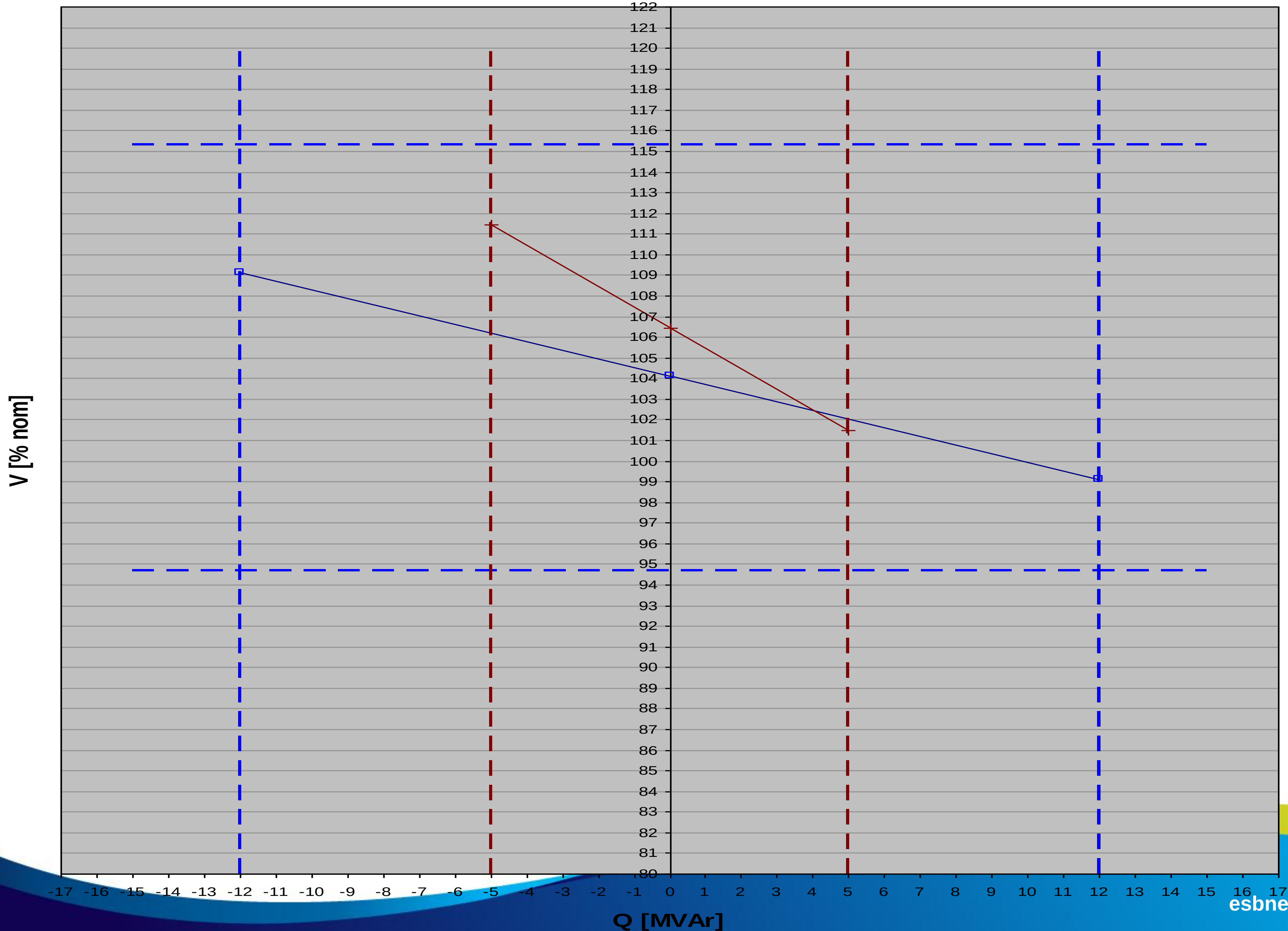
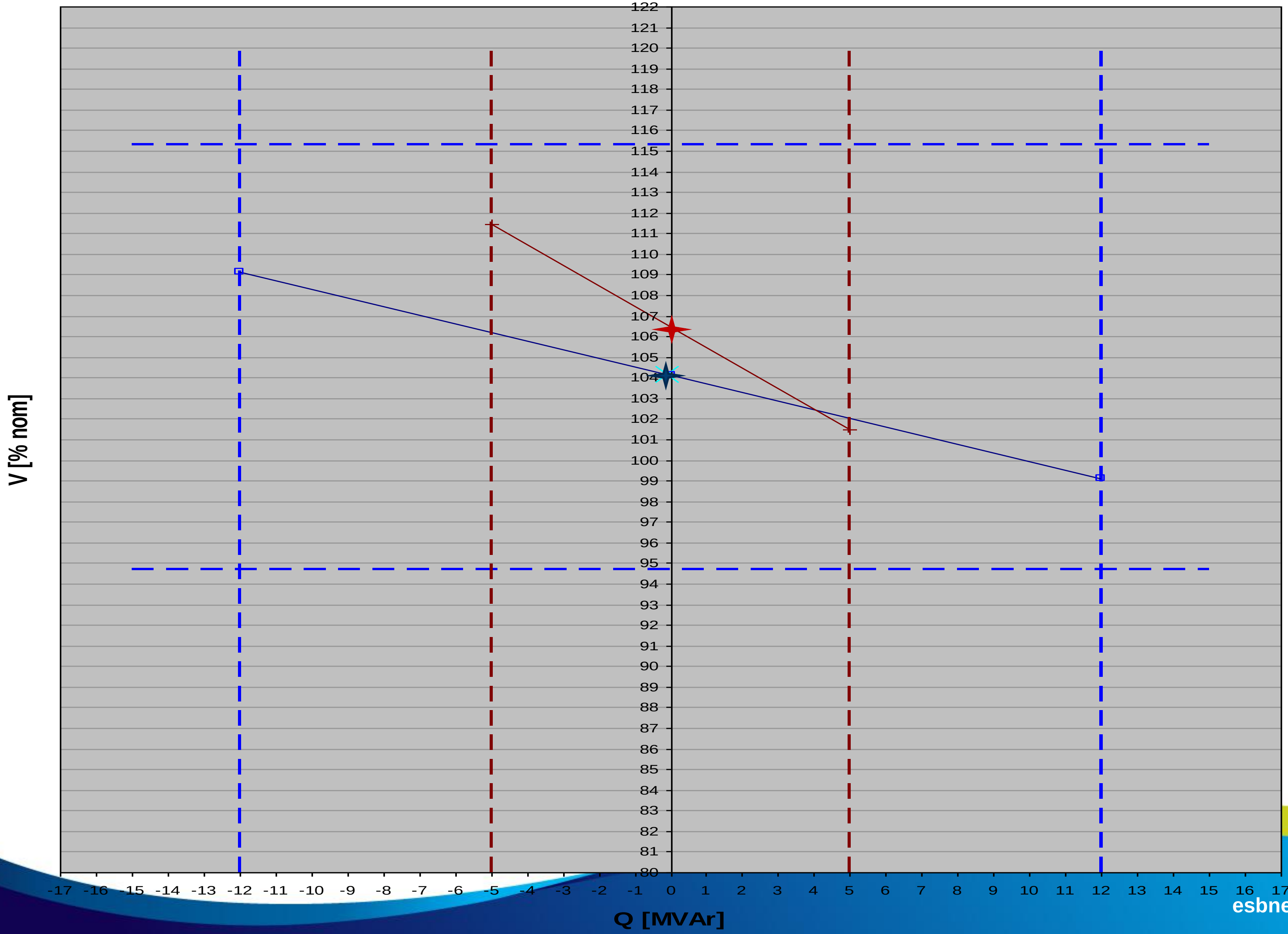
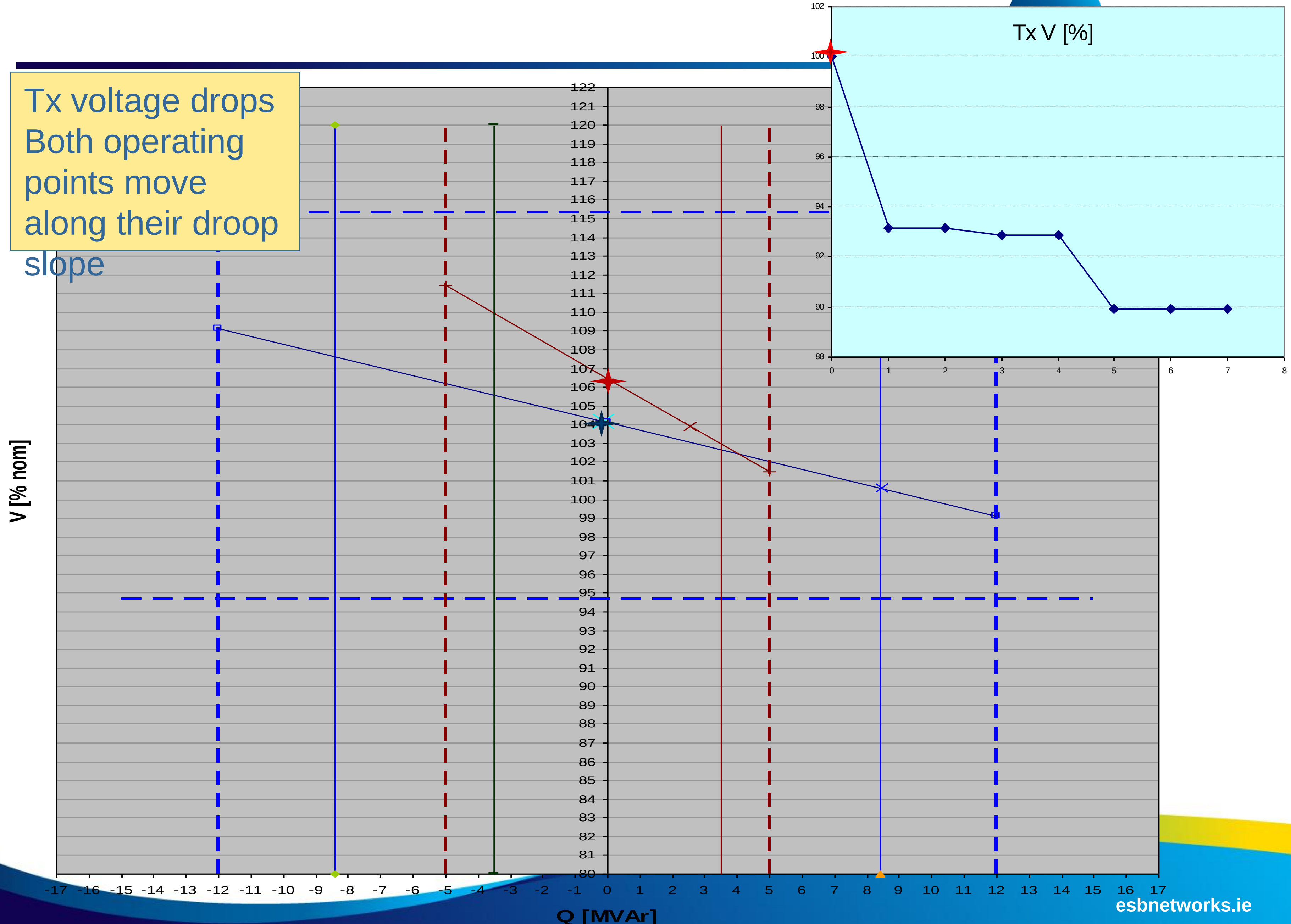


Case 3: Strong and weak on same trafo



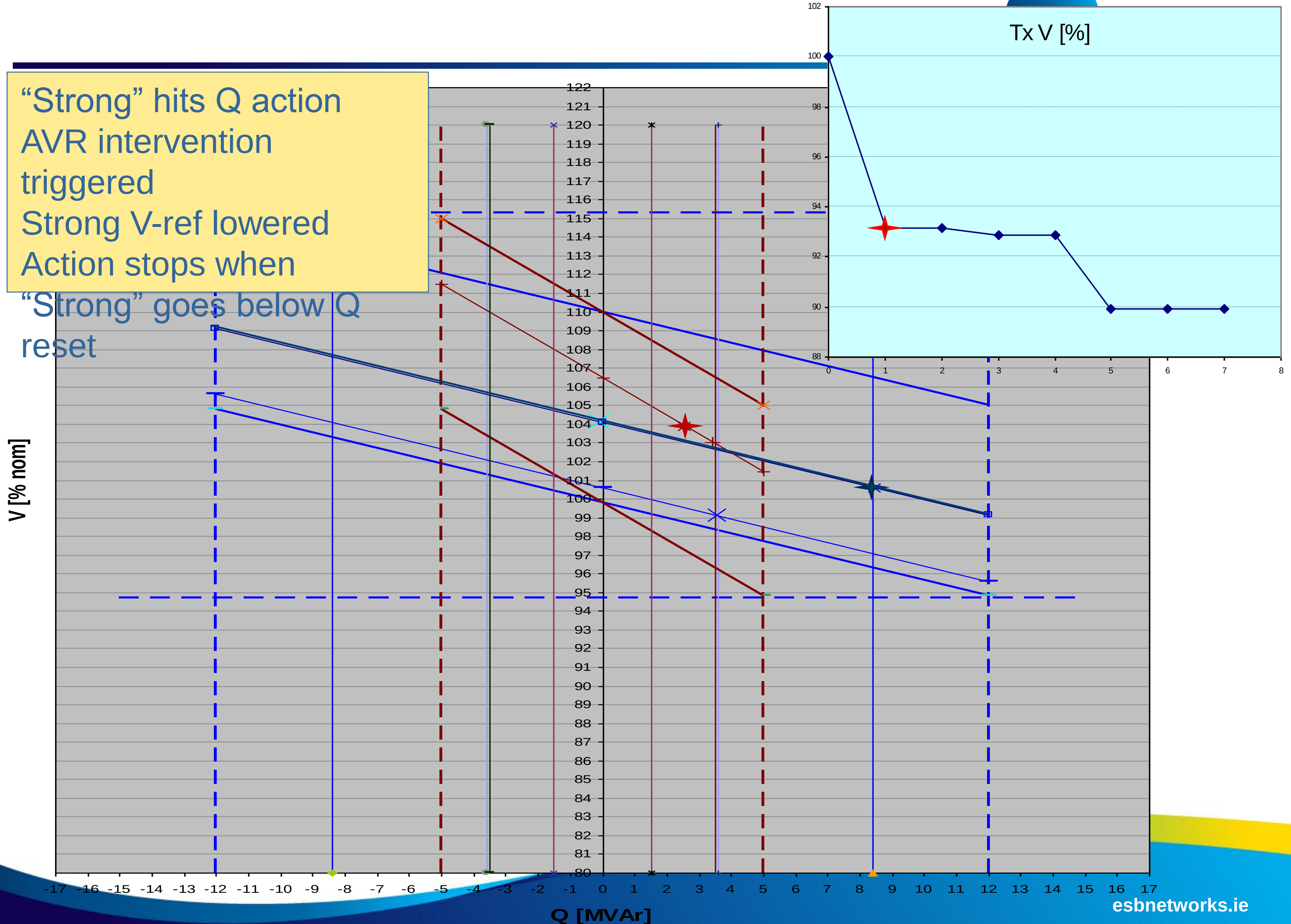
Case 3: Strong and weak on same trafo

Tx voltage drops
Both operating points move along their droop slope



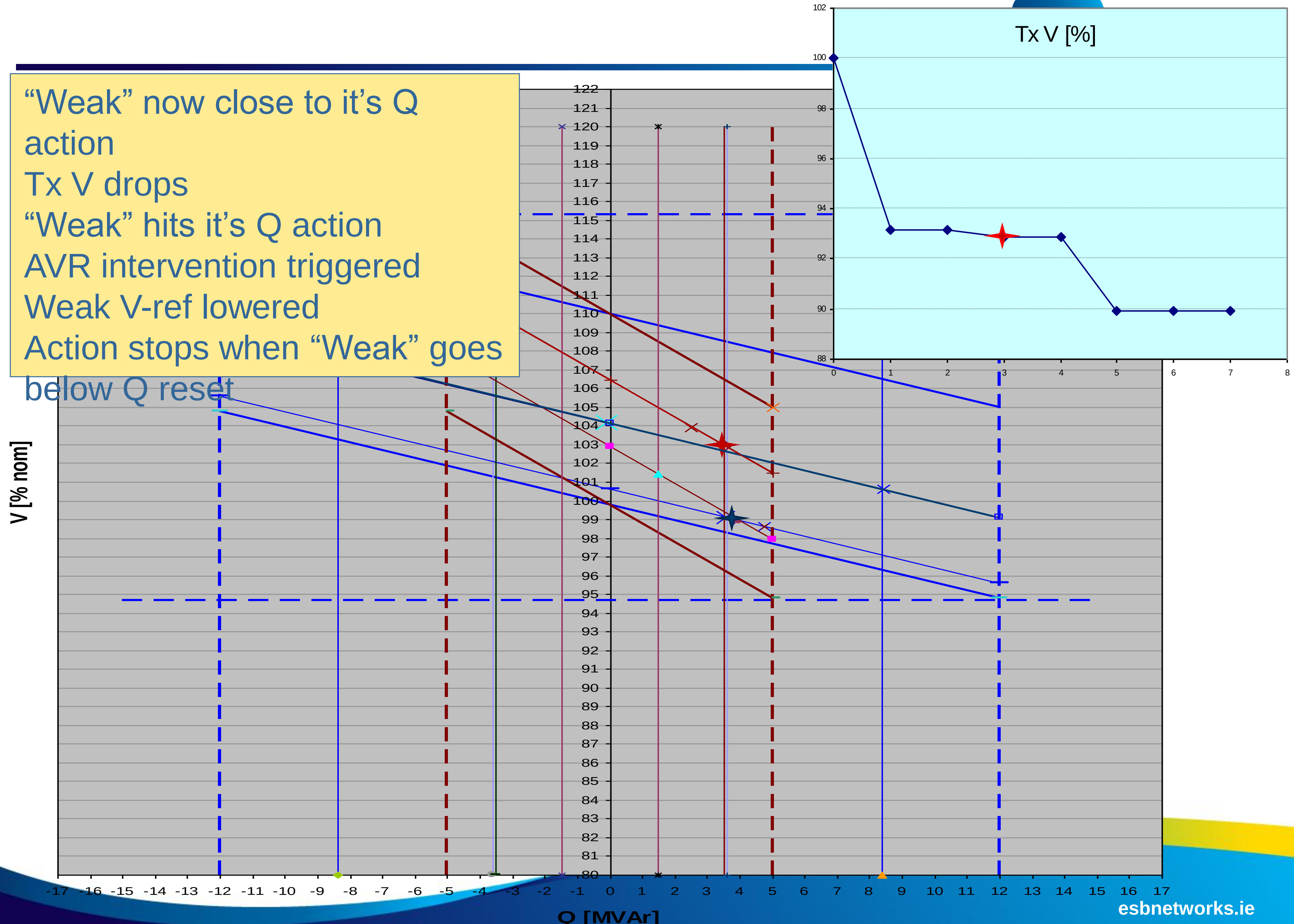
Case 3: Strong and weak on same trafo

"Strong" hits Q action
AVR intervention triggered
Strong V-ref lowered
Action stops when "Strong" goes below Q reset



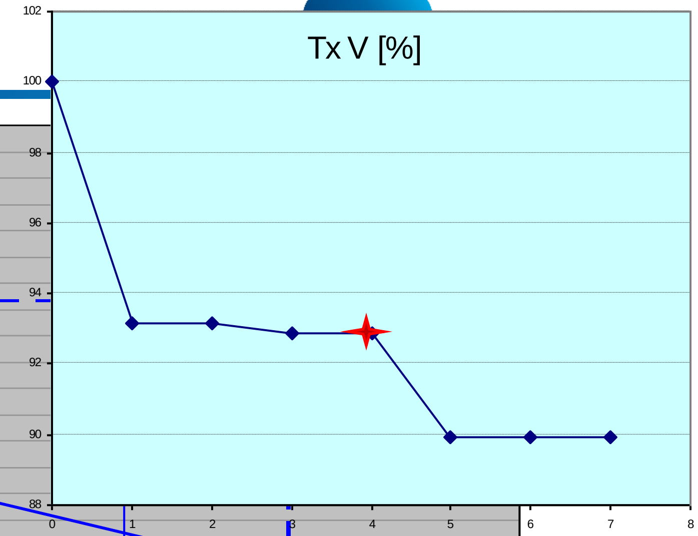
Case 3: Strong and weak on same trafo

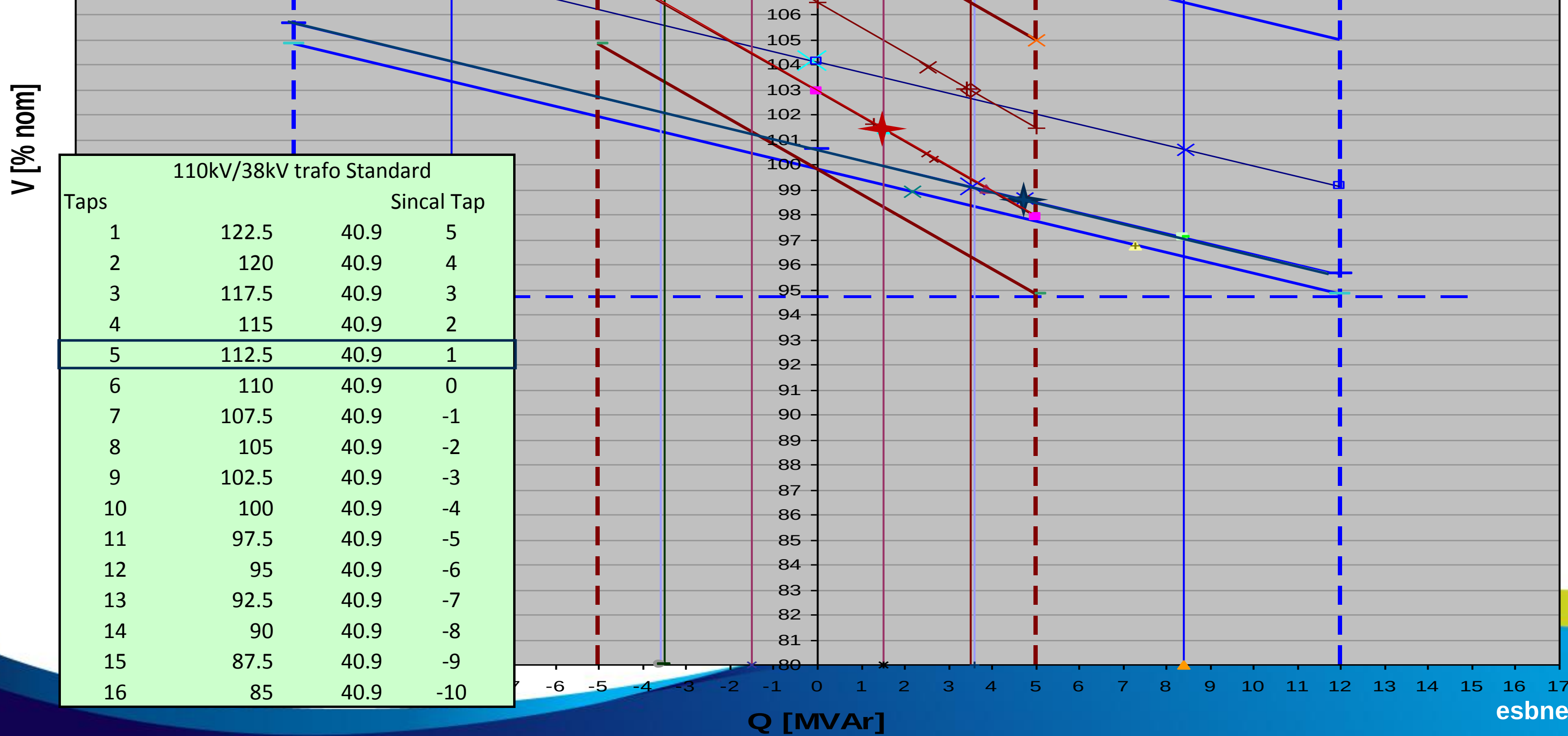
"Weak" now close to it's Q action
Tx V drops
"Weak" hits it's Q action
AVR intervention triggered
Weak V-ref lowered
Action stops when "Weak" goes below Q reset



Case 3: Strong and weak on same trafo

Tx V drops further
“strong” once again hits Q action
AVR intervention triggered
V ref lowered but hits V min
Tap change initiated
Tap until either or both come below Q reset





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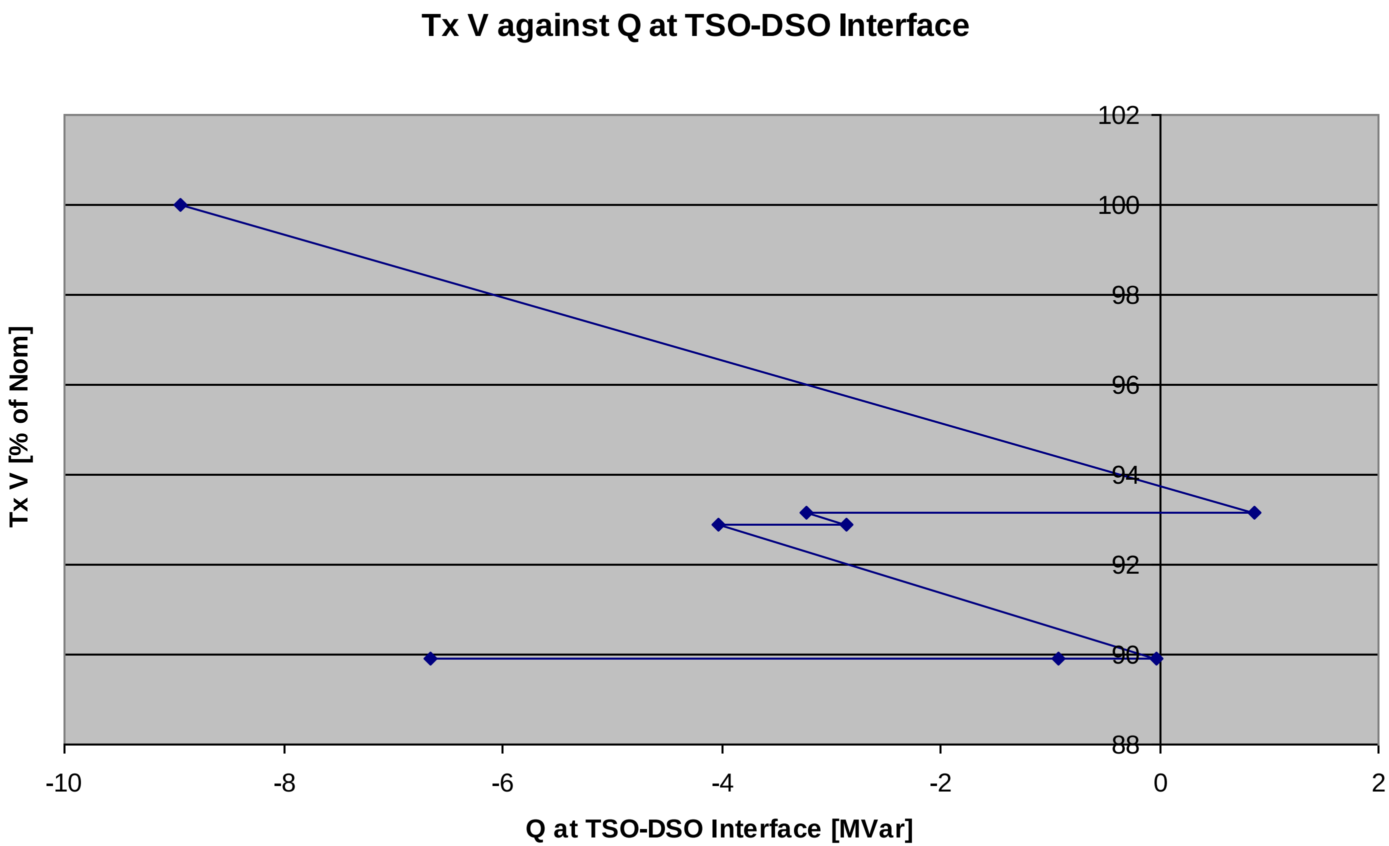
Q /V at TSO-DSO Interface



Questions ?

Managing Voltage Control on a Power System with High Renewable Penetration

RANGE OF SOLUTIONS

Andrew Keane

Managing reactive power on power systems with high renewable penetration

Range of Possible Solutions

December 2013

Dr Andrew Keane
University College Dublin

Reactive Power/Voltage Control

- Function traditionally taken care of by synchronous generators and capacitor banks
  - In some cases FACTs devices also employed

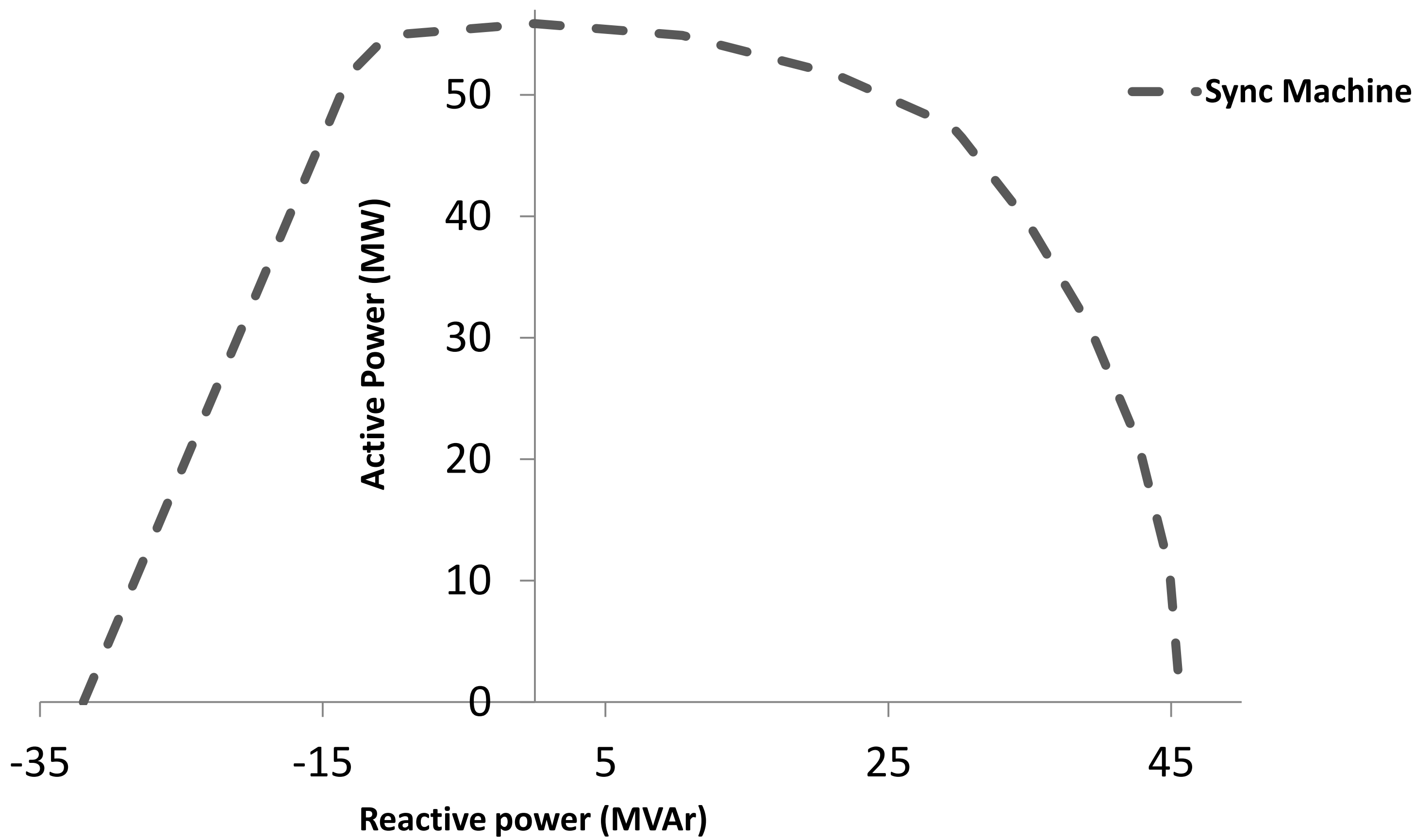
- At distribution level tap changers play a big role

Changing Circumstances

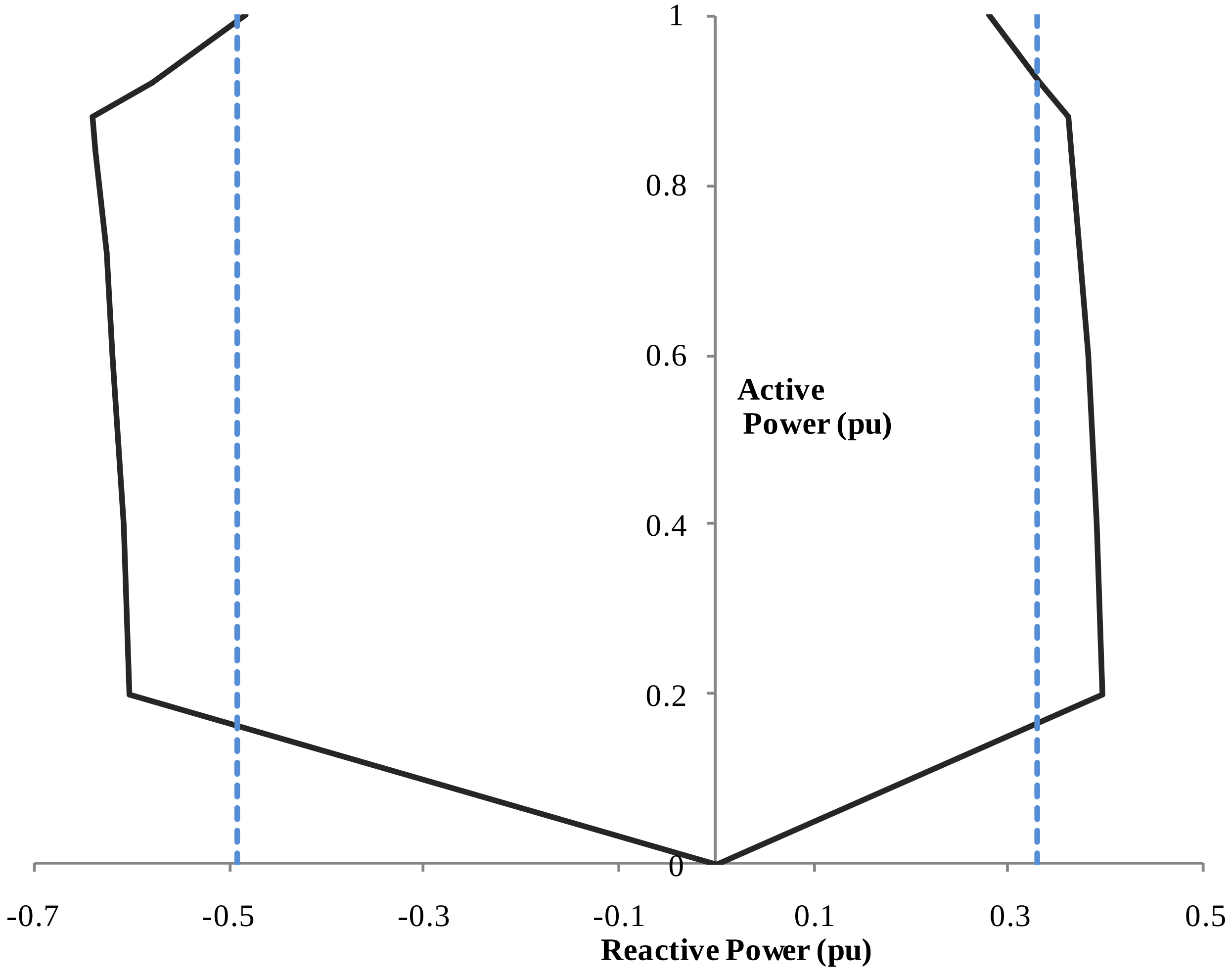
1. Renewable generation causing displacement of conventional generators

2. Renewable generation connecting to distribution system

Synchronous Machine Capability

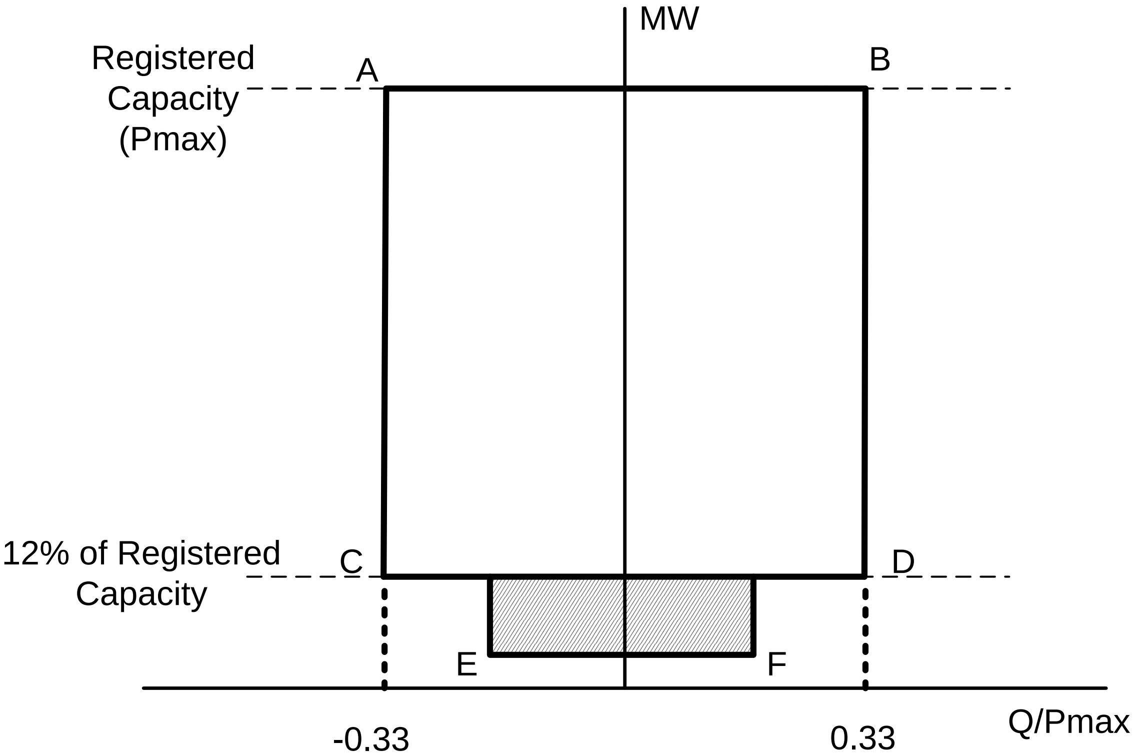


Wind P-Q Capability



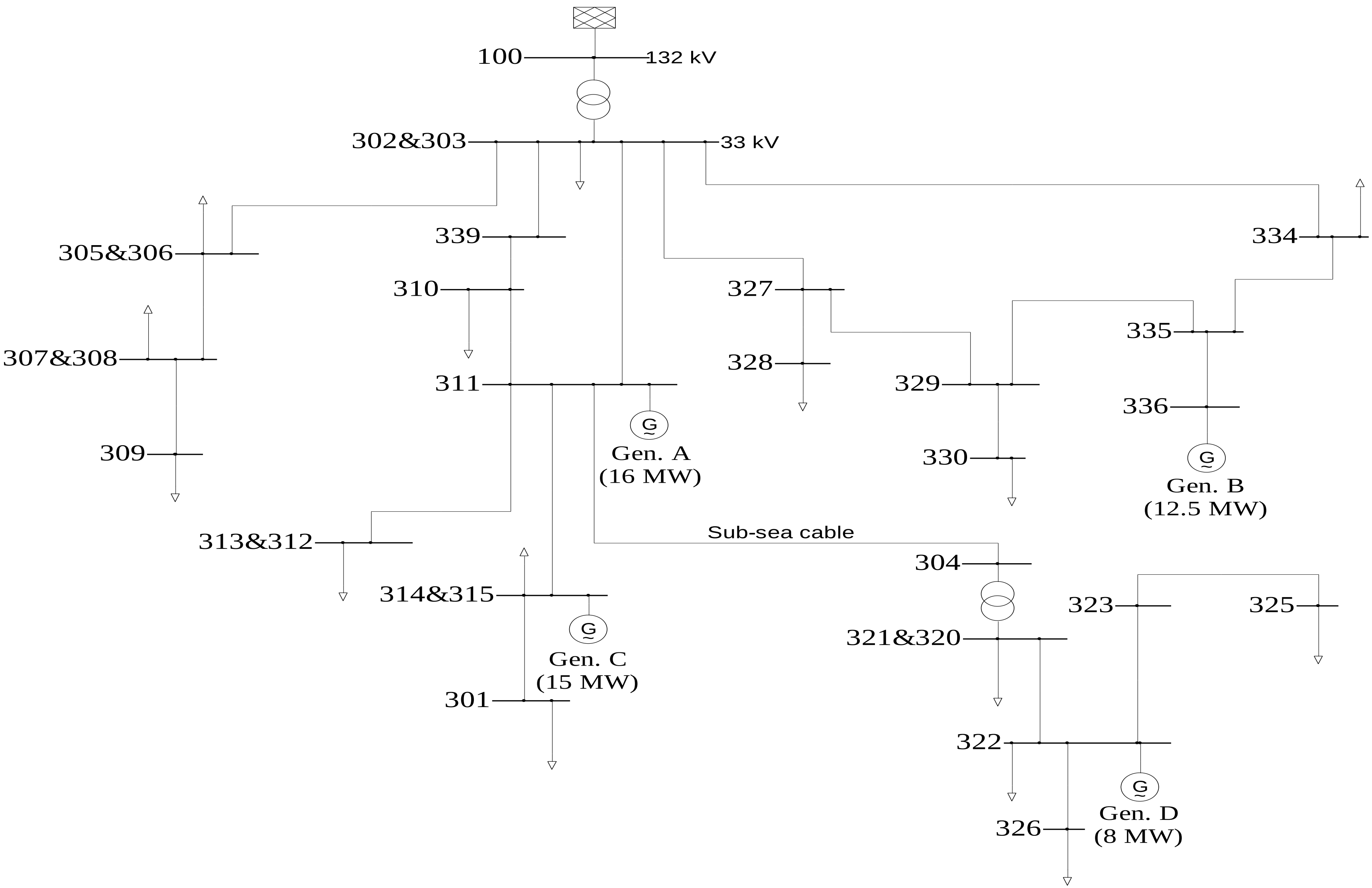
What can wind do?

- Grid code requirements

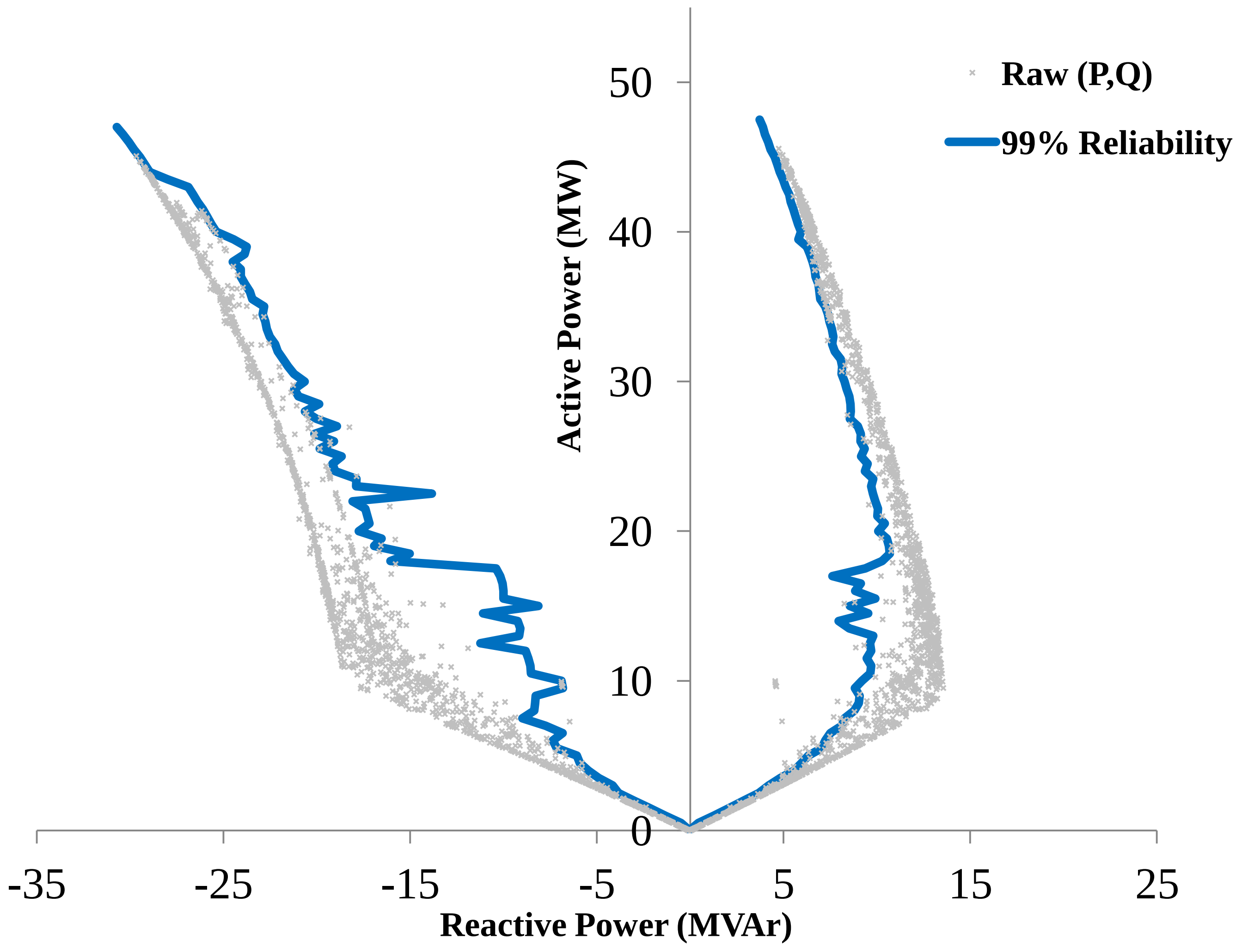


- Const. PF
- Const. V
- Const. Q

Distributed Generation



Distribution/Transmission Interface



Cuffe, P., Smith, P. And Keane A., "**Capability Chart for Distributed Reactive Power Resources**", IEEE Transactions on Power Systems, 2013

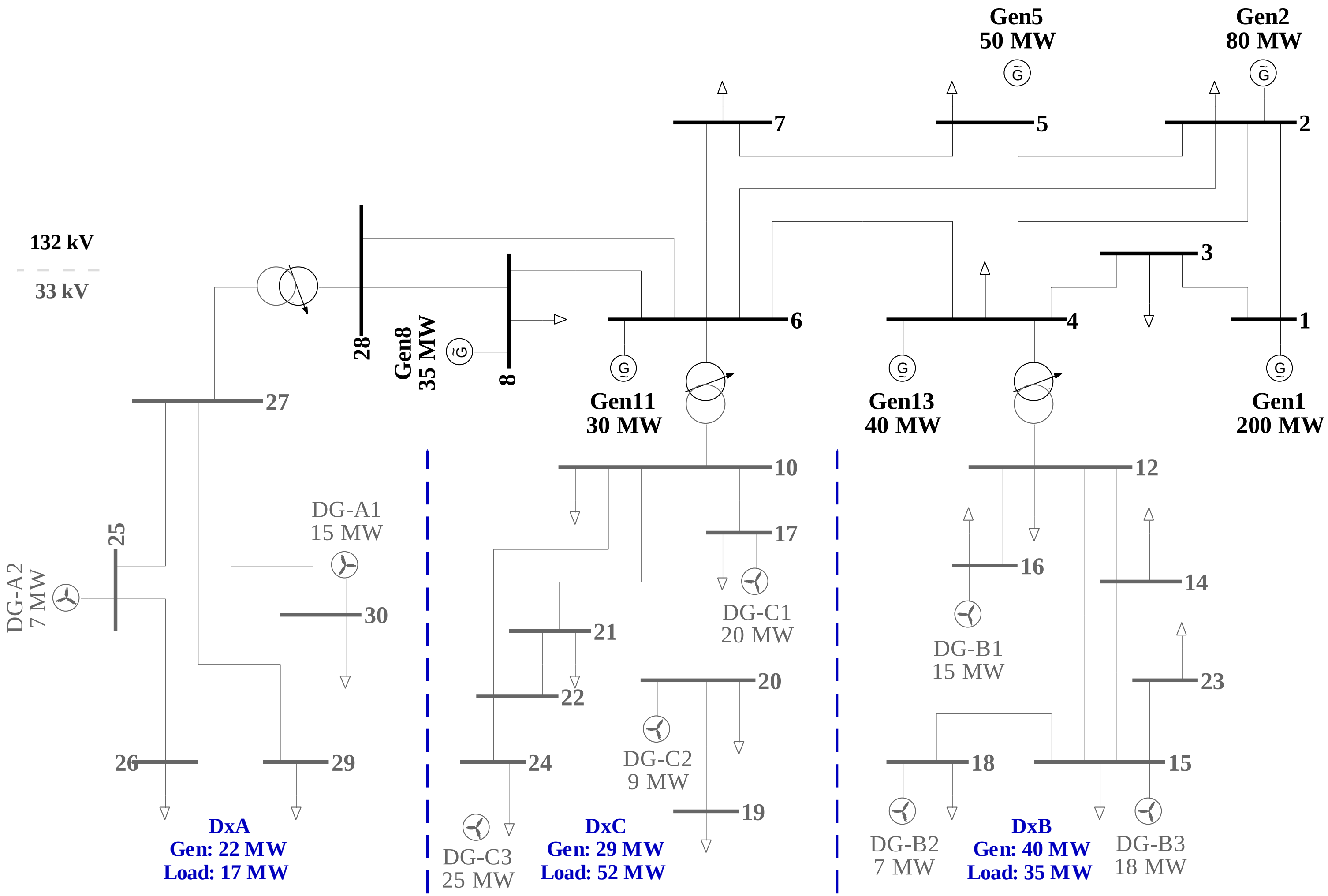
Possible Solutions

- Provision of additional MVAr capacity

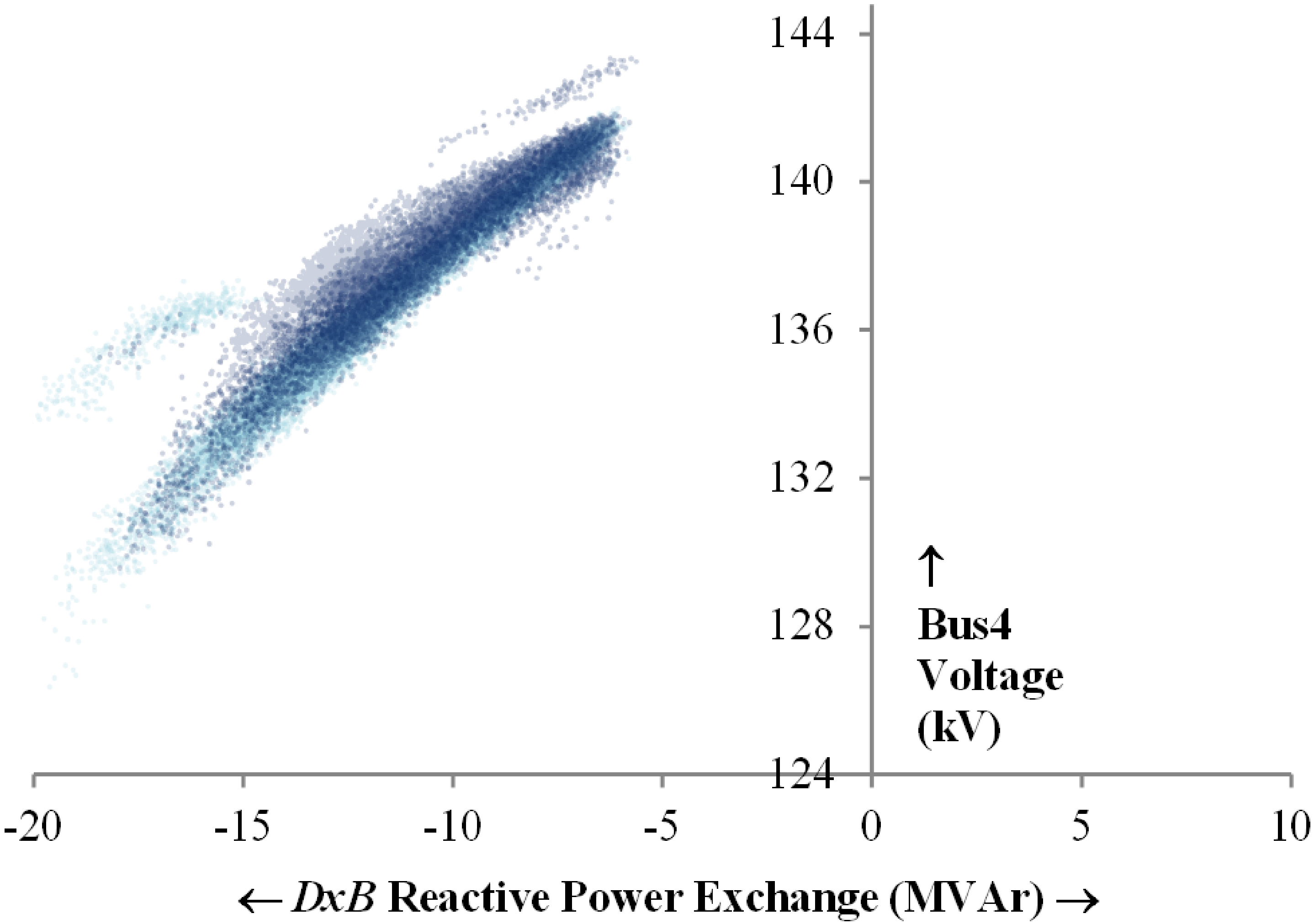
Possible Solutions

- Better utilisation of existing capacity
  - Software based solution providing enhanced controllability
  - Optimised controller settings requiring no operational change

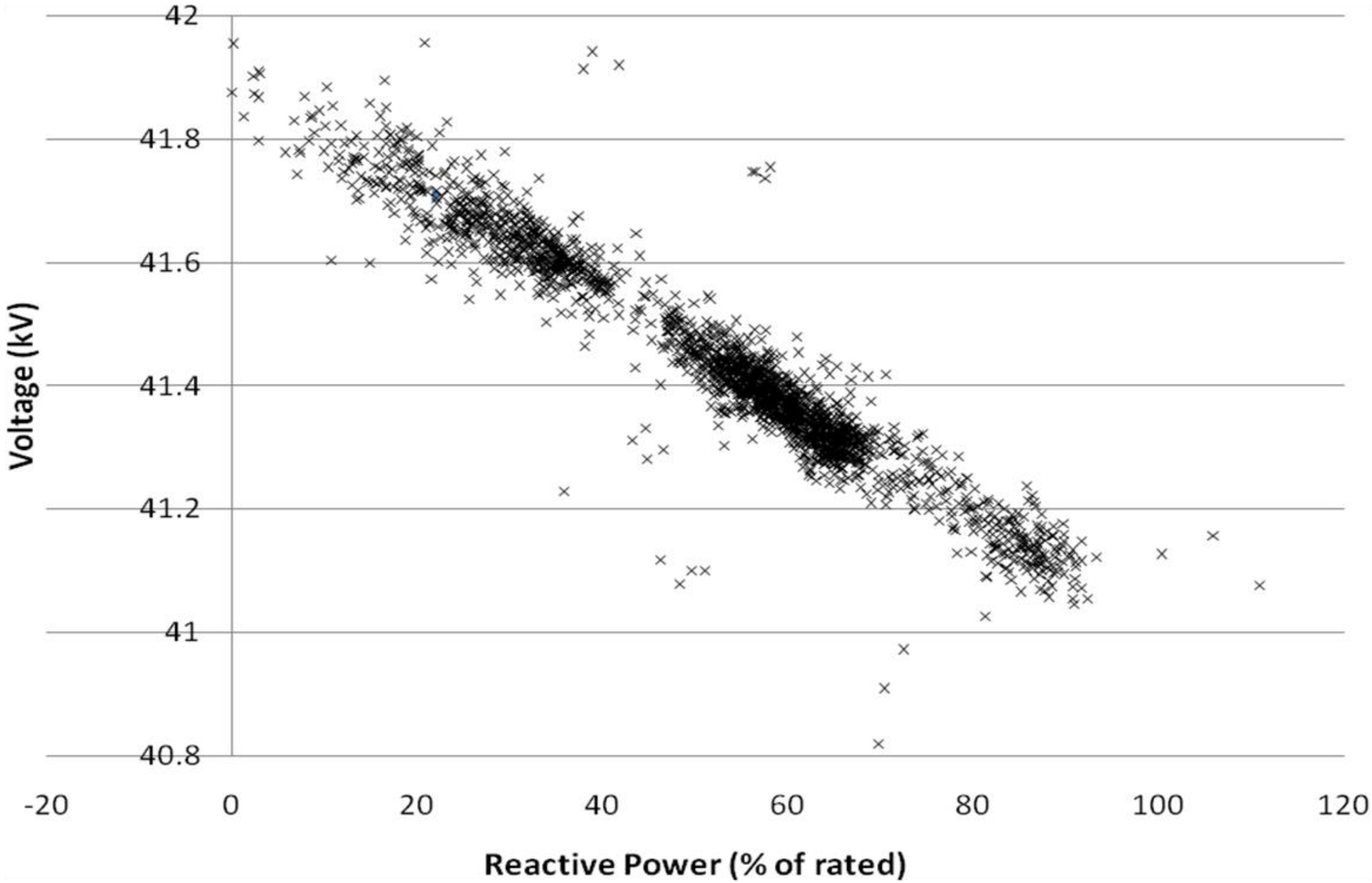
Test system


Gen5
50 MW
Gen2
80 MW
7
5
2
132 kV
33 kV
3
6
4
1
28
Gen8
35 MW
8
27
Gen11
30 MW
Gen13
40 MW
Gen1
200 MW
10
12
DG-A1
15 MW
25
17
16
DG-A2
7 MW
14
30
DG-C1
20 MW
21
DG-B1
15 MW
20
23
22
DG-C2
9 MW
26
29
24
18
15
19
DxA
Gen: 22 MW
Load: 17 MW
DG-C3
25 MW
DxC
Gen: 29 MW
Load: 52 MW
DG-B2
7 MW
DxB
Gen: 40 MW
Load: 35 MW
DG-B3
18 MW

Unity Power Factor

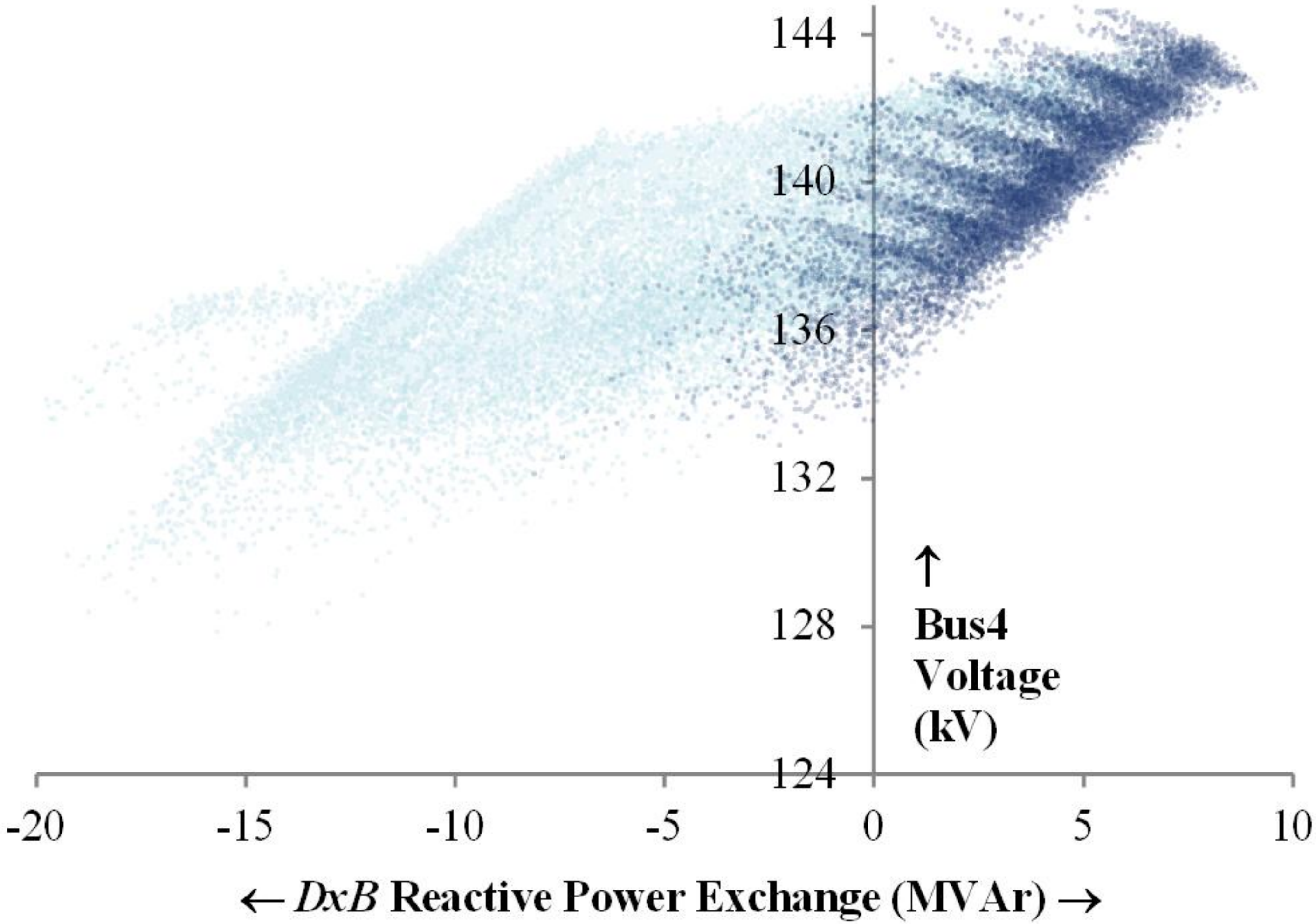


Wind Q-V Response



Keane, A., Diskin, E., Cuffe, P, Harrington, P., Hearne, T., Brooks, D., Rylander, M., and Fallon, T., "Evaluation of Advanced Operation and Control of Distributed Wind Farms to Support Efficiency and Reliability for High Penetrations of Wind Power", *IEEE Transactions on Sustainable Energy*, vol. 3, Oct 2012.

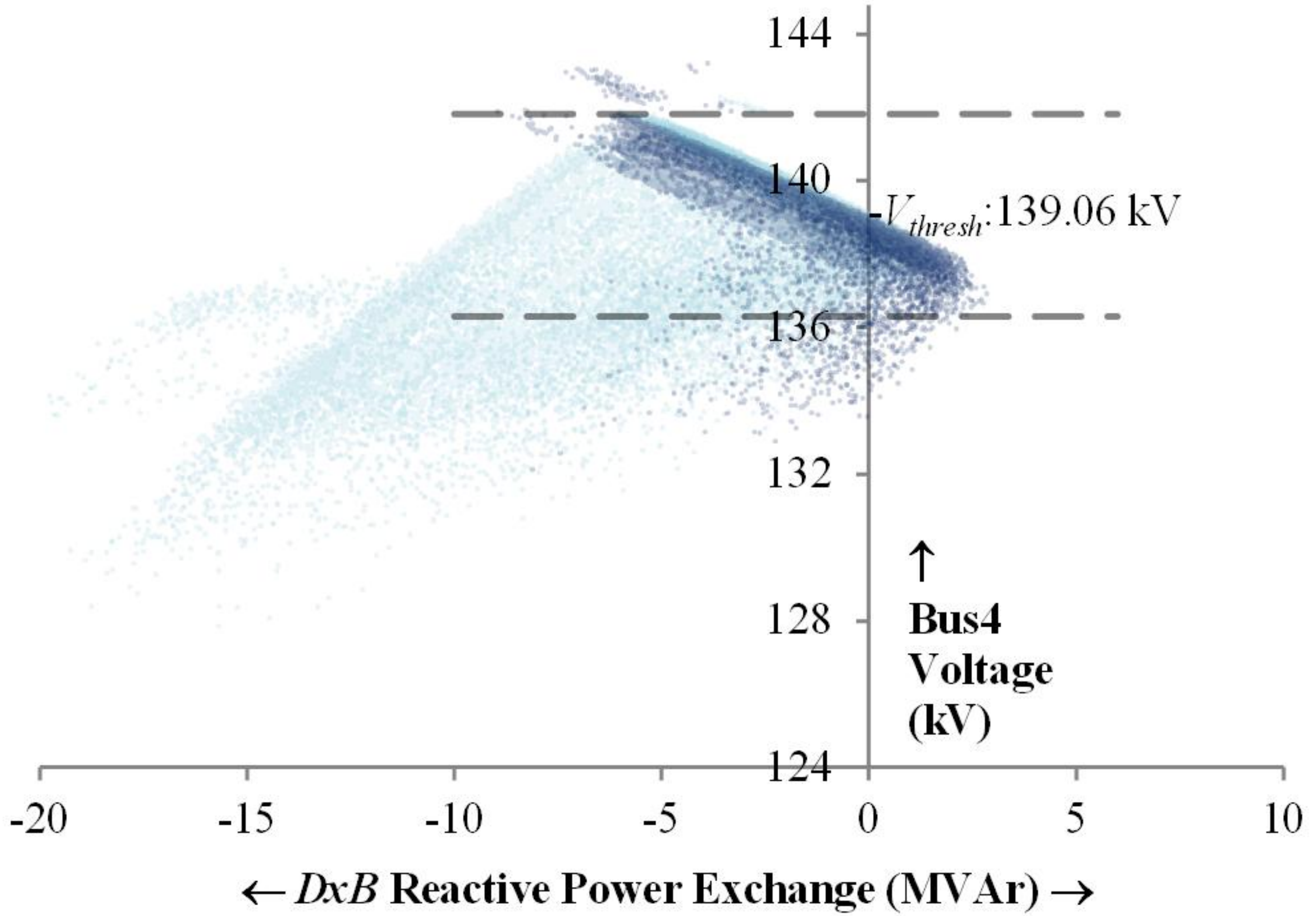
Non optimised voltage control



Possible Desired Response

- Desired response is given by **simultaneously:**
  - Maximising the aggregate reactive power *injection* for the lower-voltage periods and the *absorption* for higher-voltage periods
- Utilise multi scenario ACOPF with embedded models of voltage control and tap changer
- Determines fixed voltage set-points, droops and tap setting

Optimised settings



Cuffe, P., and Keane A., "Voltage Responsive Distribution Networks Using Enhanced Generator and Transformer Settings", IEEE Transactions on Power Systems, ***(in review)*** 2013

Result

- Optimised fixed settings for DG and trafo
- Deliver desirable voltage response at transmission
- Distribution constraints all respected

- Real time control could deliver more

Summary

- Question of capacity and location
- Scope for improvement in control of existing resources
- A lot can be achieved with optimised settings
- Real time control has potential for further benefits

Acknowledgements

sfi

erc
electricity research centre

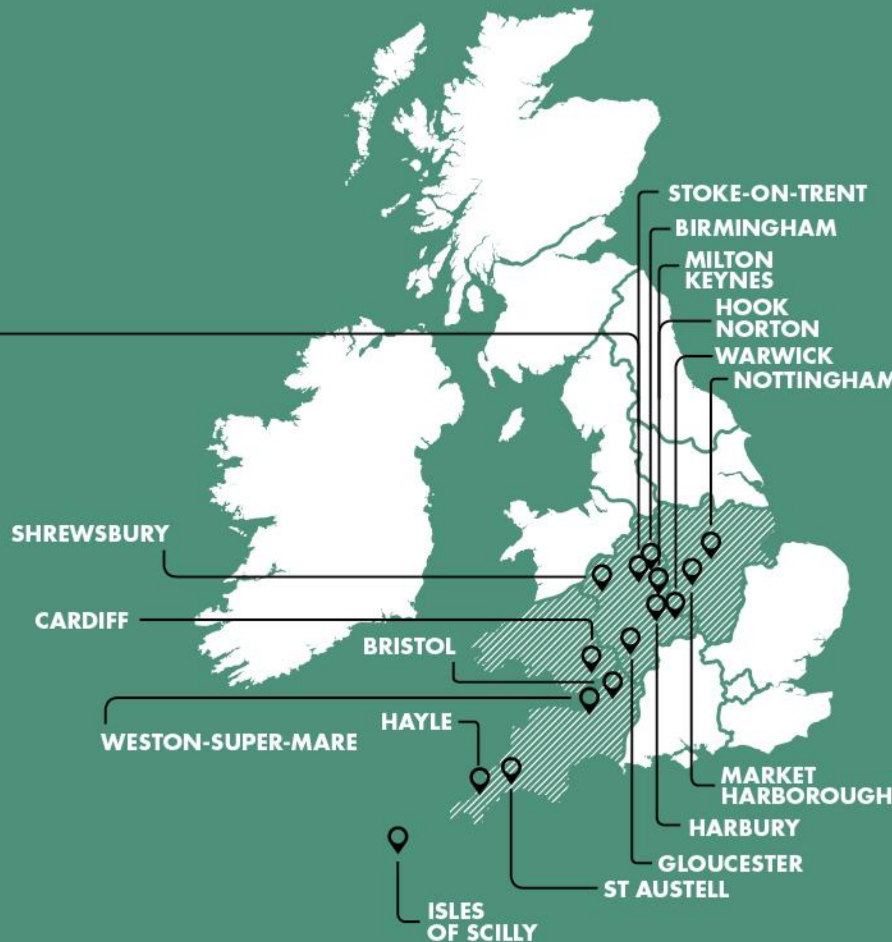
SEVENTH FRAMEWORK PROGRAMME

Managing Voltage Control on a Power System with High Renewable Penetration

SOLUTION CASE STUDY

Steve Gough
Douglas Cheung

NEXT GENERATION NETWORKS



HV Voltage Control

Hitachi's D-SVC integration onto the 11kV distribution network

Steven Gough – WPD

Douglas Cheung – Hitachi Europe

WESTERN POWER DISTRIBUTION INNOVATION

Innovation Strategy

Networks	Customers	Performance
		
Demonstrating alternative investment strategies to facilitate the UK's Low Carbon Transition	Testing innovative solutions to make it simple for customers to connect Low Carbon Technologies	Developing new solutions to improve network and business performance

Stakeholder Engagement and Knowledge Management

Western Power Distribution projects:

- Low Carbon Hub
- Network Templates
- Sola Bristol
- Falcon
- FlexDGrid
- Clean Energy Balance
- Isles of Scilly Smart Grid
- Echo
- Smart Hooky
- HV Voltage Control
- Community Energy Action
- LV Sensors
- Electric Boulevards
- Super Conducting Fault Current Limiter (energy technologies institute)
- Isentropic Energy Storage (energy technologies institute)
- Carbon Tracing
- Fault Level Monitoring
- Control Centre Links
- Early Learning
- Seasonal Generation
- Suburban PV Impact

Project Specifics

- Two phases
  - A 400kVar D-SVC on the end of a 11kV feeder adjacent to a 1.8MW windfarm
  - Three 400kVar D-SVCs spread across two feeders of a Primary Substation's network with a centralised control system D-QVC
- Looking to investigate effectiveness of using reactive power for controlling voltage at feeder ends
- Specifically looking to help the integration for further DG across rural networks

LCNF Project Overview

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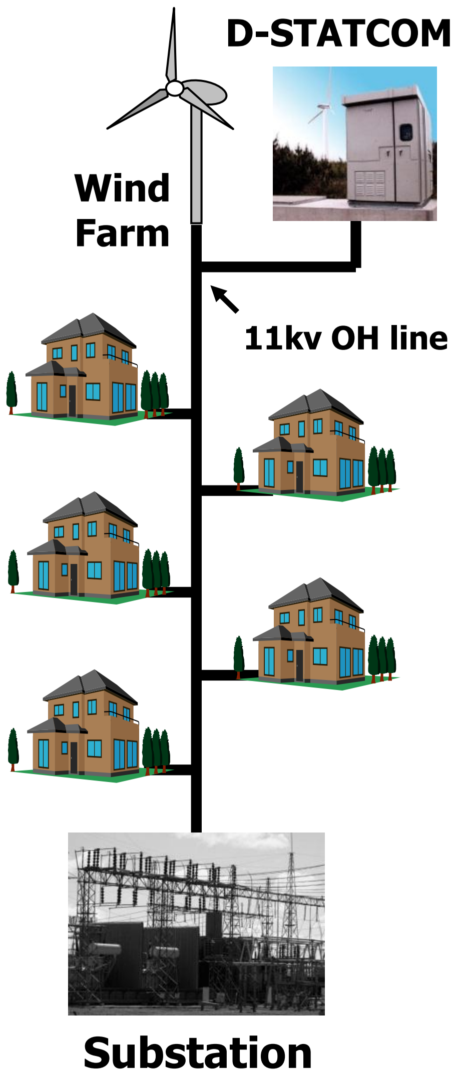
LCNF Tier 1 project



Background

- As DG (Distributed Generation) becomes more common, the growing number of renewable connections to distribution lines is expected to cause voltage fluctuations (specifically high or low voltage) due to the variable power output of the DG. In turn this can affect the efficiency and capacity of the distribution network.

Goals

- Determine the effectiveness of D-STATCOM as a dynamic voltage control system in rural 11kV networks to address voltage fluctuation.
- Optimise control by using a D-VQC (Voltage and Reactive Power Control System) to network multiple D-STATCOMs.

Scope

- 2 Strand project, initially 1 D-STATCOM as proof of concept, then 3 additional units as well as a D-VQC server.

Expected Benefits

- Improvement of power quality and mitigation of voltage spikes issues, thereby increasing network stability, efficiency and load capacity in distribution networks.
- Learning from project will be beneficial for informing DNOs business case for alternative responses to network rebuild.

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

LCN Fund
Low Carbon Networks

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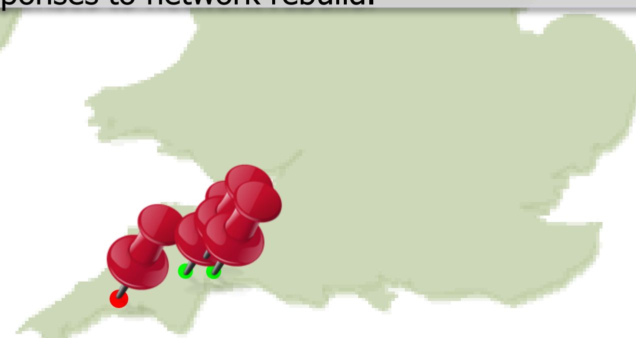
4 Project Locations
- ● Agreed
- ● Tentative



Power Quality Problems Created by RE

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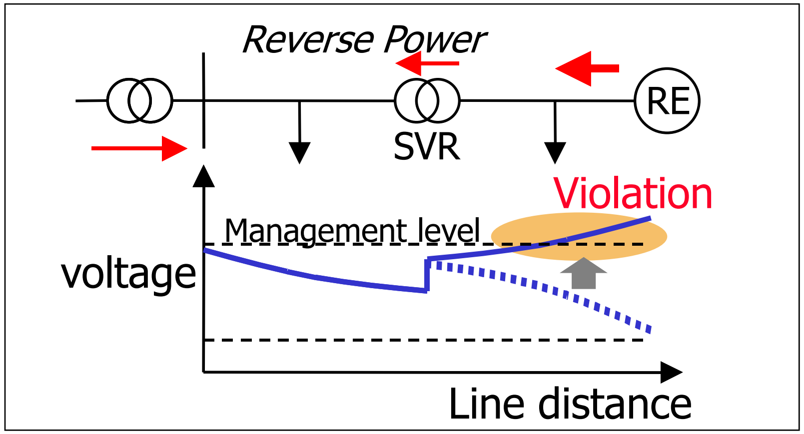
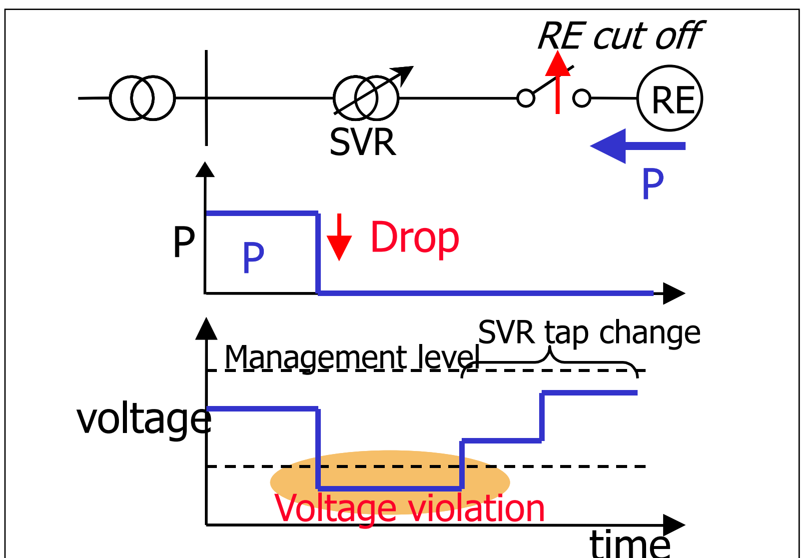
Violation of Voltage management level

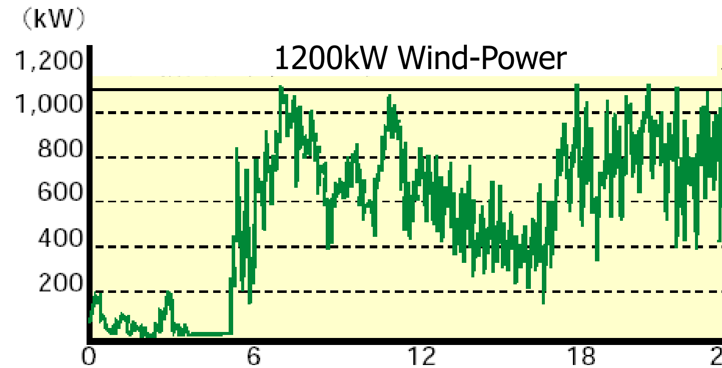


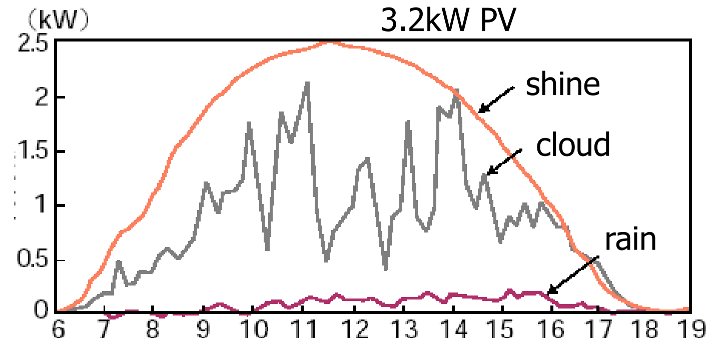
(a) Reverse Power Flow from RE



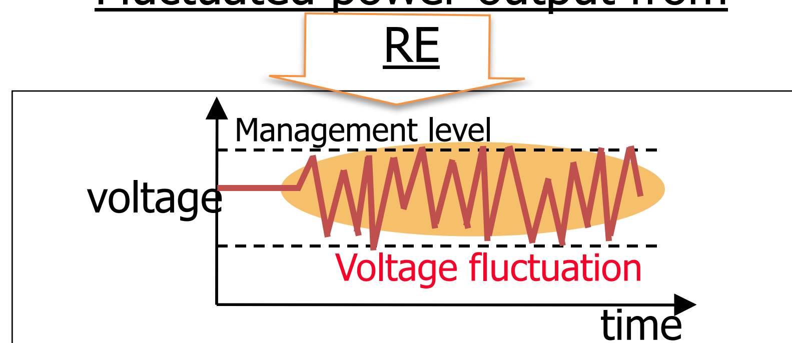
(b) Generator Cut Off

Voltage fluctuation





Fluctuated power output from RE



SVR: Step Voltage Regulator
RE: Renewable Energy

What is a STATCOM?

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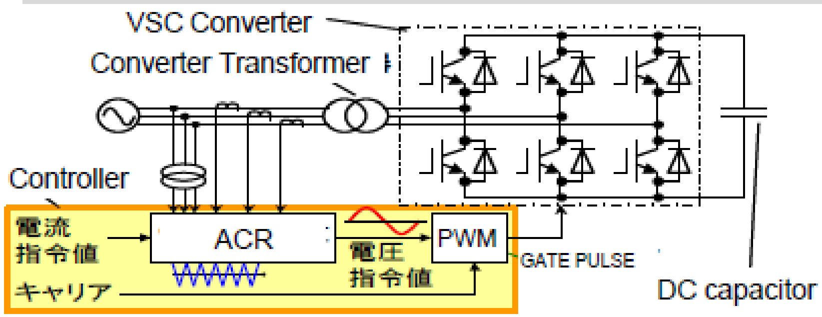
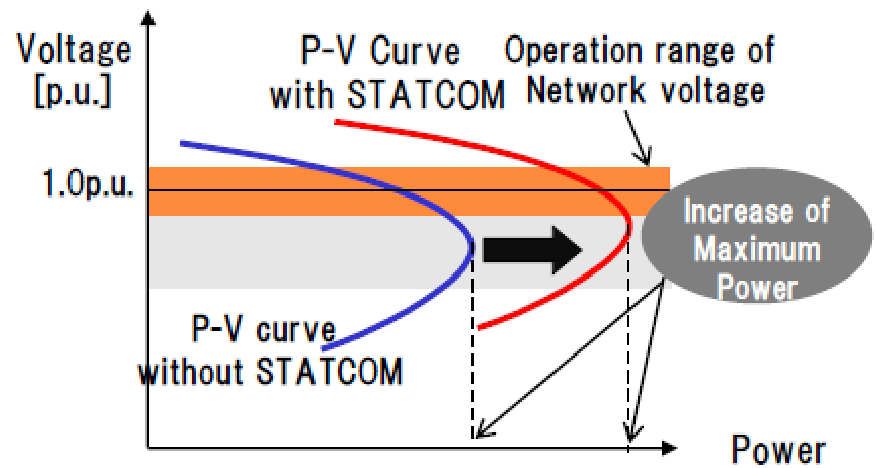
STATCOM (Static synchronous Compensator) is a high speed SVC (Static Var Compensator) using IGBT converter

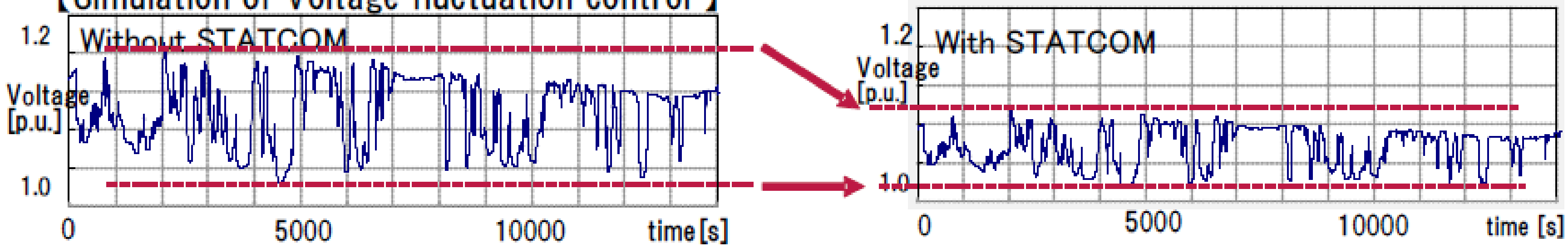
Reduce Voltage fluctuation	Avoid voltage instability
・Voltage fluctuation caused by wind turbine and/or mega solar can be suppressed by STATCOM	・Transfer capability can be increased by keeping power system voltage by STATCOM



【20MVA STATCOM】



【Simulation of Voltage fluctuation control】



Control Block Diagram of D-SVC/D-STATCOM

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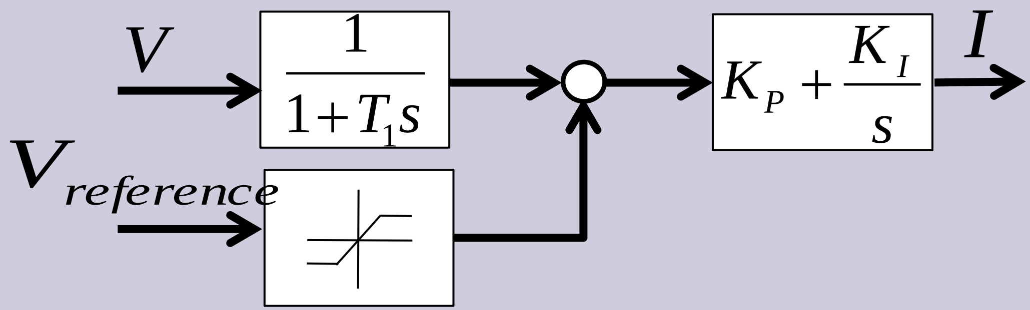
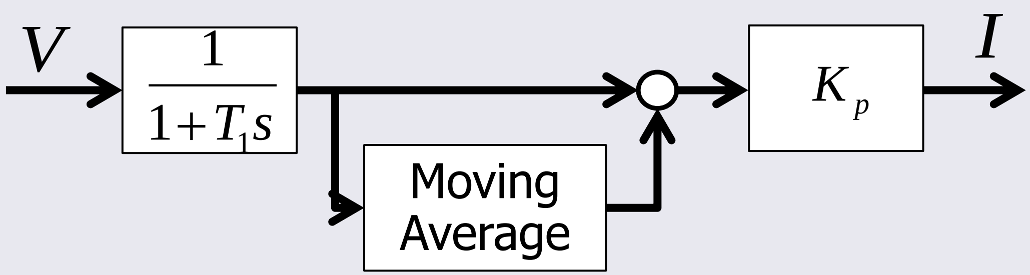
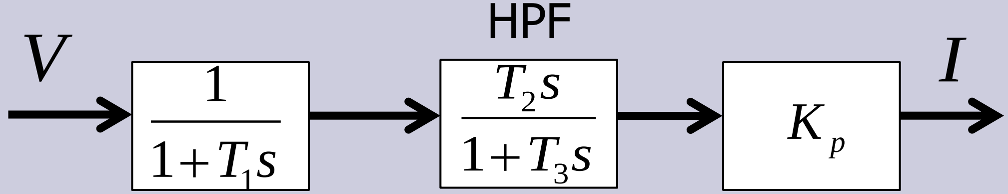
Mode	Block Diagram	Target
AVR		All fluctuations
ARV		Long-term fluctuation (minutes)
SFV		Short-term fluctuation (seconds)

AVR : Automatic Voltage Regulation, ARV : Average Reference Voltage
SFV : Short-term Fluctuation of Voltage, VSC : Voltage Source Converter

Using Reactive Power to Control Voltage

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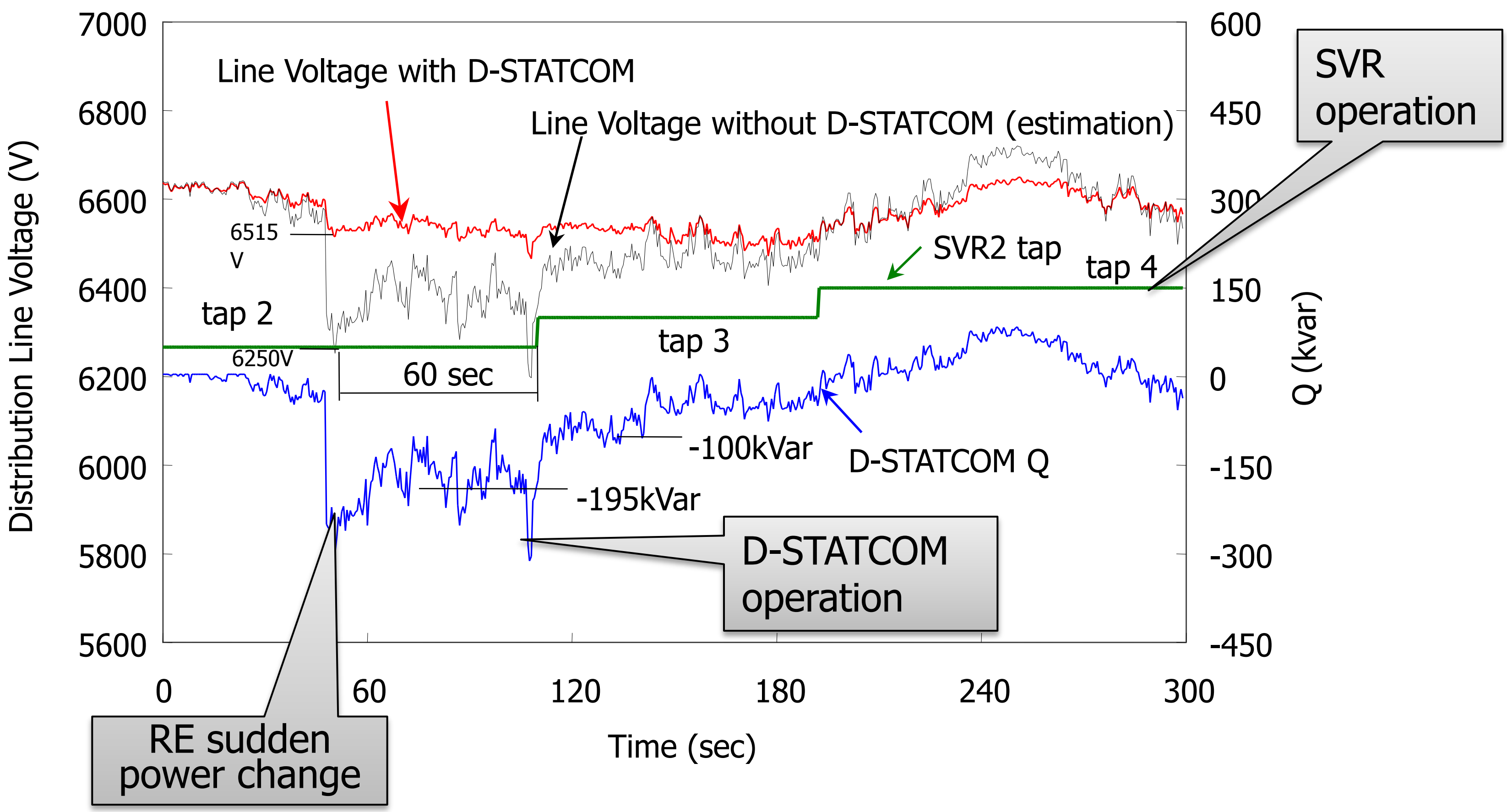
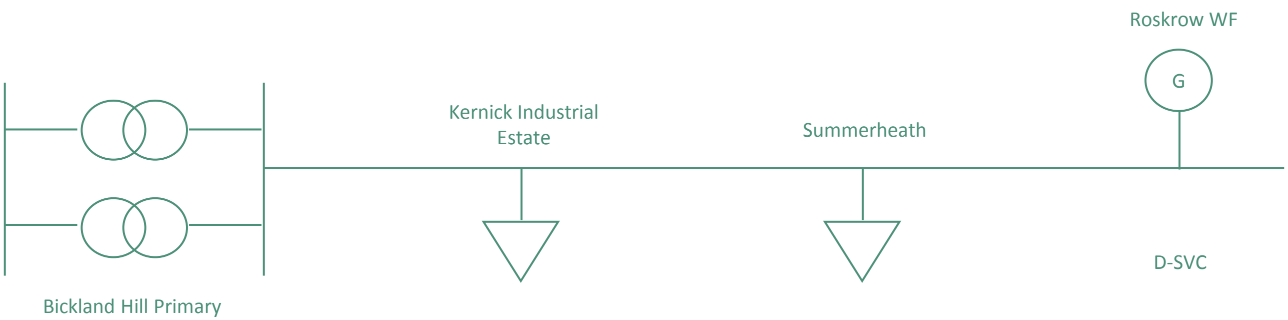
Reactive power can be used to control the distribution line voltage against sudden power change of RE between taps of SVR



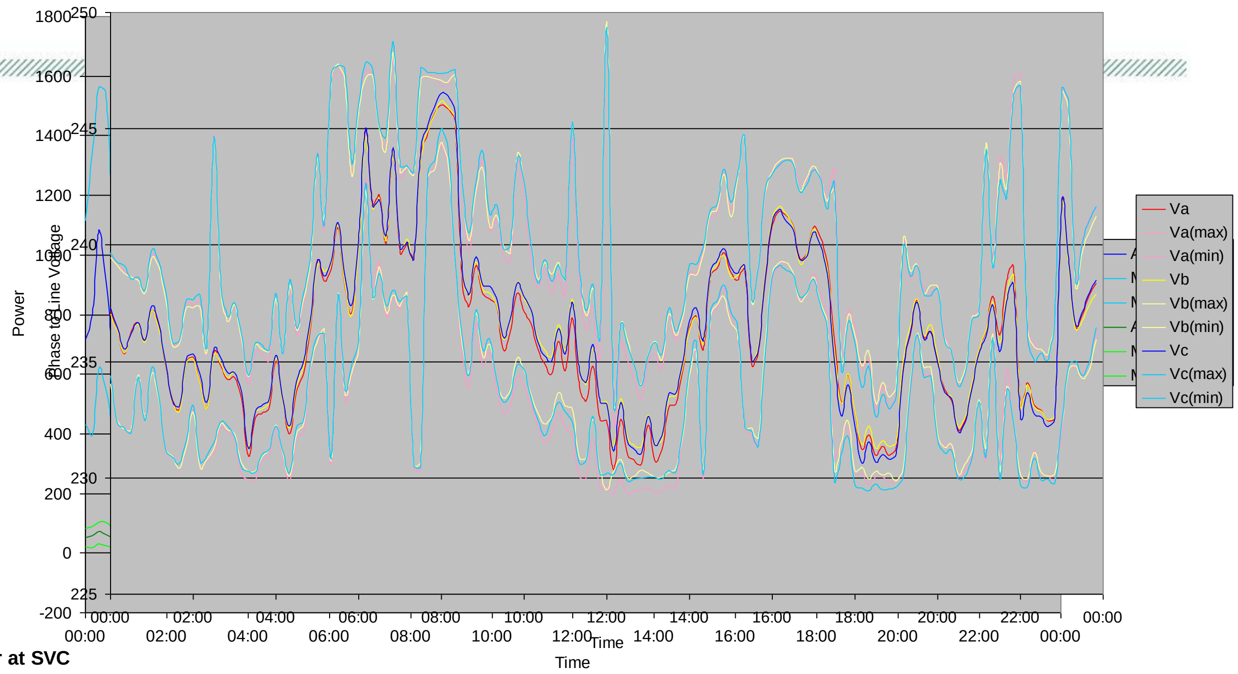
Phase 1

- D-SVC is installed on site adjacent to a 1.8MW windfarm in Cornwall
- Protection was installed on the LV side of the transformer as there was not a metering unit
- Monitoring equipment was installed along the feeder
- D-SVC has been running on various modes for nearly a year and a half

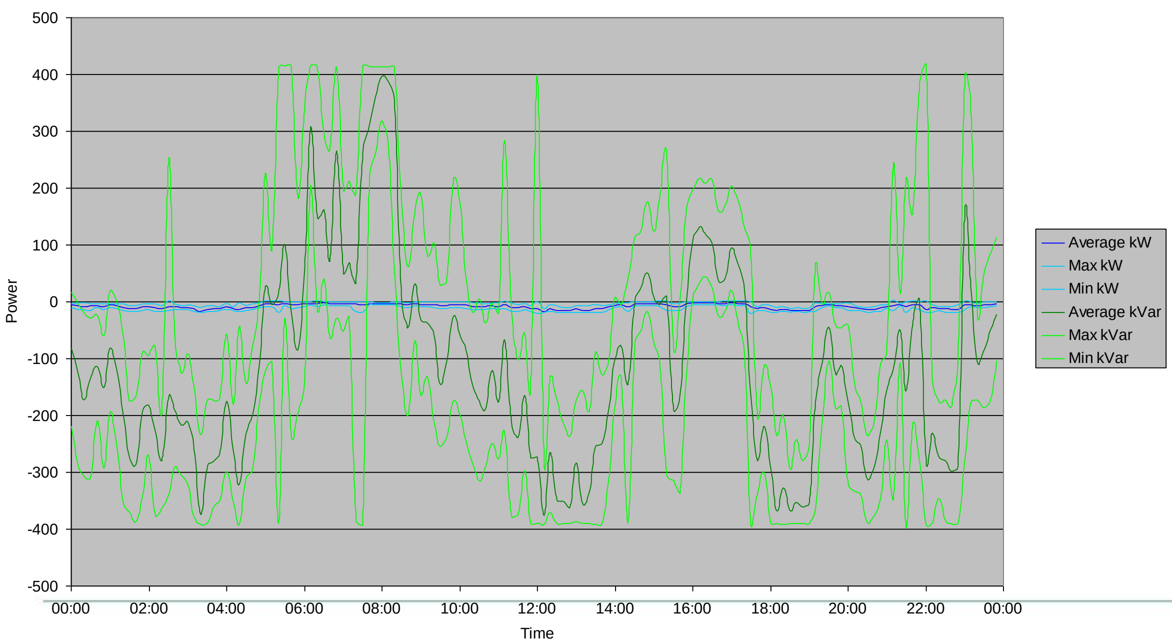


WESTERN POWER DISTRIBUTION
INNOVATION

Phase 1 Output Graphs (1)



Real and Reactive Power at SVC

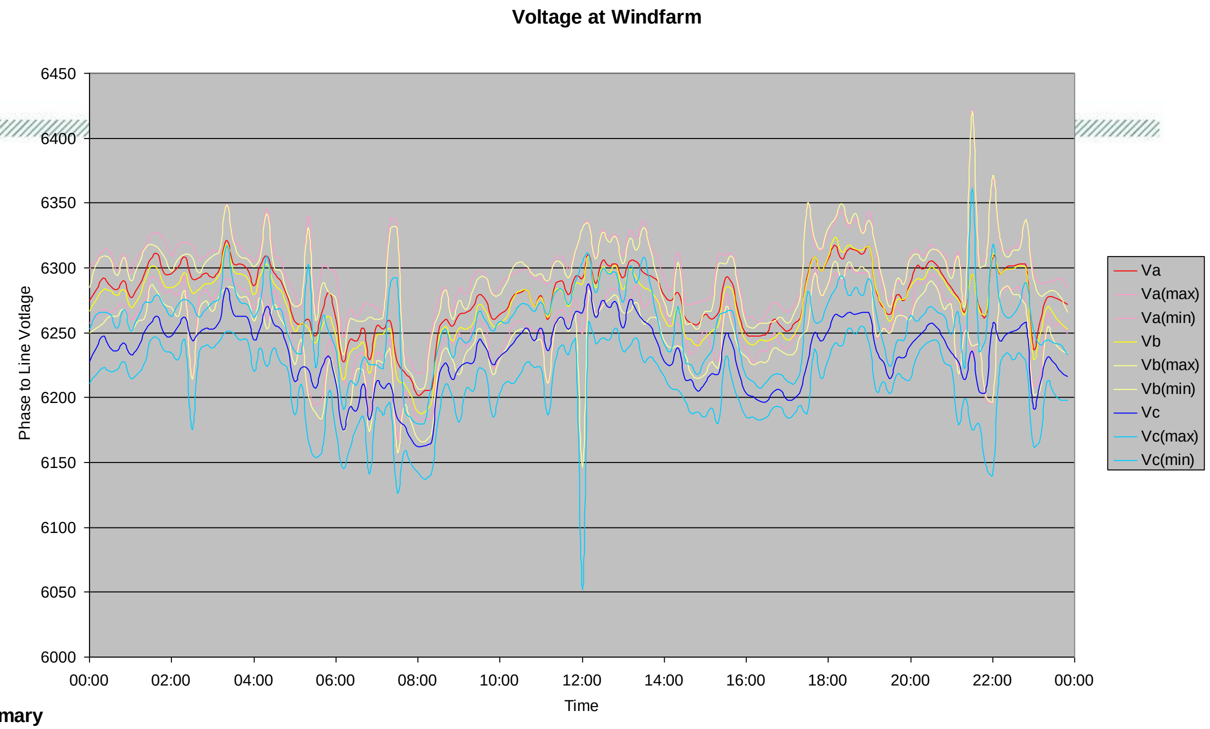


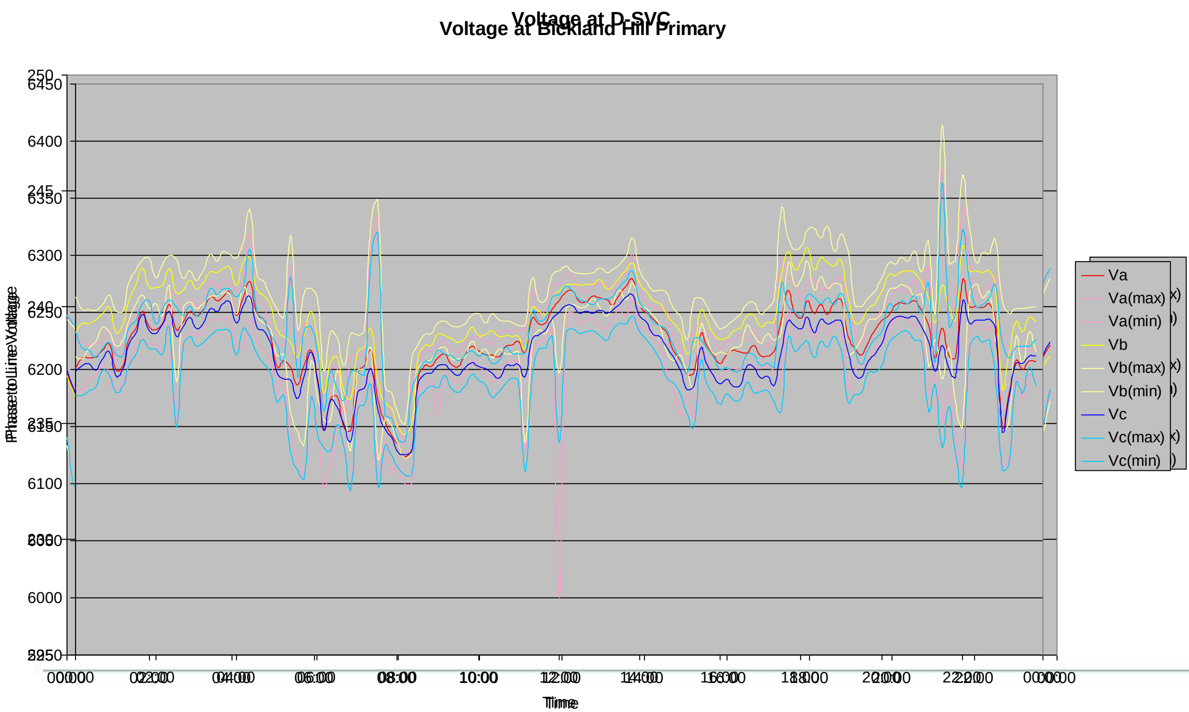
WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

WESTERN POWER DISTRIBUTION INNOVATION

Phase 1 Output Graphs (2)

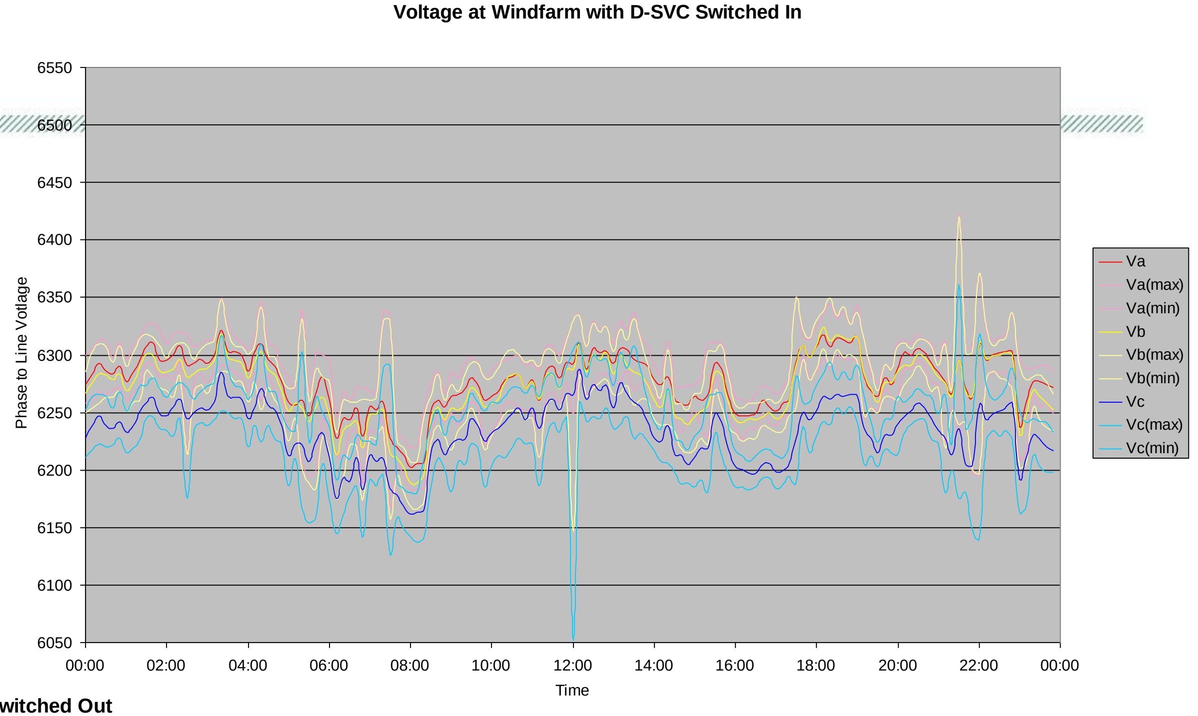


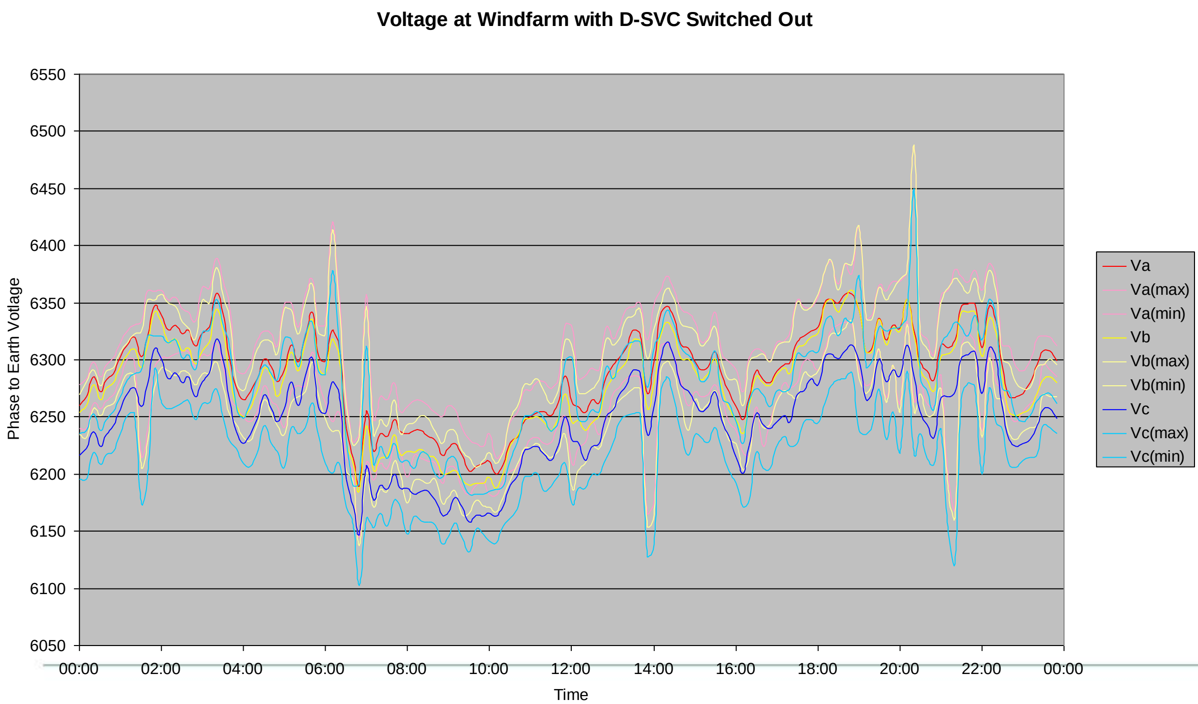


WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

Phase 1 Output Graphs (3)

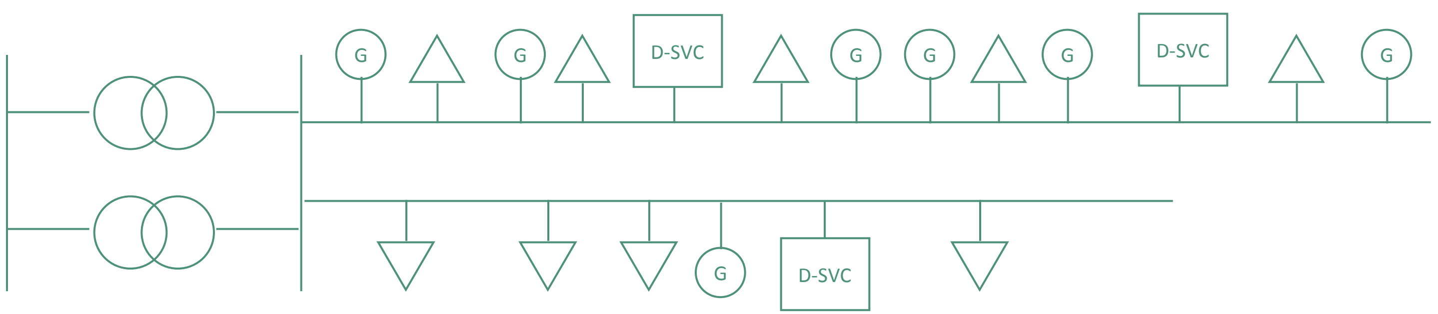




Serving the Midlands, South West and Wales

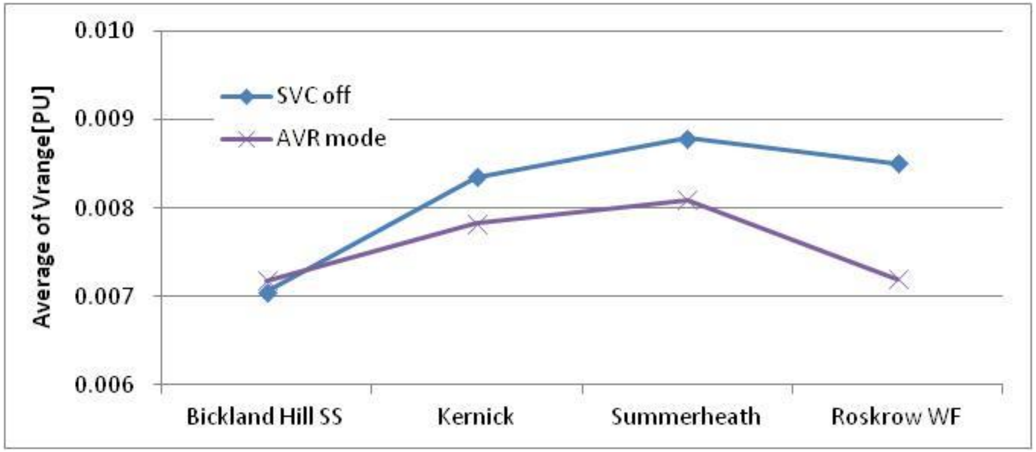
Plans for Phase 2

- Three D-SVCs will be used on one primary two on a feeder with multiple small generators and the other a feeder with one larger generator
- A D-VQC (Voltage and Reactive Power (Q) Control System) will be used at the primary to control all three D-SVCs and the tap changer at the primary substations
- This will demonstrate cohesive voltage optimisation across the primary



Learning so far

- Sizing and impedance the transformer is import to get right for a D-SVC.
- The D-SVC can help smooth the voltage
- The D-SVC can help reduce the voltage range seen on the 11kV
- D-SVC over and under voltage protection needs to be on the HV side of the transformer



WESTERN POWER DISTRIBUTION
INNOVATION

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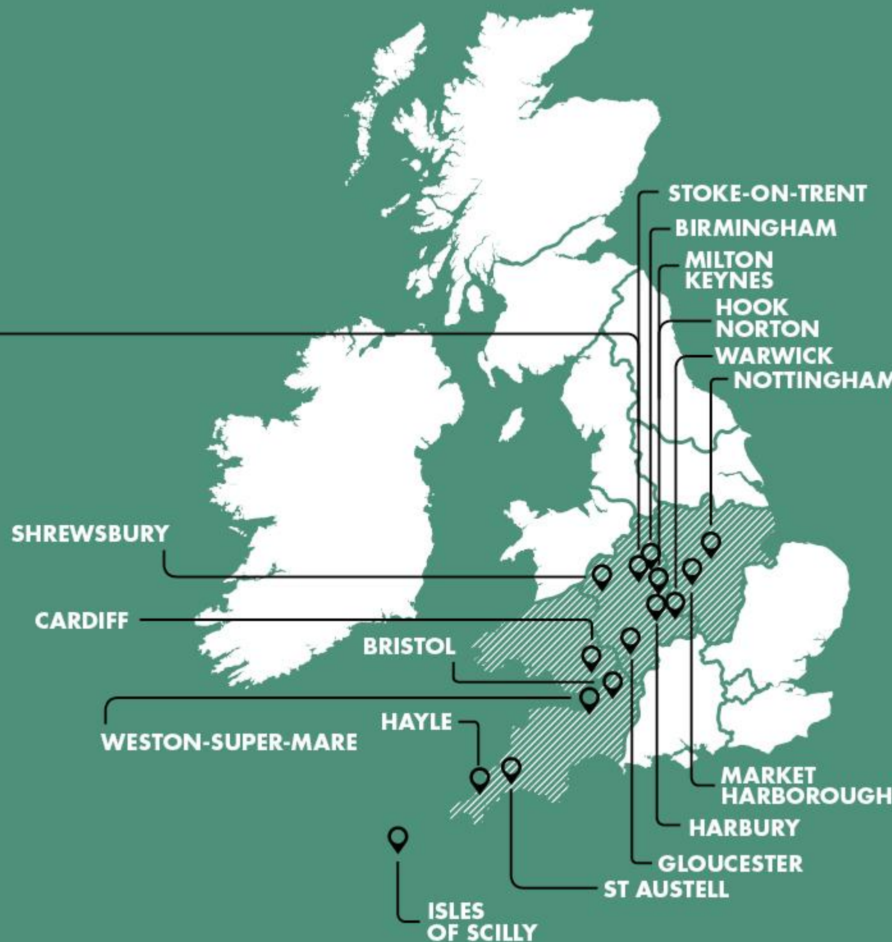
NEXT GENERATION NETWORKS



Any Questions?

Steven Gough – WPD

Douglas Cheung – Hitachi Europe

Questions & Answers

Managing Voltage Control on a Power System with High Renewable Penetration

PUBLICATIONS

cigré
INTERNATIONAL COUNCIL
ON LARGE ELECTRIC SYSTEMS

Paris 2012 & 2014

- **2012 - SC B4 HVDC and Power Electronics**
  - **PS2 > HVDC and FACTS Technology Developments**
    - FACTS equipment
  - **PS3 > Applications of HVDC and FACTS**
    - FACTS equipment for increased AC network performance
    - Use of Power Electronics to facilitate the integration of large renewable energy sources into AC networks
- **2014 - SC B4 HVDC and Power Electronics**
  - **PS2 > FACTS Systems and Applications**
    - Renewable Resources Integration
    - Increased network performance

Publications

- **Technical Brochures**
  - TB 523 System Complexity and Dynamic Performance
  - TB 310 Coordinated Voltage Control in Transmission Networks.
  - TB 371 Static Synchronous Series Compensator

- **Session Papers / Electra**
  - Comparison of the dynamic response of wind power generators of different technologies in case of voltage dips
  - Voltage and VAr Support in System Operation
  - Development and testing of ride-through capability solutions for a wind turbine with doubly fed induction generator using VSC t
  - Real time dynamic security assessment and control by combining FACTS and SPS
  - FACTS for enabling wind power generation