Fast Fault Current Injection GC0111

Antony Johnson

National Grid

January 2019

Summary

- Current Status
- Comments received following updated text in January 2019
- Updated formulas and examples
- Revised text additional flexibility / updates to recongise plant types
- Examples – Power Park Modules
- Other issues
- Compliance
- Next Steps

Current Status

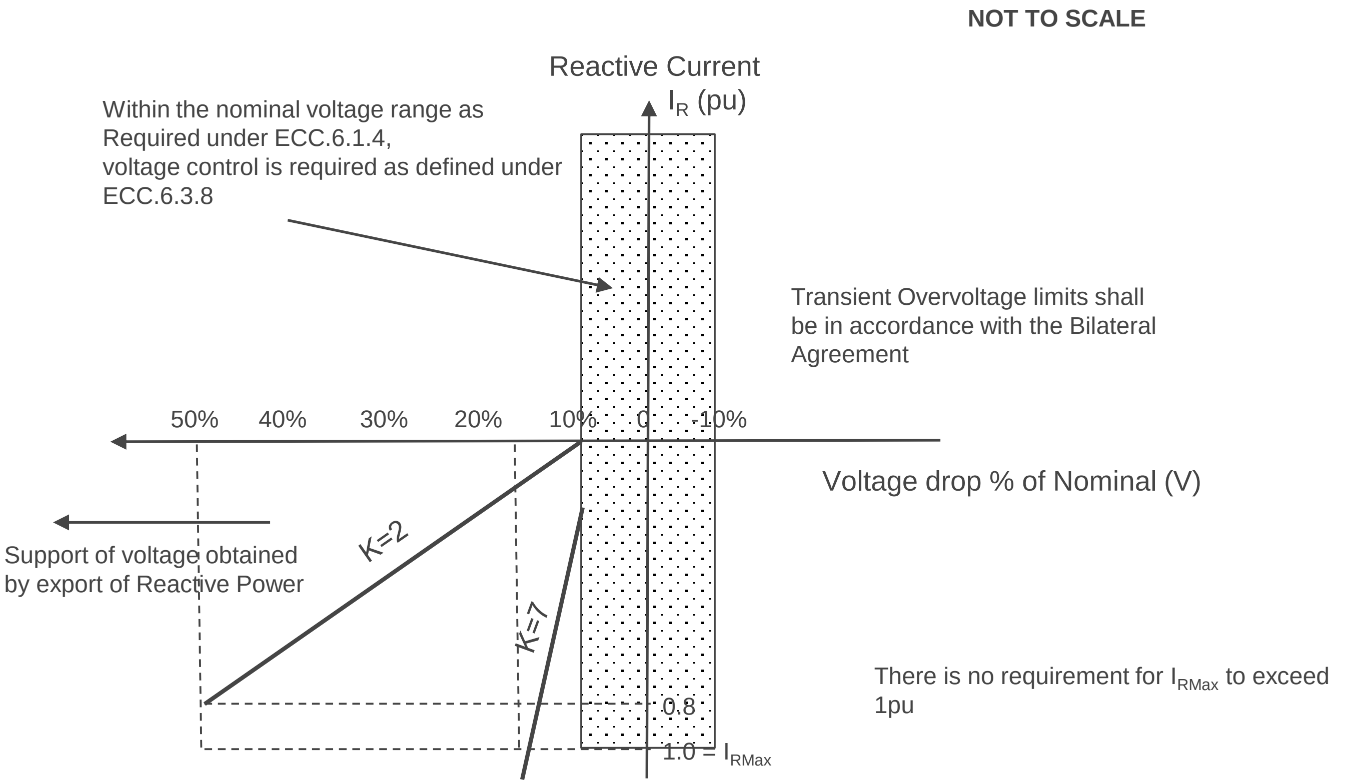
- Following the last GC0111 meeting held on 6th December a number of additional comments were received which were added and the revised wording and legal drafting was issued early in the new year
- A number of comments have been received which include:-
  - Definition of $V_{insensitivity}$ / examples / compliance - Siemens
  - Clarification of 0.65 x I_R and slope line – Drax Power
  - Active Current contribution - Senvion
  - Numerous comments from GE
    - To be discussed during the meeting
  - Additional comments from Senvion on GE's comments
  - Several comments received on the referencing to formula's and Iprefault – P2A Analysis

Additional Comments

- National Grid have number of additional comments which include:
- Concerns over the difference in reactive current injection between the pre-fault operation between full lead and full lag
- Concerns over the K factor
- Compliance issues
- Transition between the normal operating mode of operation and fault ride through

Reactive Current / Voltage Curve

FFCI Figure ECC.16.3.16(a)



Reactive Current / Voltage curve – Parameters (1)

- Where:-
- V - Actual voltage at the Grid Entry Point or User System Entry Point during the fault
- I_R - The reactive current supplied under fault conditions where:-
- $I_R = \Delta V_1.k + |I_{Prefault}|$ Equation (1)
- I_R The Reactive Current supplied under fault conditions shall be above the shape shown in Figure ECC.16.3.16(b) and Figure ECC.16.3.16(c) with the peak steady state reactive current defined by Equation (1) above. This value is capped at a maximum of 1.0pu.
- There is no requirement for I_R to exceed 1.0pu (I_{RMAX}) but this would not preclude a Power Park Module (or any constituent Power Park Unit) or HVDC Equipment from supplying more should it wish to do so.
- $|I_{prefault}|$ is the modulus of the prefault reactive current in per unit the prefault reactive current ($I_{prefault}$) for a future fault ride through event, shall be determined when the voltage has returned above the minimum levels specified in ECC.6.1.4,

Reactive Current / Voltage curve – Parameters (2)

ΔV_1 = 0.9 - $V_{retained}$

~~Vprefault - Is the Prefault Positive Phase Sequence RMS voltage in per unit~~

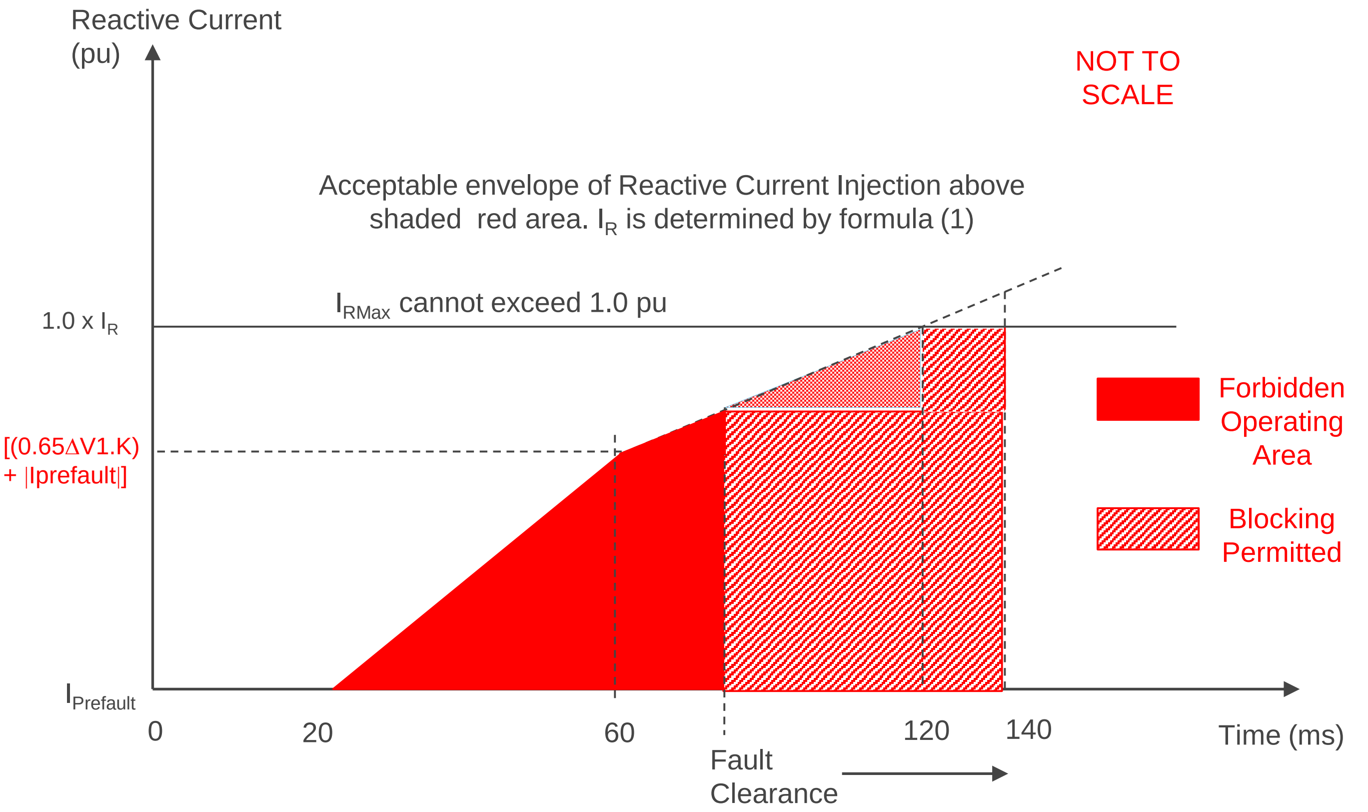
~~Vinsensitivity Is the difference in magnitude between the pre-fault voltage and the minimum continuous operating voltage as defined in ECC.6.1.4 (ie Vprefault – 0.9) - Default setting 0.1 unless otherwise agreed.~~

$V_{retained}$ – Is the retained positive sequence voltage at the Grid Entry Point or User System Entry Point (under fault conditions)

k – Is the gain factor (range proposed 2 – 7) – Default setting 2.5

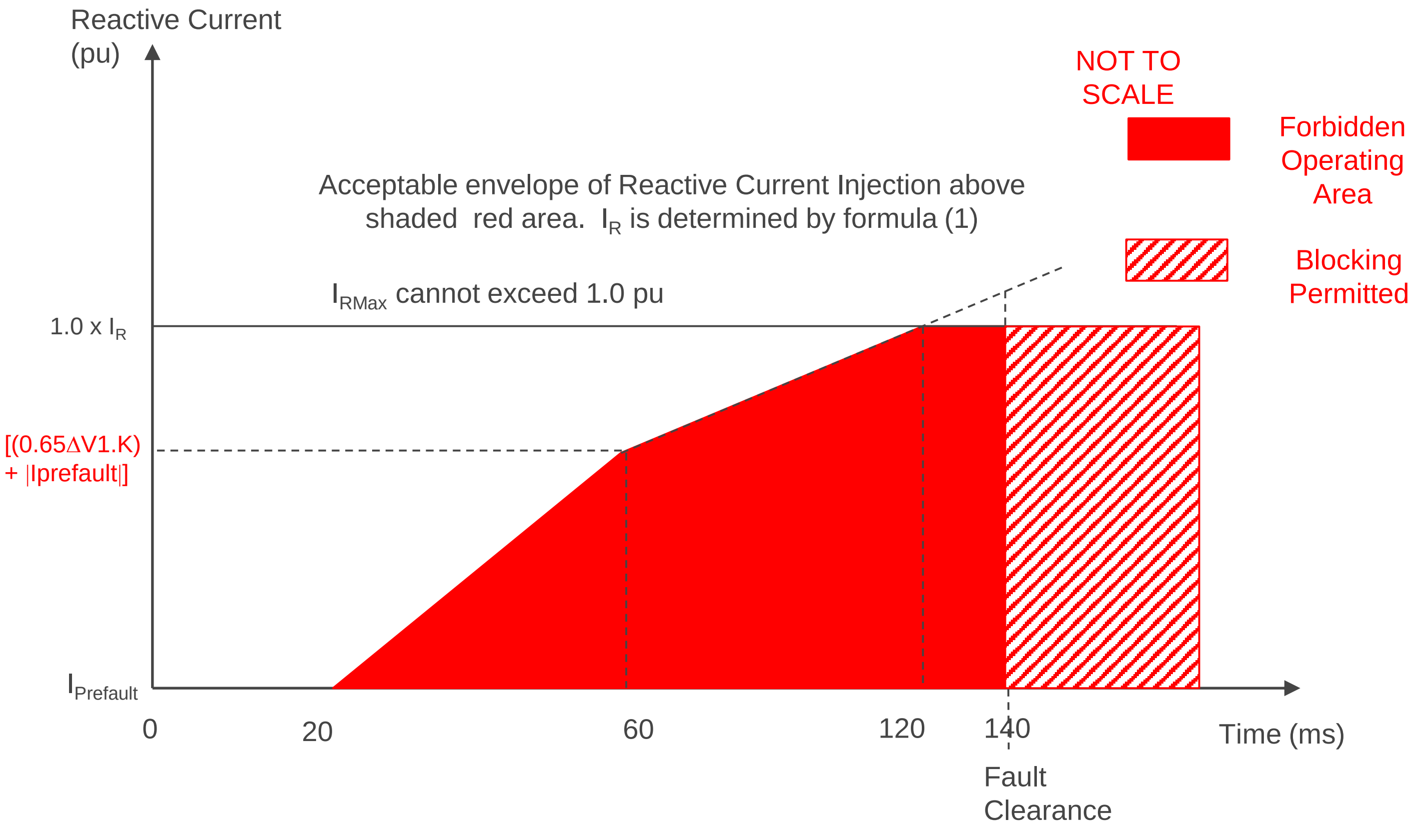
I_{RMAX} - The maximum current which shall, as a minimum, be above the shaded areas defined by Figures ECC.16.3.16(b) or ECC.16.3.16(c). There is no requirement for the maximum supplied current to exceed 1.0pu.

FFCI Figure ECC.16.3.16(b)



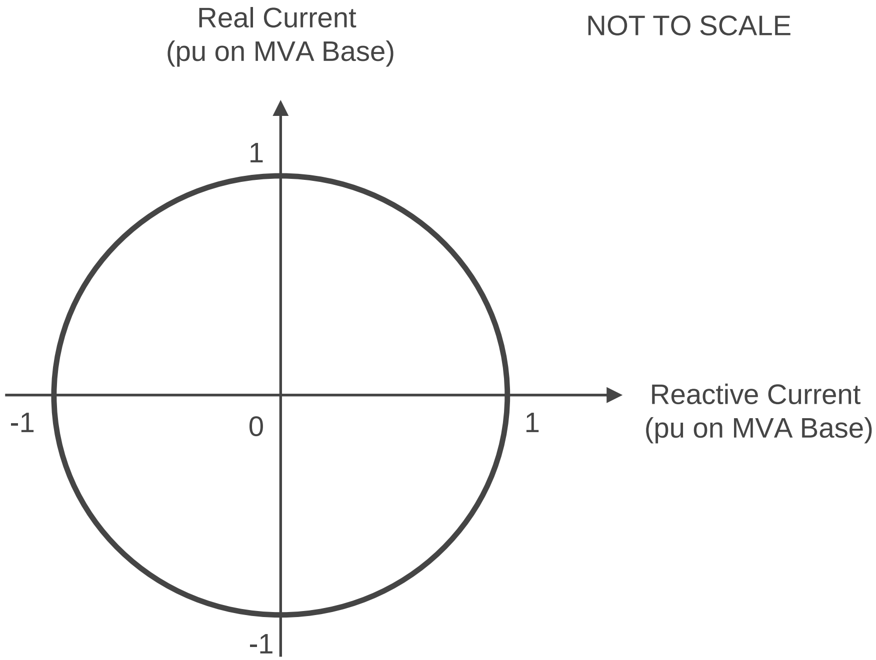
nationalgridESO

FFCI Figure ECC.16.3.16(c)



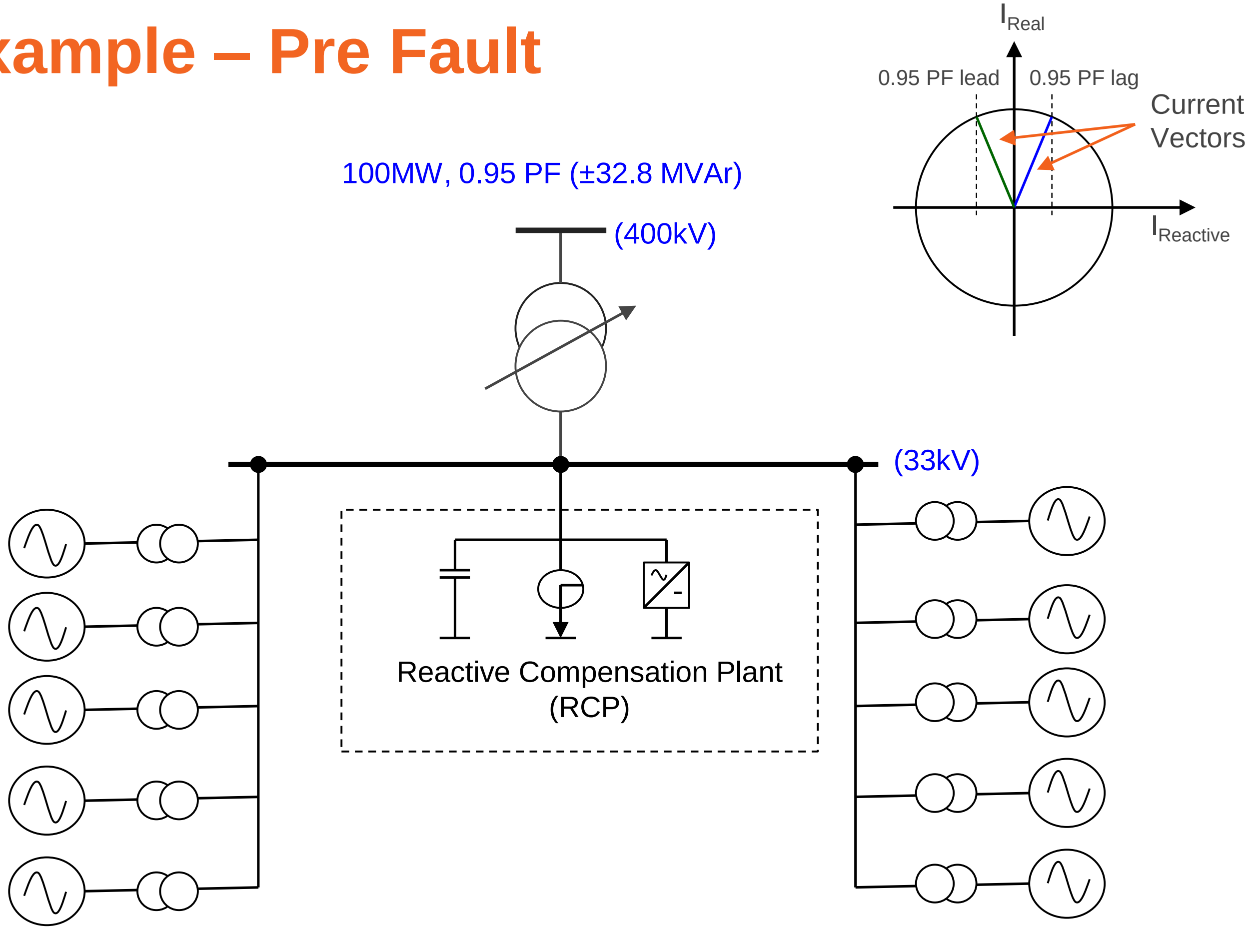
nationalgridESO

Active / Reactive Current Circle Diagram *(FFCI Figure ECC.16.3.16(d)*

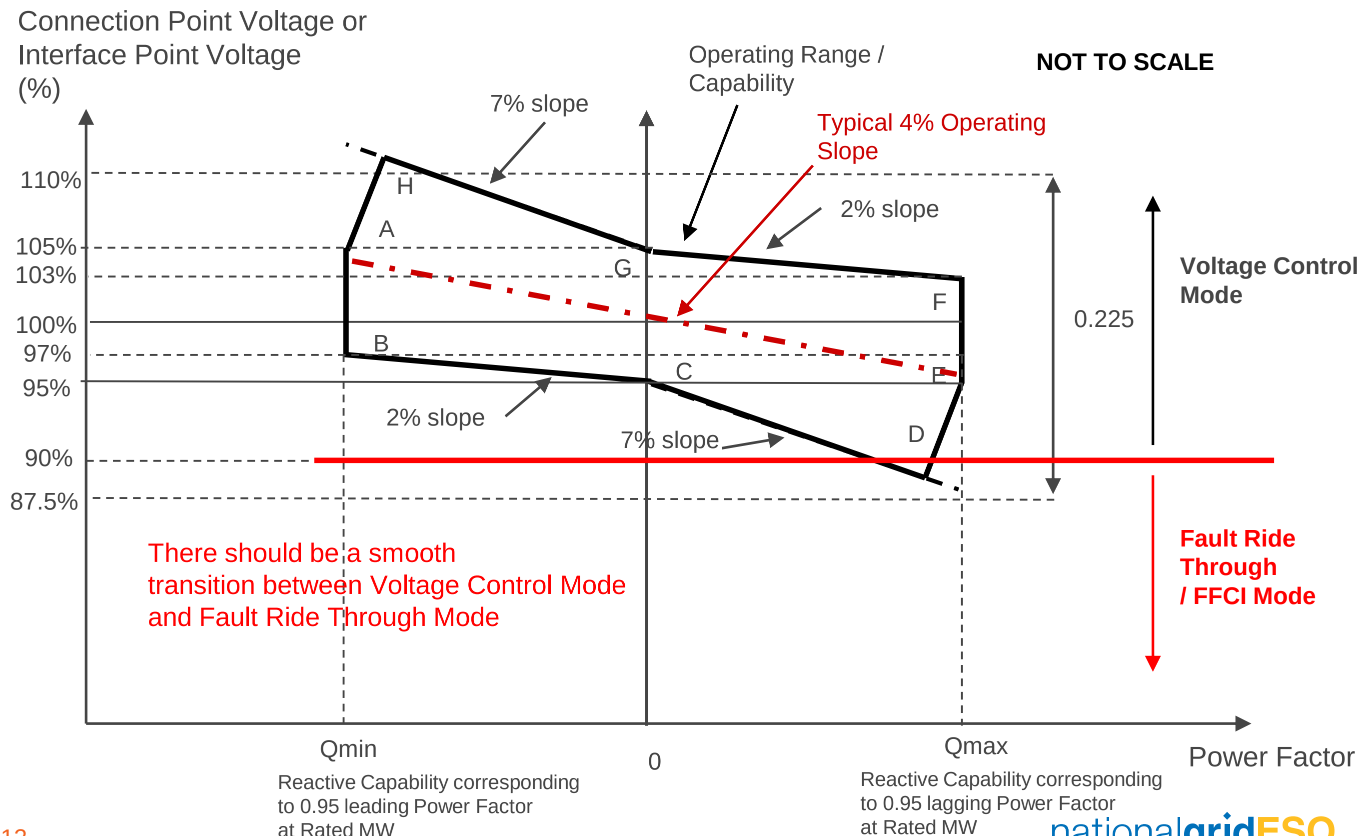


NOTE:- 1 pu current is the rated current of the Power Park Module or HVDC Equipment when operating at full MW output and full leading or Lagging MVAr capability (eg for a 100MW Power Park Module Rated Current would be obtained when the Power Park Module is supplying 100MW and 0.95 Power Factor lead or 0.95 Power Factor lag at the Connection Point). Note this is the rating of the converter. When I_R is less than 1.0 pu any residual reactive current should be supplied as Active Current

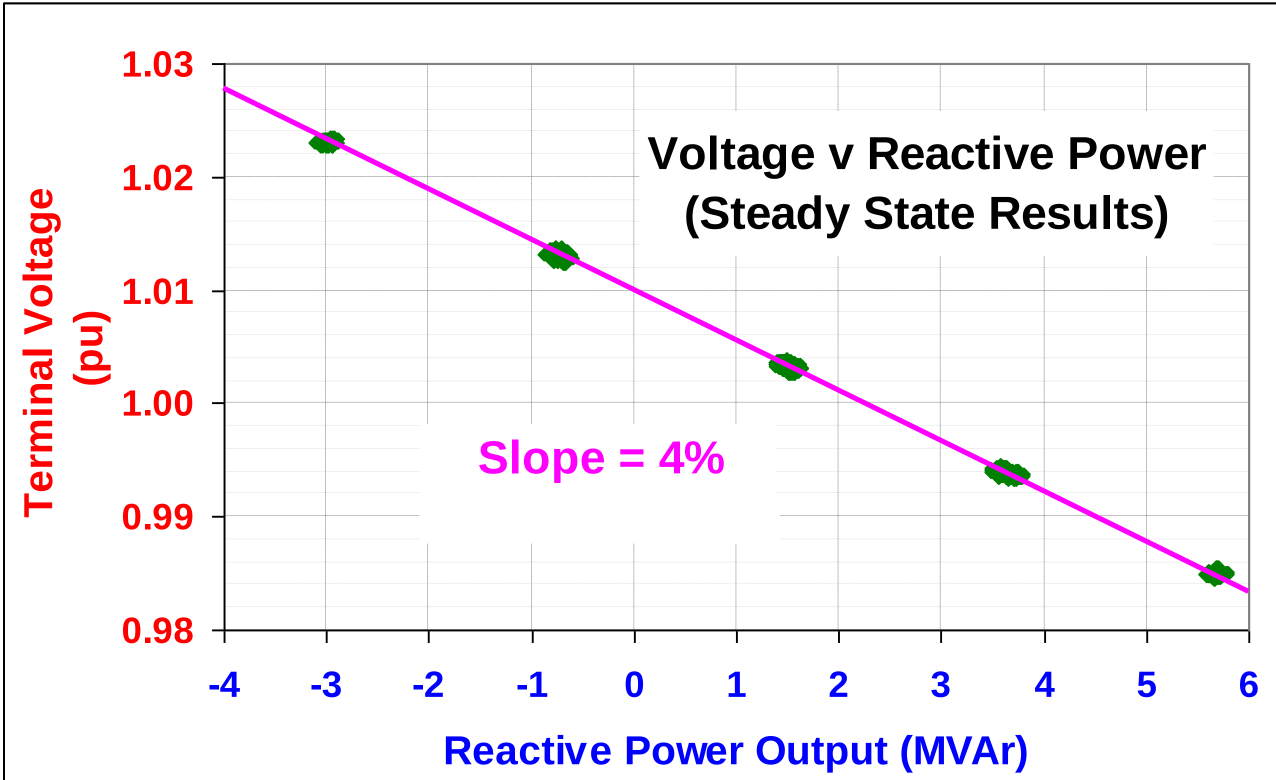
Example – Pre Fault



Steady State Voltage Control – Pre Fault



Voltage Control Testing – Slope (Pre Fault)

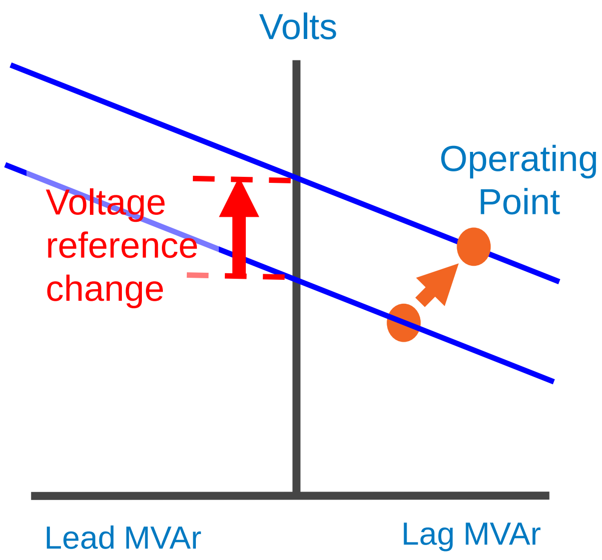


nationalgridESO

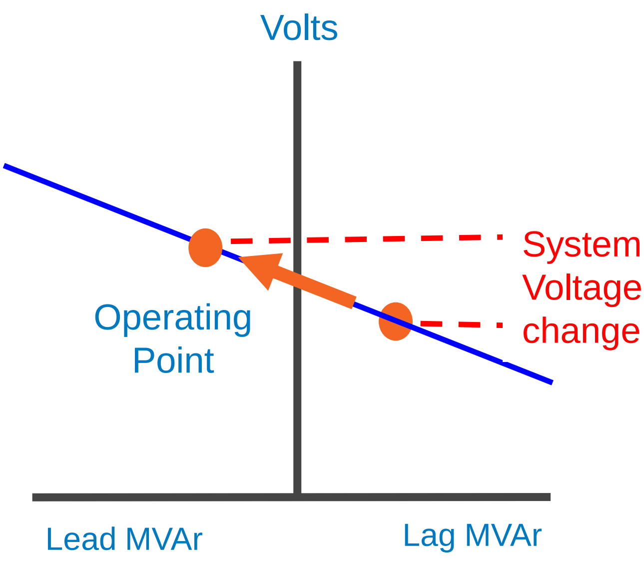
13

Voltage Control Testing – Pre fault

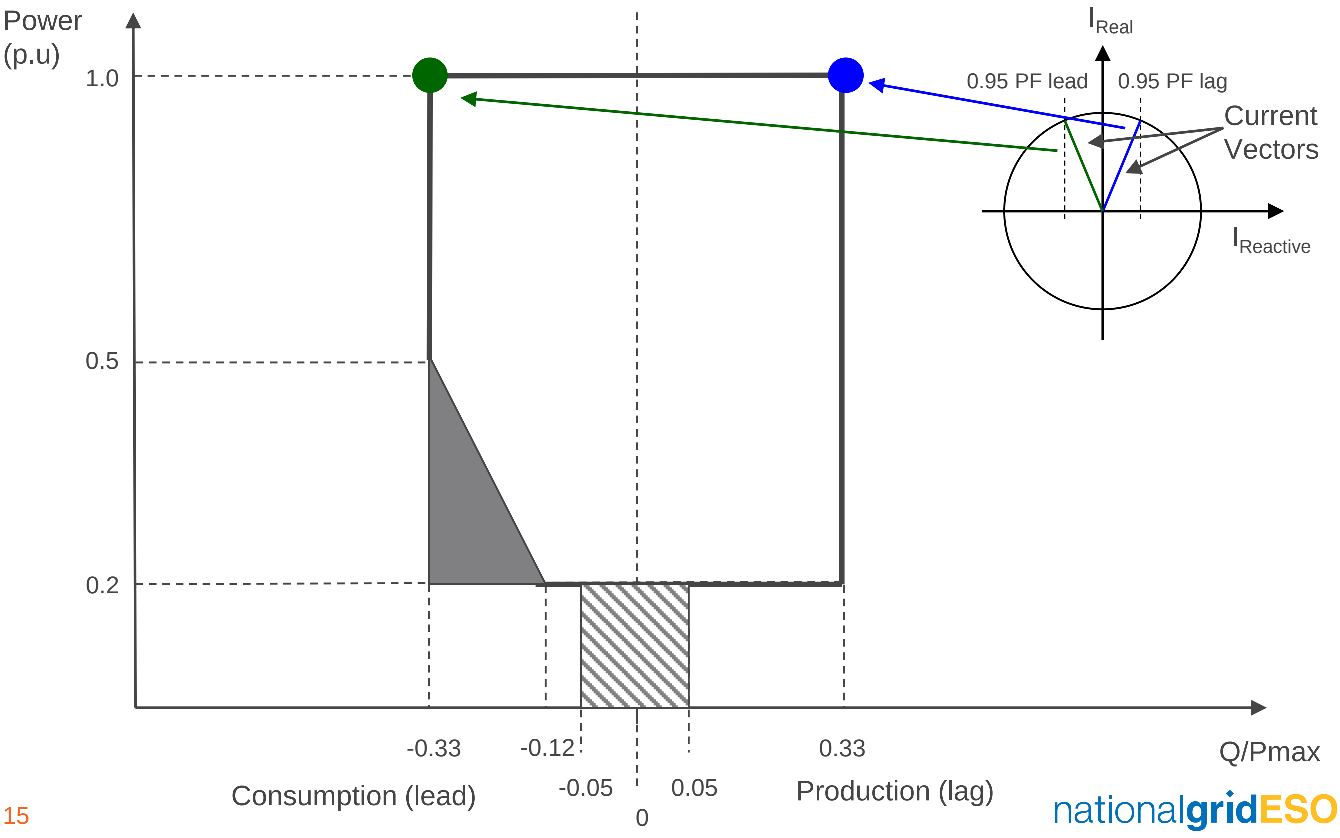
Step to voltage reference



- External Tap change



PPM Reactive Capability Requirements – Type C&D (ECC.6.3.2.4.4)



nationalgridESO

Why is Voltage Control Relevant for Fast Fault Current Injection (1)

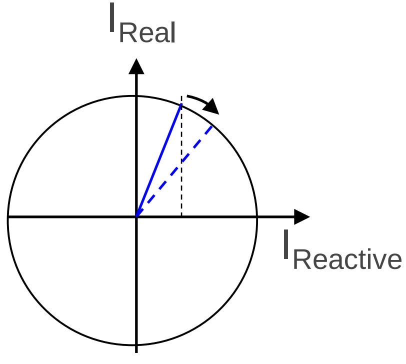
- Fast fault current injection is dependent upon the pre fault voltage
- Recalling that
- I_R Reactive current supplied under fault conditions where:
- $I_R = \Delta V_1.k + |I_{prefault}|$
- and

$\Delta V_1 = 0.9 - V_{retained}$

nationalgridESO

Why is Voltage Control Relevant for Fast Fault Current Injection (2)

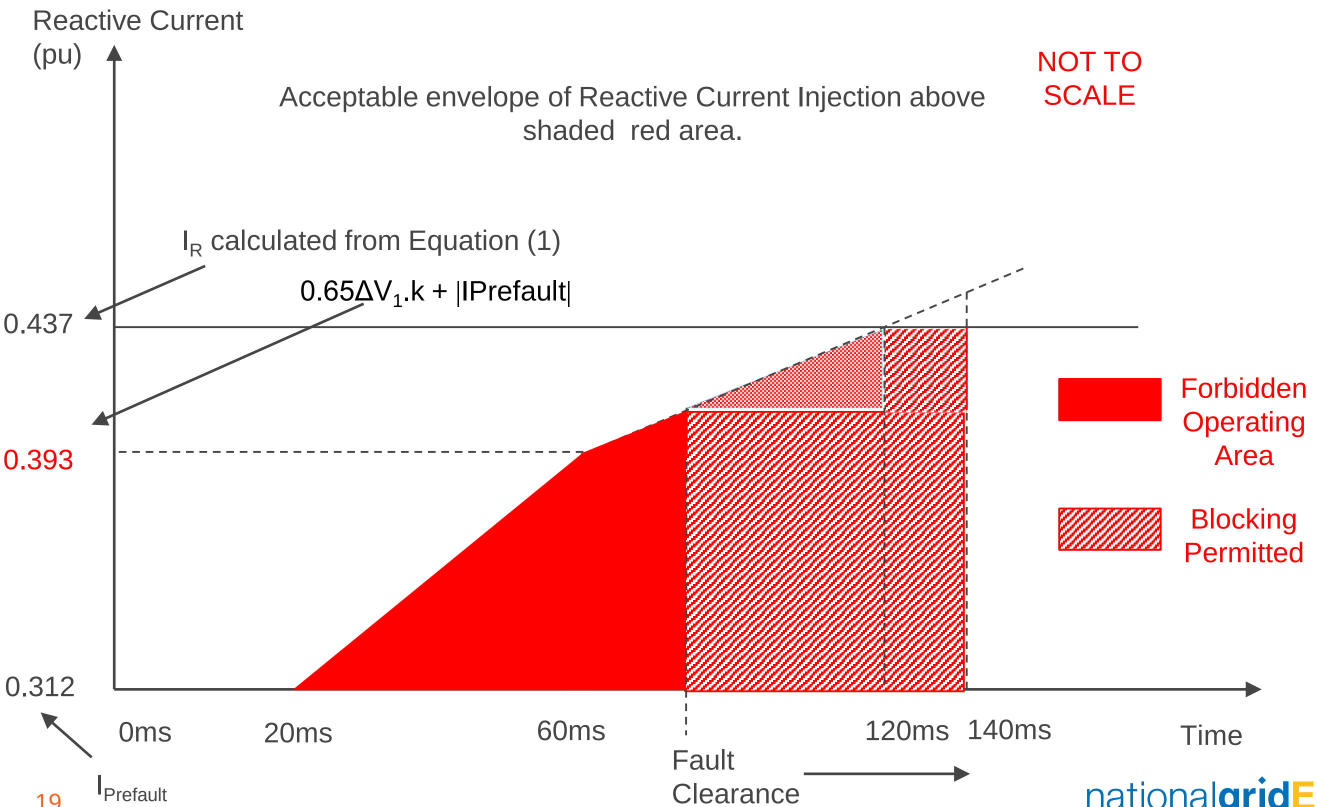
- In summary under pre-fault conditions with the Power Park Module operating at full leading conditions or full lagging conditions at Rated MW output it will be operating at rated current and therefore the additional current supplied will be limited under fault conditions.
- NOTE – With priority given to reactive current - under a voltage dip condition the vector will start to move along the locus resulting in an increase in the reactive current



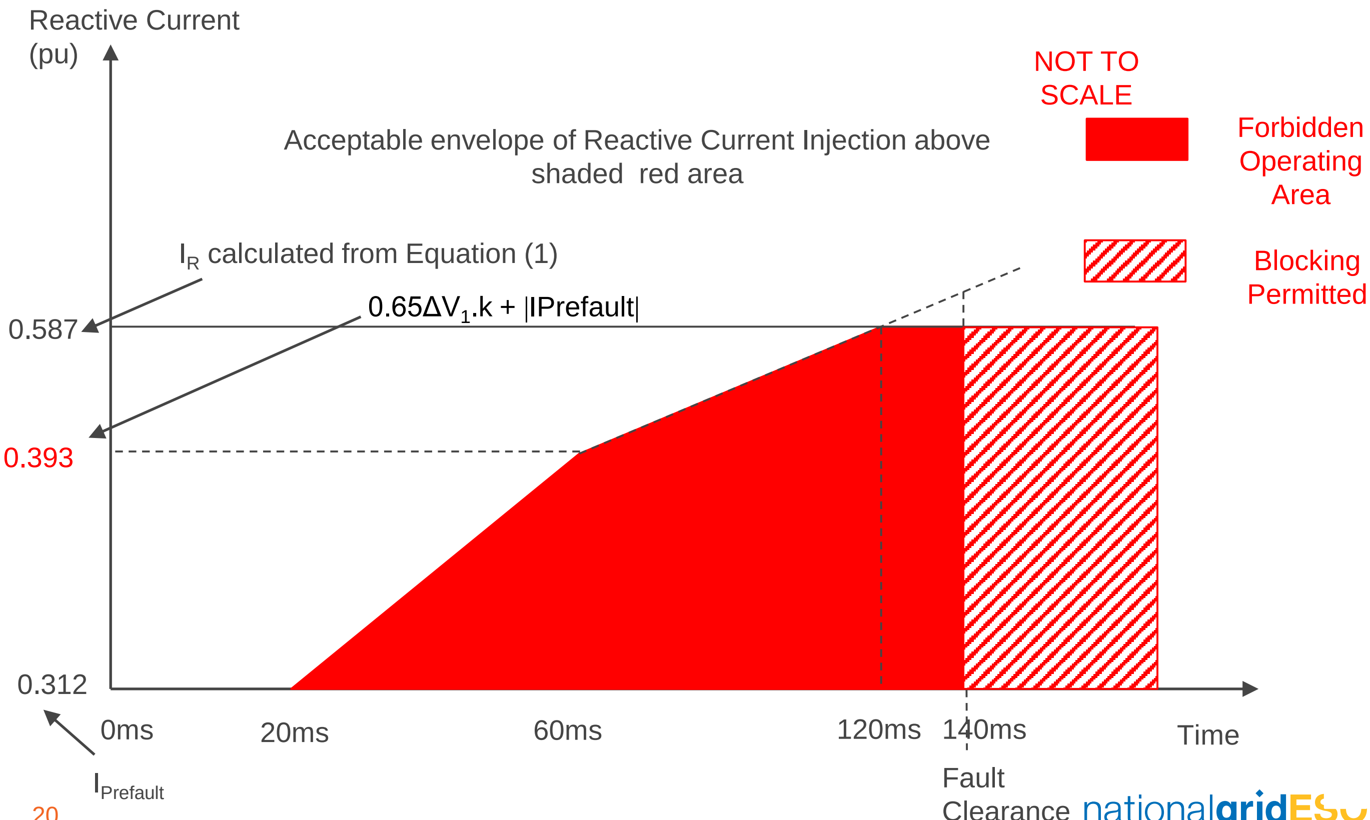
Example 1 – Power Park Module (Slide 10) operating at full MW output and full MVAr lag – volt drop to 85% and K = 2.5

- Wind farm is operating at 100MW output and 0.95 PF lagging (ie 32.8MVAr or export to the System)
- $I_R = \Delta V_1.k + |I_{prefault}|$
- And $\Delta V_1 = 0.9 - V_{retained}$
- If V Prefault = 0.96 pu and Q max = 0.95 PF lag on a 4% droop
- In this case the retained voltage ($V_{retained}$) is 0.85 pu
- $\Delta V_1 = 0.9 - V_{retained} = 0.9 - 0.85 = 0.05$
- $I_{prefault}$ = sin(arccos0.95) = 0.312pu
- $I_R = \Delta V_1.k + |I_{prefault}| = 0.05 \times 2.5 + 0.312 = 0.437$pu
- $I_R = (0.65\Delta V_1.k) + |I_{prefault}| = (0.65 \times 0.05 \times 2.5) + 0.312 = 0.3933$

Example 1 - FFCI Figure ECC.16.3.16(b)



Example 1 - FFCI Figure ECC.16.3.16(c)



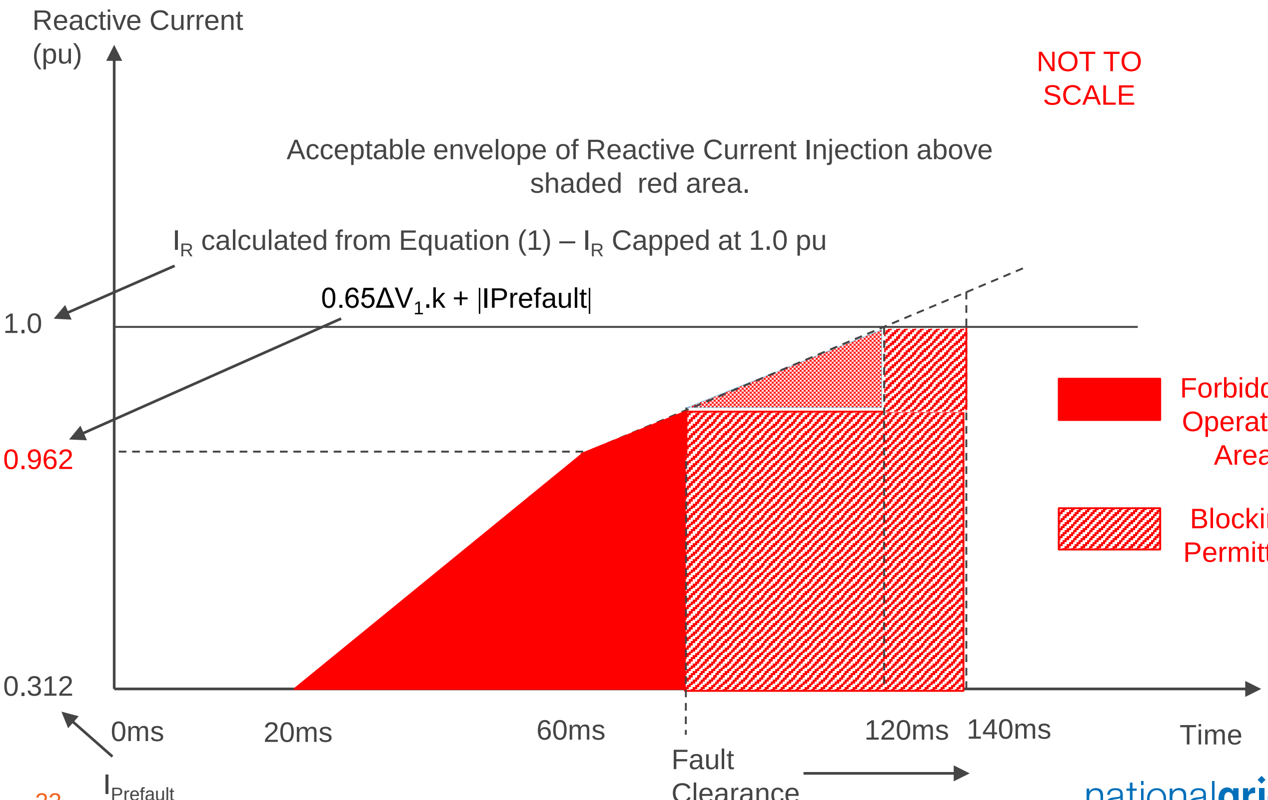
nationalgridESO

Example 3 – Power Park Module (Slide 11) operating at full MW output and full MVAr output – volt drop to 50% and and K = 2.5

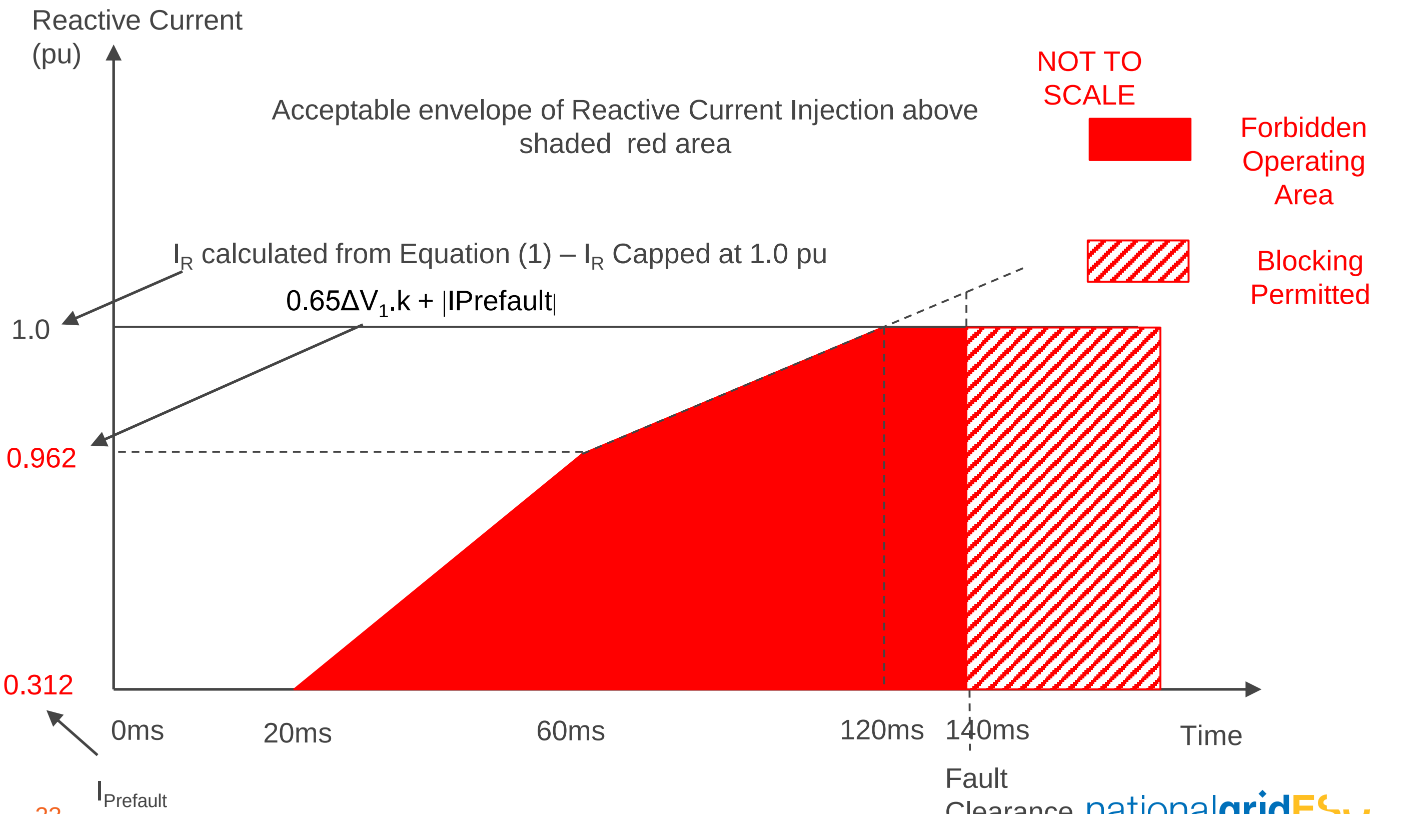
- Wind farm is operating at 100MW output and 0.95 PF lagging (ie 32.8MVAr or export to the System)
- $I_R = \Delta V_1.k + |I_{Prefault}|$
- And $\Delta V_1 = 0.9 - V_{retained}$
- If V Prefault = 0.96p.u and Q max = 0.95 PF lag on a 4% droop
- In this case the retained voltage ($V_{retained}$) is 0.5 pu
- $\Delta V_1 = 0.9 - V_{retained} = 0.9 - 0.5 = 0.4$
- $I_{prefault} = \sin(\arccos 0.95) = 0.312$pu
- $I_R = \Delta V_1.k + |I_{Prefault}| = 0.4 \times 2.5 + 0.312 = 1.312$ pu – *capped at 1.0pu reactive current*
- $I_R = (0.65\Delta V_1.k) + |I_{prefault}| = (0.65 \times 0.4 \times 2.5) + 0.312 = 0.962$ pu

nationalgridESO

Example 3 - FFCI Figure ECC.16.3.16(b)



Example 3 - FFCI Figure ECC.16.3.16(c)



nationalgridESO

Example 6 – Power Park Module (Slide 11) operating at full MW output and Unity Power Factor – volt drop to 85% and K = 2.5

- Wind farm is operating at 100MW output and operating at unity power factor (ie 0 MVAr export to the System)
- $I_R = \Delta V_1.k + |I_{prefault}|$
- And $\Delta V_1 = 0.9 - V_{retained}$
- If V Prefault = 1.0 p.u and Q = 0 on a 4% droop with a target voltage setpoint of 1.0pu.
- In this case the retained voltage ($V_{retained}$) is 0.85 pu
- $\Delta V_1 = 0.9 - V_{retained} = 0.9 - 0.85 = 0.05$
- $I_{prefault} = \sin(\arccos 1) = 0pu$
- $I_R = \Delta V_1.k + I_{Prefault} = 0.05 \times 2.5 + 0 = 0.125pu$
- $I_R = (0.65\Delta V_1.k) + |I_{prefault}| = (0.65 \times 0.05 \times 2.5) + 0 = 0.08125$

Example 7 – Power Park Module (Slide 11) operating at full MW output and Unity Power Factor – volt drop to 50% and K = 2.5

- Wind farm is operating at 100MW output and operating at unity power factor (ie 0 MVAr export to the System)
- $I_R = \Delta V_1 . k + |I_{prefault}|$
- And $\Delta V_1 = 0.9 - V_{retained}$
- If V Prefault = 1.0 p.u and Q = 0 on a 4% droop with a target voltage setpoint of 1.0pu.
- In this case the retained voltage ($V_{retained}$) is 0.85 pu
- $\Delta V_1 = 0.9 - V_{retained} = 0.9 - 0.5 = 0.4$
- $I_{prefault} = \sin(\arccos 1) = 0pu$
- $I_R = \Delta V_1 . k + I_{Prefault} = 0.4 \times 2.5 + 0 = 1pu$
- $I_R = (0.65 \Delta V_1 . k) + |I_{prefault}| = (0.65 \times 0.4 \times 2.5) + 0 = 0.65$

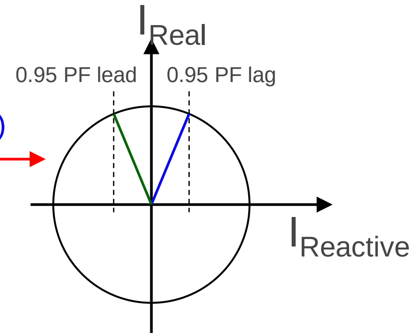
Example 10 – Power Park Module (Slide 11) operating at full MW output and full MVAr output – volt drop to 85% and K = 2.5

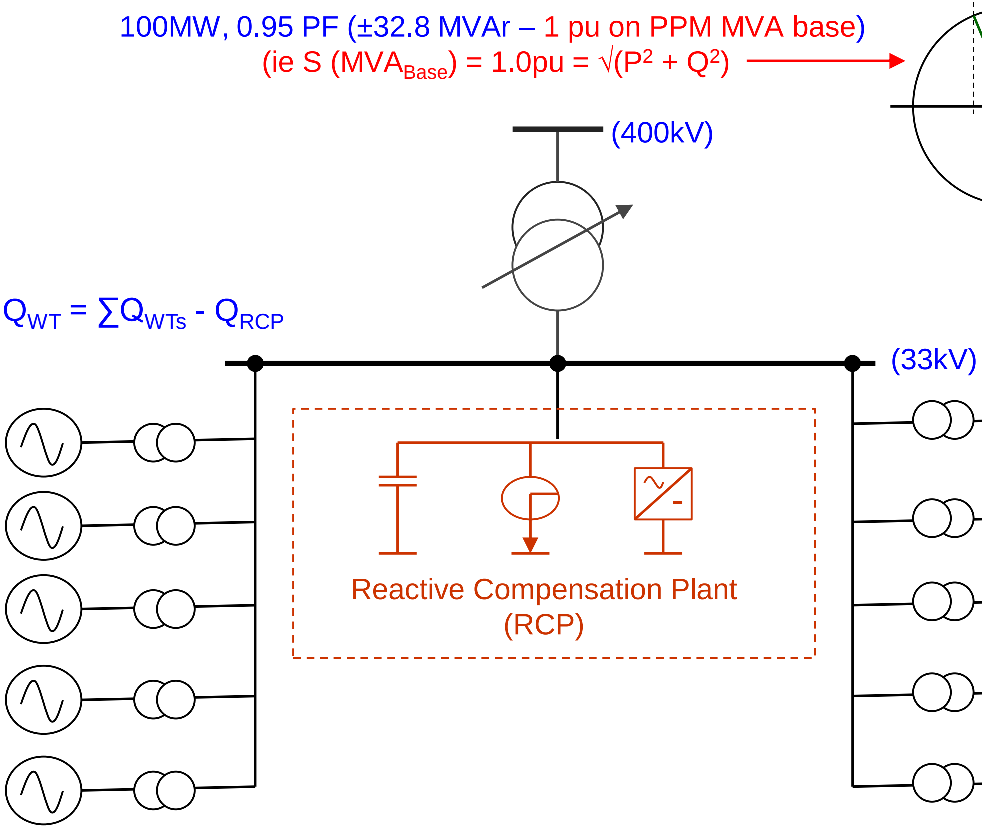
- Wind farm is operating at 100MW output and 0.95 PF leading (ie - 32.8MVAr import to the System)
- $I_R = \Delta V_1.k + |I_{Prefault}|$
- And $\Delta V_1 = 0.9 - V_{retained}$
- If V Prefault = 1.04p.u and Q max = 0.95 PF lead on a 4% droop
- In this case the retained voltage ($V_{retained}$) is 0.85 pu
- $\Delta V_1 = 0.9 - V_{retained} = 0.9 - 0.85 = 0.05$
- $I_{prefault}$ = sin(arccos-0.95) = -0.312pu (lead)
- $I_R = \Delta V_1.k + |I_{Prefault}| = 0.05 \times 2.5 + 0.312 = 0.437$
- $I_R = (0.65\Delta V_1.k) + |I_{prefault}| = (0.65 \times 0.05 \times 2.5) + 0.312 = 0.393$
- As per lagging case

Requirements from a Power Park Unit Perspective

- The requirements for FFCI are generally defined at the Connection Point of the Power Park Module although the legal text also specifies the requirement can be demonstrated at the Power Park Unit terminals if required.
- This can be achieved by starting with the Rating of the PPM at the Connection Point
- Subtract any external reactive power compensation equipment contribution (MVAr) on the MVA base and calculate the wind turbine contribution. This could be achieved by dividing the total contribution by the number of turbines assuming they are all the same type and rating

Power Park Unit Contribution





Other Issues

- As part of this work, it has been identified that there are differences between the characteristics of full converter based plant and DFIG Machines.
- The drafting has been amended to state “To permit additional flexibility for example from **Power Park Modules** made up of full converter machines, DFIG machines, induction generators or **HVDC Systems** or **Remote End HVDC Converters**, **The Company** will permit transient deviations below the shaded area shown in Figure ECC.16.3.16(b) or ECC.16.3.16(c) but the total reactive current supplied during this period shall be at least that bound by the shaded area shown in Figure ECC.16.3.16(b) or ECC.16.3.16 (c).

Compliance

- Table A.3.5.1 – Typo from HVDC Implementation – should be 0% for HVDC Equipment
- Typo’s – (i) / (ii) etc
- Type tested solutions – to be confirmed
- Queries on Fault Ride Through current injection testing

Next Steps

- National Grid welcome comments on the revised text but are very keen to finalise this solution.
- Stakeholders requested to identify if there are broadly comfortable or would wish to raise a workgroup alternative.
- Views on implementation
- Voting