Advanced Voltage Controls for a Wind Power Plant

Panel Session: Reactive power capabilities of wind turbine generators and representation in load flow studies

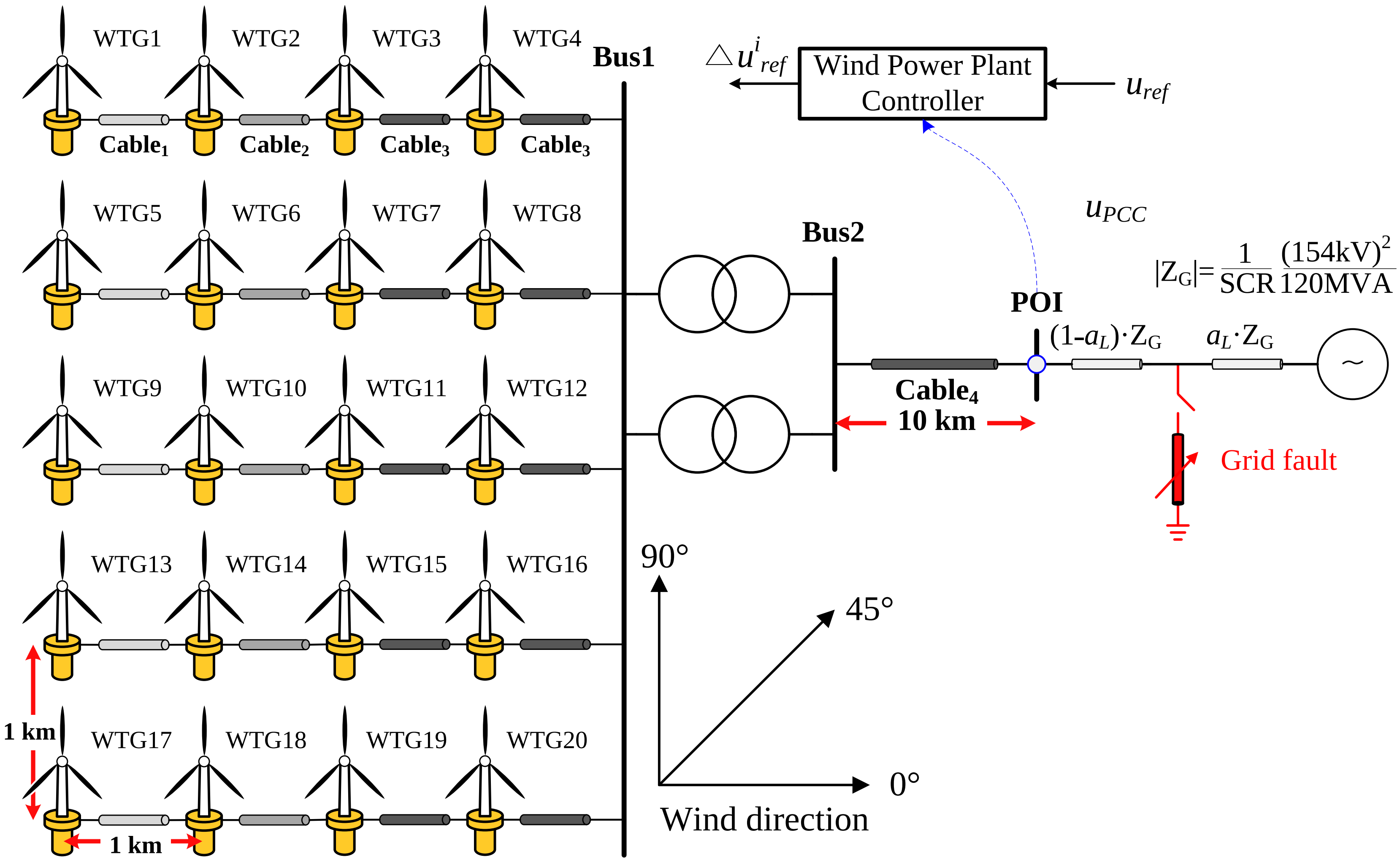
Presenter: Eduard Muljadi[1]
Co-authors: Yongcheol Kang[2], Jinho Kim[2]
[1]National Renewable Energy Laboratory, [2]Chonbuk National University

IEEE-PES-General Meeting
July 17 – 21 2016, Boston MA

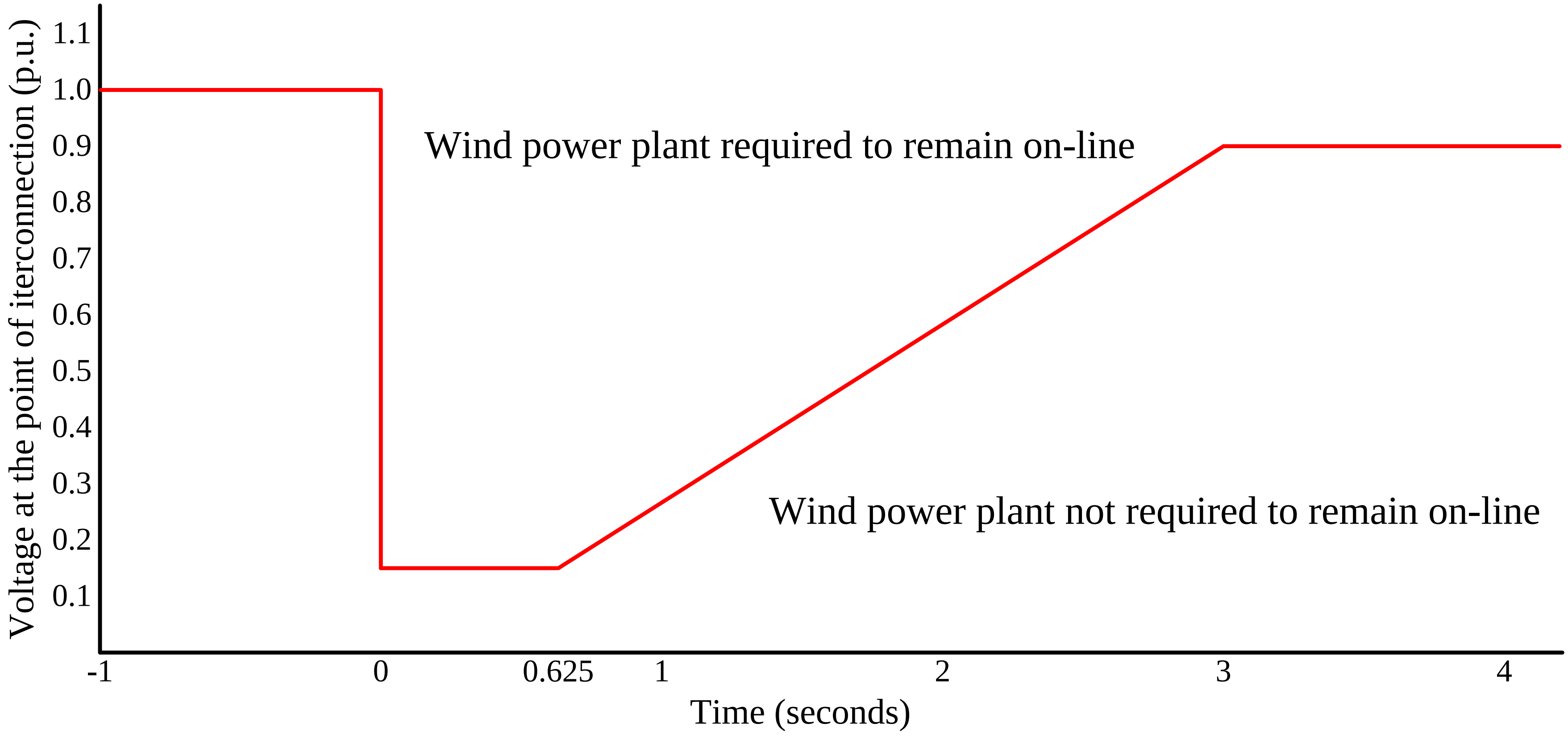
NREL/PR-5D00-66795

Advanced control scheme for a WPP

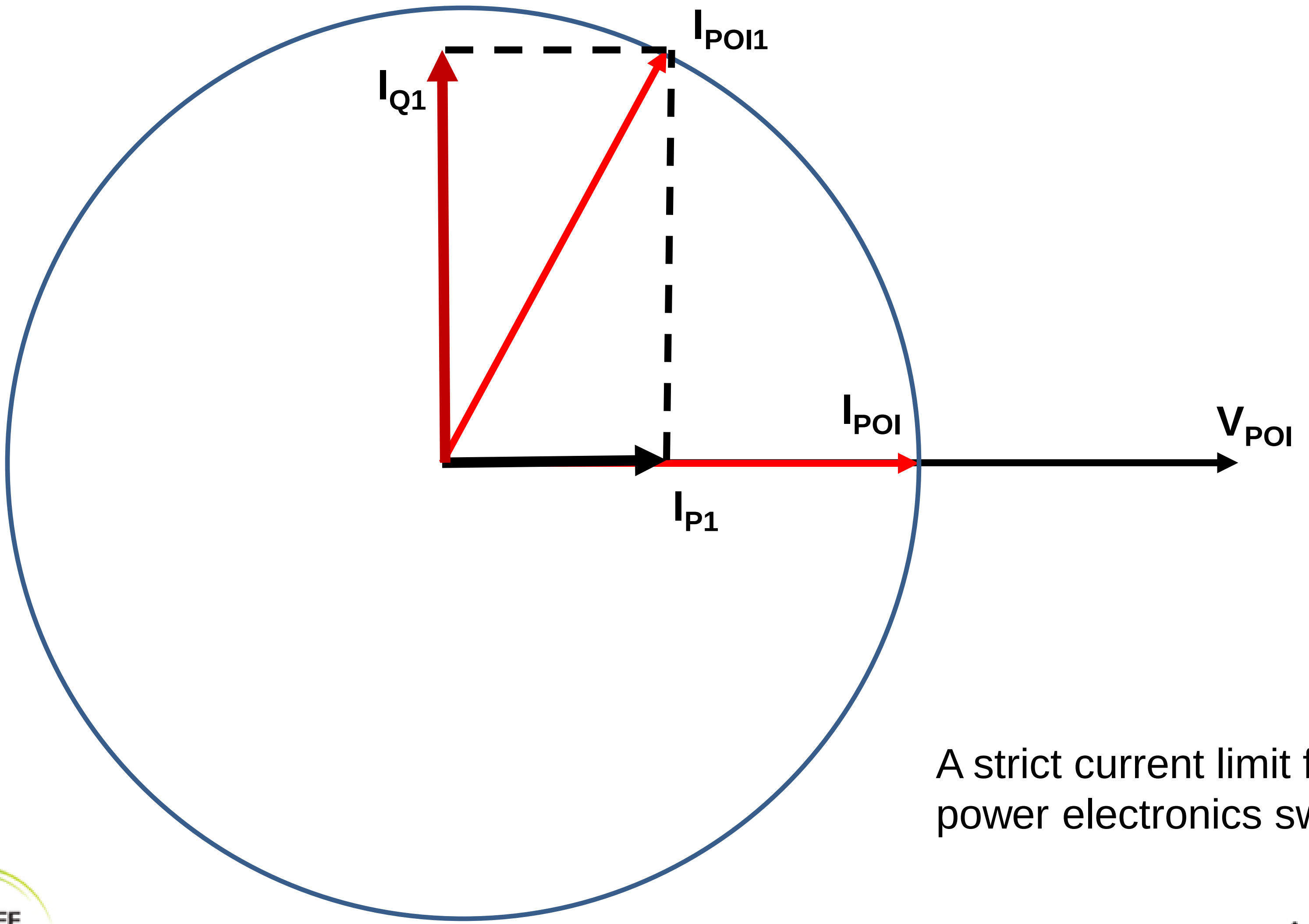
- Both the wind power plant (WPP) level and the wind turbine generator (WTG) level
- Diversity within WPP is considered
- Include high voltage mitigation at the fault clearance
- The controller takes advantage of available reactive power at each WTG
- The reactive power is adaptively controlled as a function of the voltage deviation


WTG1
WTG2
WTG3
WTG4
Bus1
$\triangle u^{i}_{ref}$
Wind Power Plant Controller
u_{ref}
$Cable_1$
$Cable_2$
$Cable_3$
$Cable_3$
WTG5
WTG6
WTG7
WTG8
u_{PCC}
Bus2
$|Z_G| = \frac{1}{SCR} \frac{(154kV)^2}{120MVA}$
POI
$(1-a_L) \cdot Z_G$
$a_L \cdot Z_G$
WTG9
WTG10
WTG11
WTG12
$Cable_4$
10 km
Grid fault
WTG13
WTG14
WTG15
WTG16
90°
45°
1 km
WTG17
WTG18
WTG19
WTG20
0°
Wind direction
1 km

Voltage Ride Through

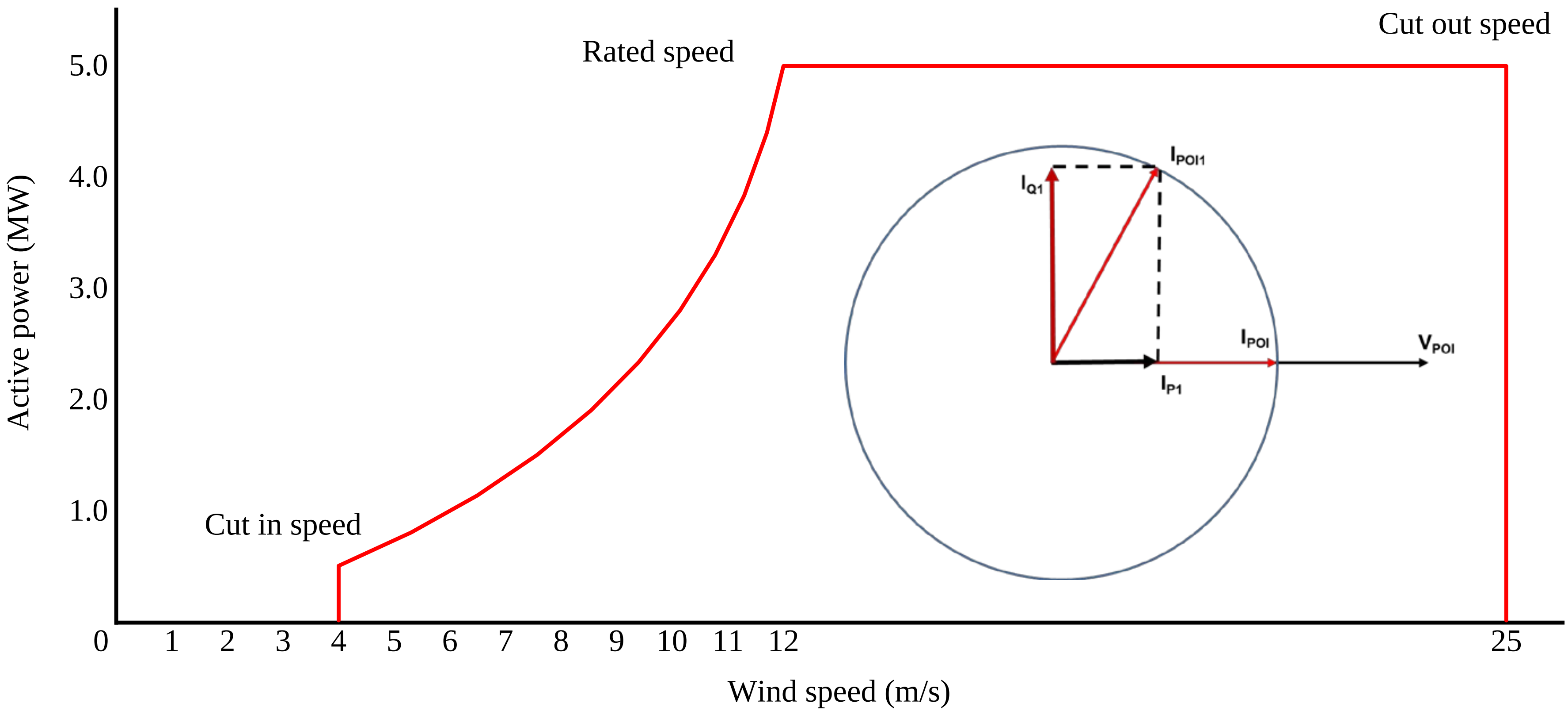


Operating Currents (Converter Based)

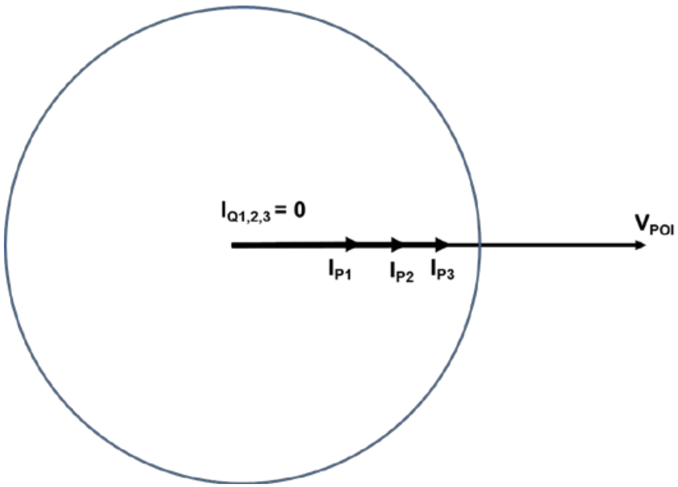


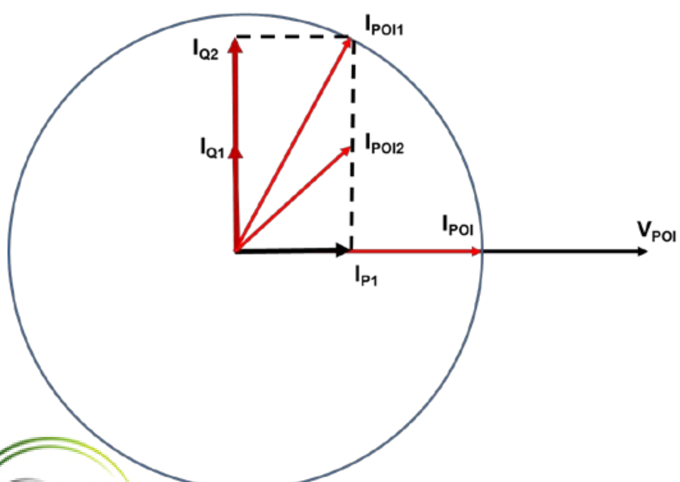
A strict current limit for
power electronics switches

Typical Operating Region of a WTG



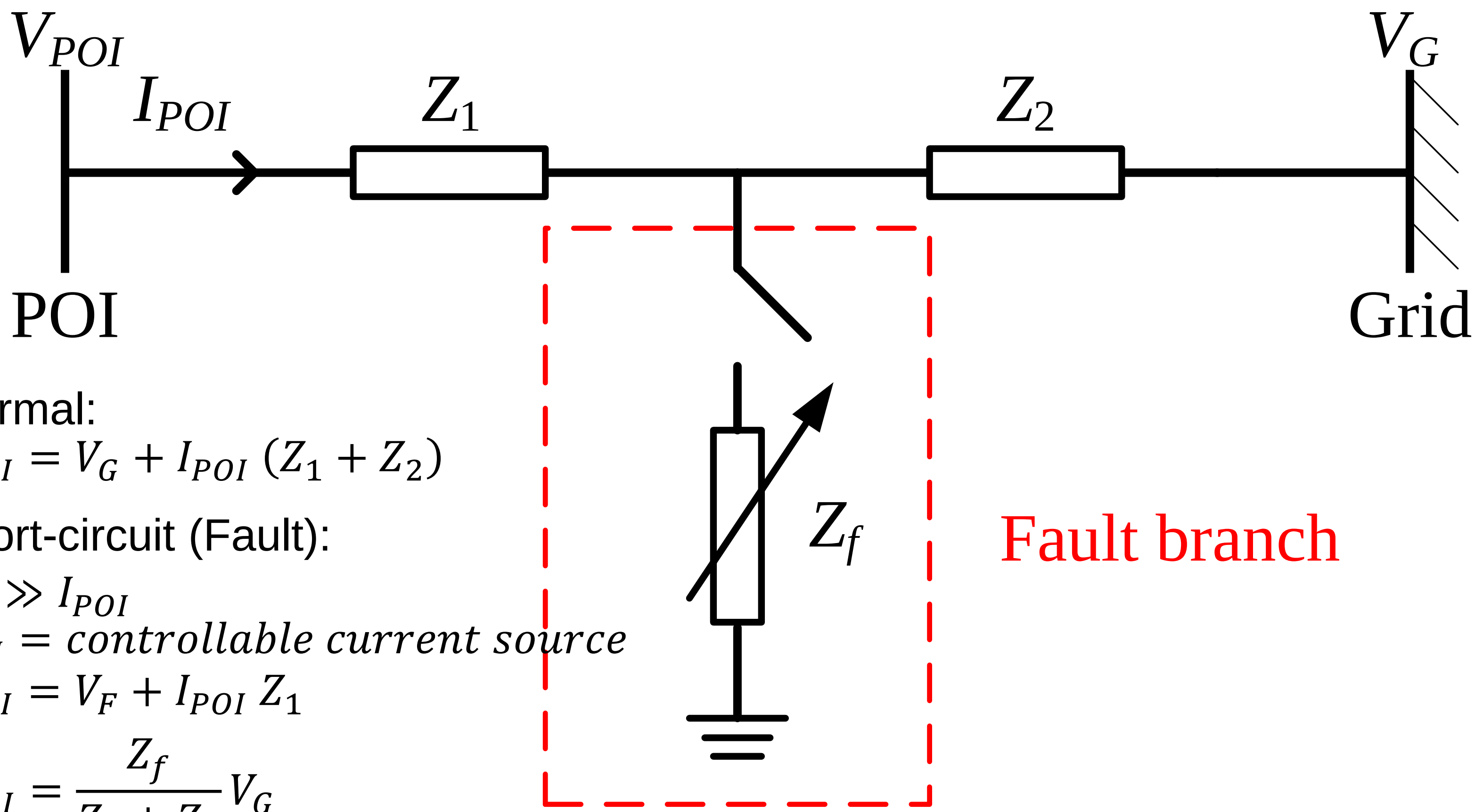
Reactive Power Control Options





- Options 1: PF = 1 (or fixed)
  - adopted by many WPP
  - I_Q = 0 (or proportional to I_p)
  - I_P = varies with wind speed until I_{prated} is reached.
  - Voltage is controlled by the utility
- Options 2: controllable reactive power
  - I_Q is controlled to compensate voltage drop along the lines in normal operation.
  - I_Q is controlled to provide LVRT (I_{Qmax}); $Q_{max} = \sqrt{[(S_{max})^2 - (P)^2]}$

Simplified Representation of a Faulted Line



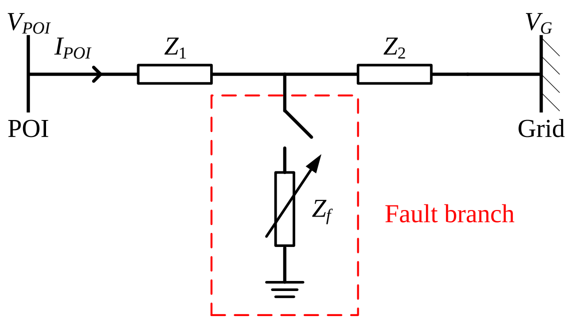
Normal:

$$V_{POI} = V_G + I_{POI}\,(Z_1 + Z_2)$$

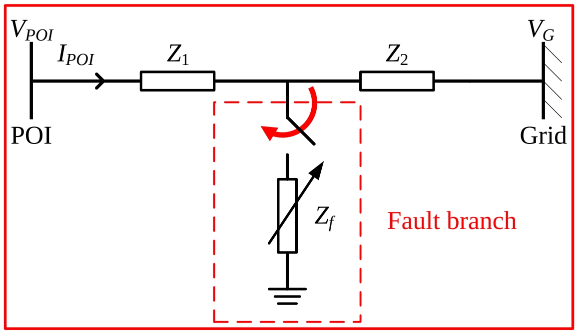
Short-circuit (Fault):

$$I_{SC} \gg I_{POI}$$
$$I_{POI} = controllable\ current\ source$$
$$V_{POI} = V_F + I_{POI}\,Z_1$$
$$V_{POI} = \frac{Z_f}{Z_f + Z_2} V_G$$

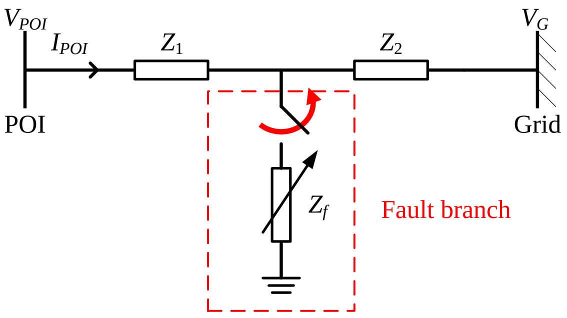
Sequence of Fault Event and Recovery



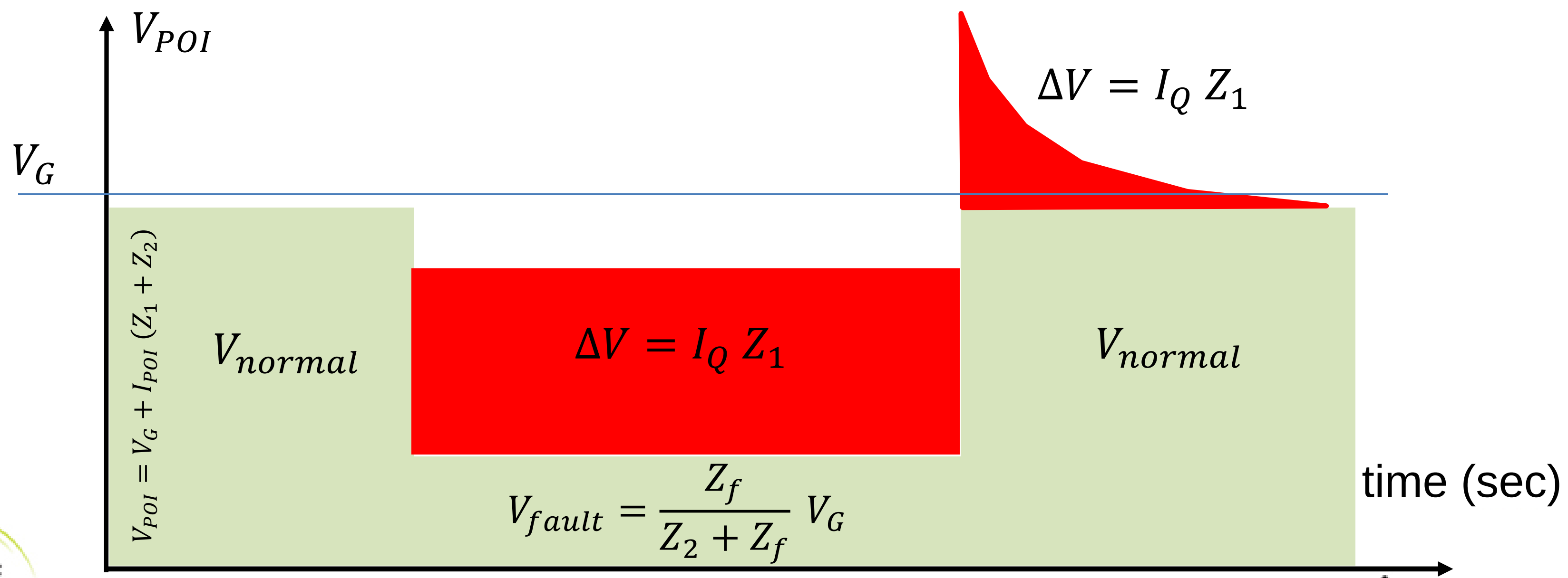
Pre-fault



Fault Event



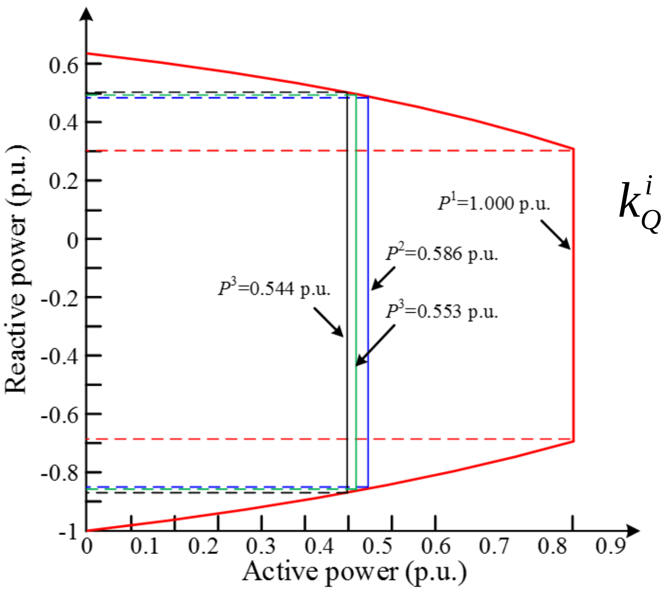
Fault Clearance



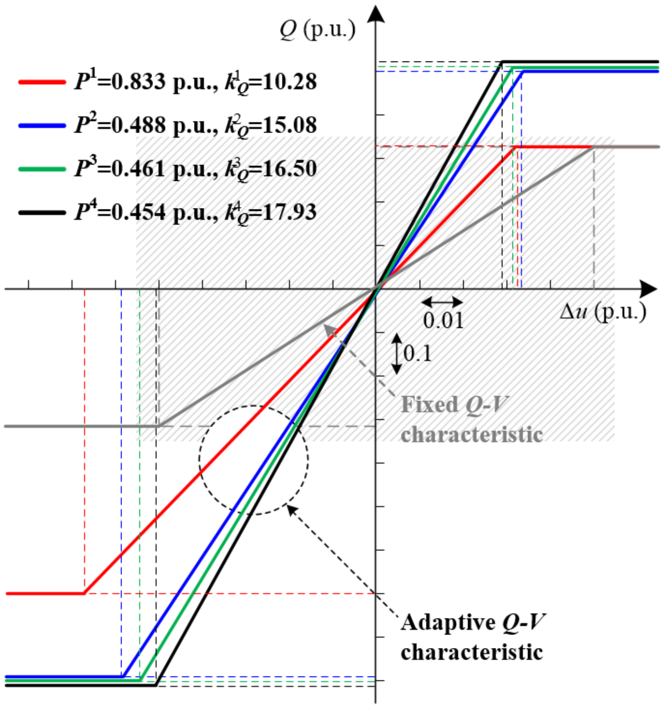
Adaptive Q-V Control Function

Adaptive Q-V characteristic of a DFIG to correct voltage deficit during fault event

- Function: Q injection depending on voltage deficit
- Linear region: Gain of Q-V characteristic in proportion to Q capability
- Saturation region: Q_{max} and Q_{min} depending on Q capability



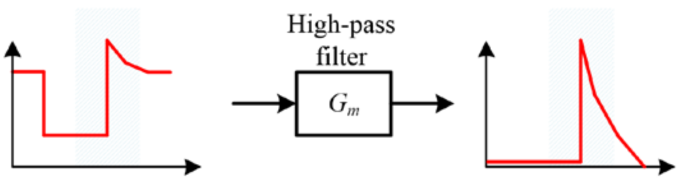
$$k_Q^i = \frac{Q_{max}^i - Q_{min}^i}{\Delta v}$$



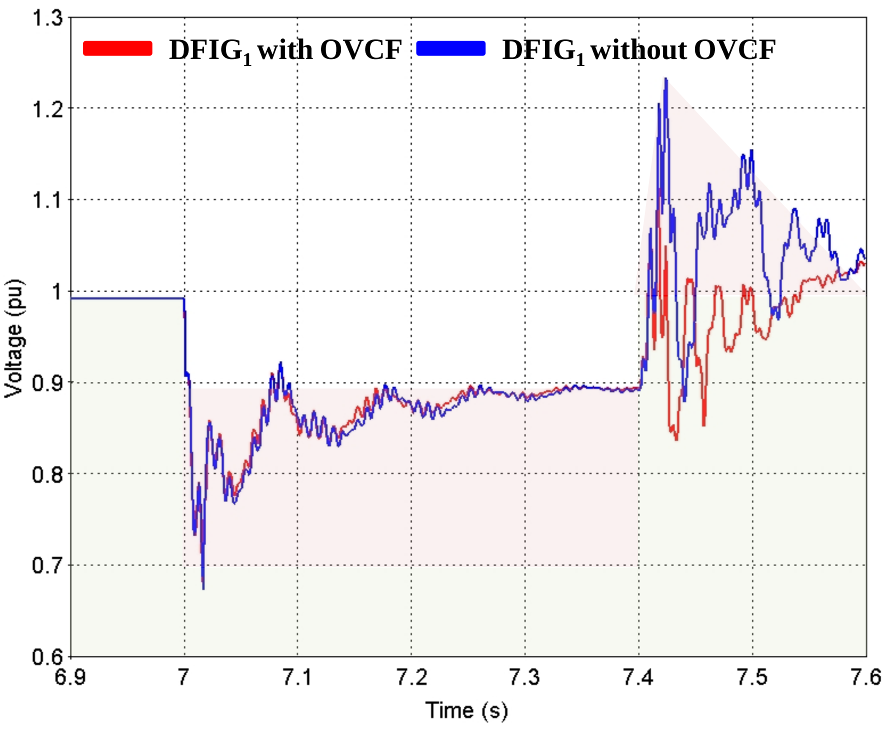
Over Voltage Control Function (OVCF)

OVCF of WPP to avert a sudden overvoltage at the removal of the fault

- Function: Q reduction of a WPP in proportion to the rate of the change of the voltage
- High-pass filter (G_m) is activated only to overcome sudden overvoltage at the removal of the fault



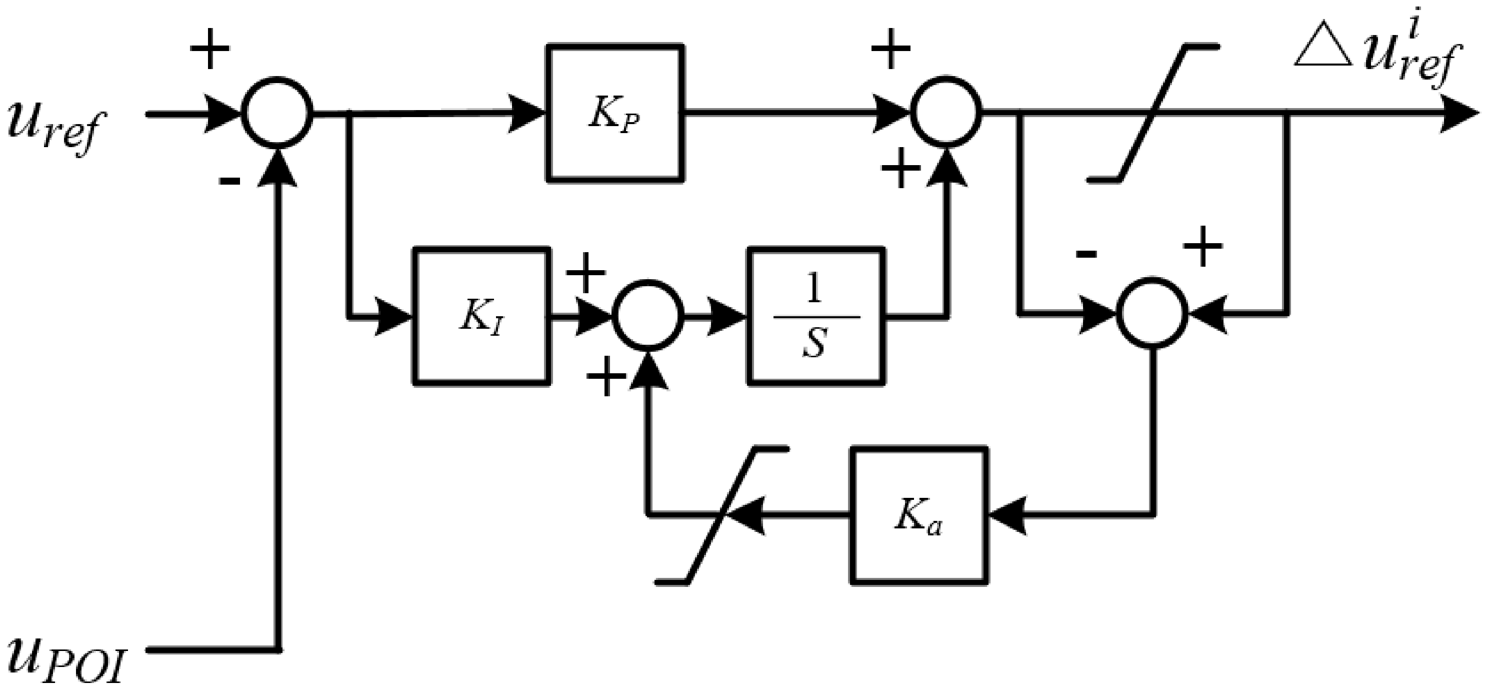
$$G_m(s) = \begin{cases} 0 & \text{for } u_{POI} \le 0.90\ \text{p.u.} \\ \dfrac{s}{s+d} & \text{for } u_{POI} > 0.90\ \text{p.u.} \end{cases}$$



Plant Level Controller

Plant level controller provides voltage regulation at the POI

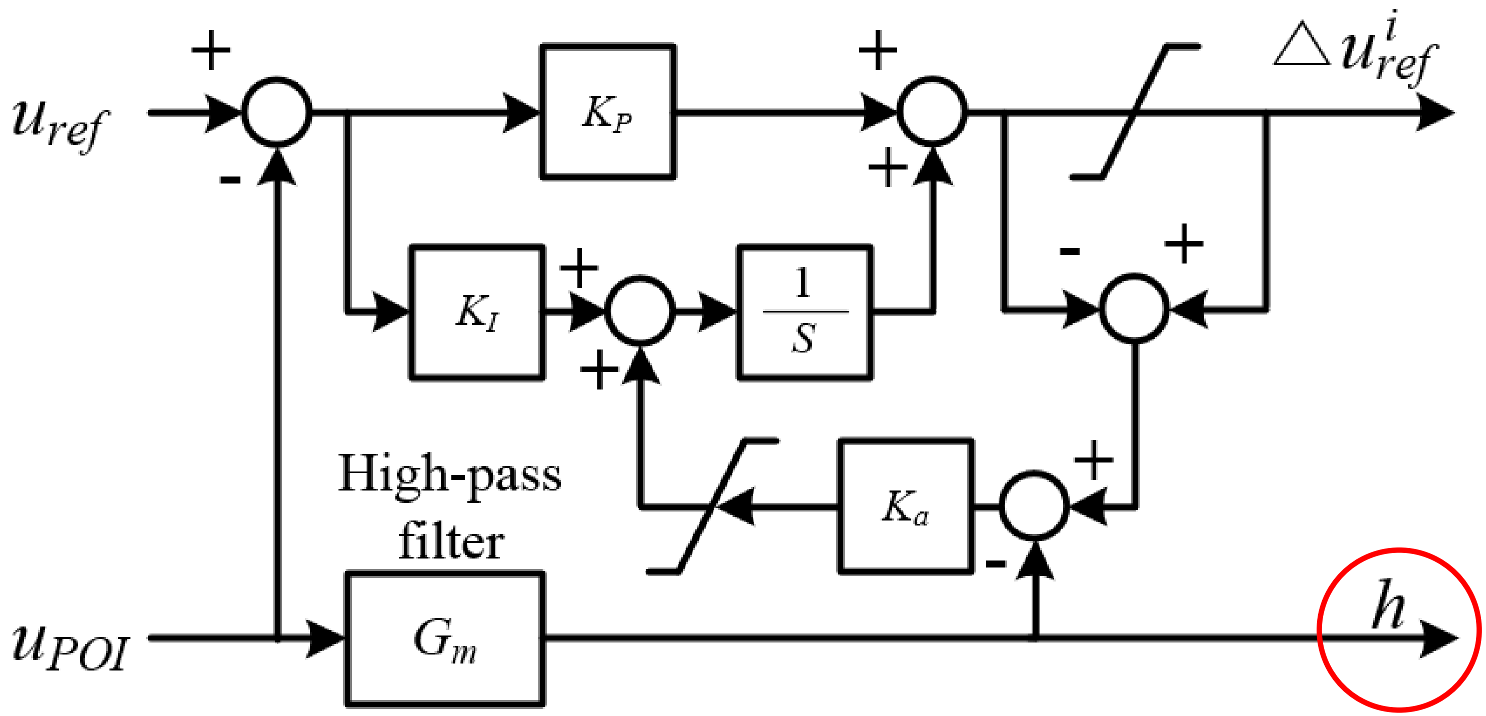
- Function: Calculating and sending partial voltage set-point (Δu^{i}_{ref}) to wind turbine generators
- It helps to correct a voltage deficit during a fault event
- It might commit the sudden overvoltage at the removal of the fault because of surplus of Δu^{i}_{ref}



Plant Level Controller (including OVCF)

Plant level controller provides voltage regulation at the POI

- Function: Providing Δu^{i}_{ref} and high-pass filter output (h) to wind turbine generators (WTGs)
- It helps to correct a voltage deficit during a fault event as well as overcome a sudden overvoltage at the removal of the fault



G_m is activated only to overcome sudden overvoltage at the removal of the fault.

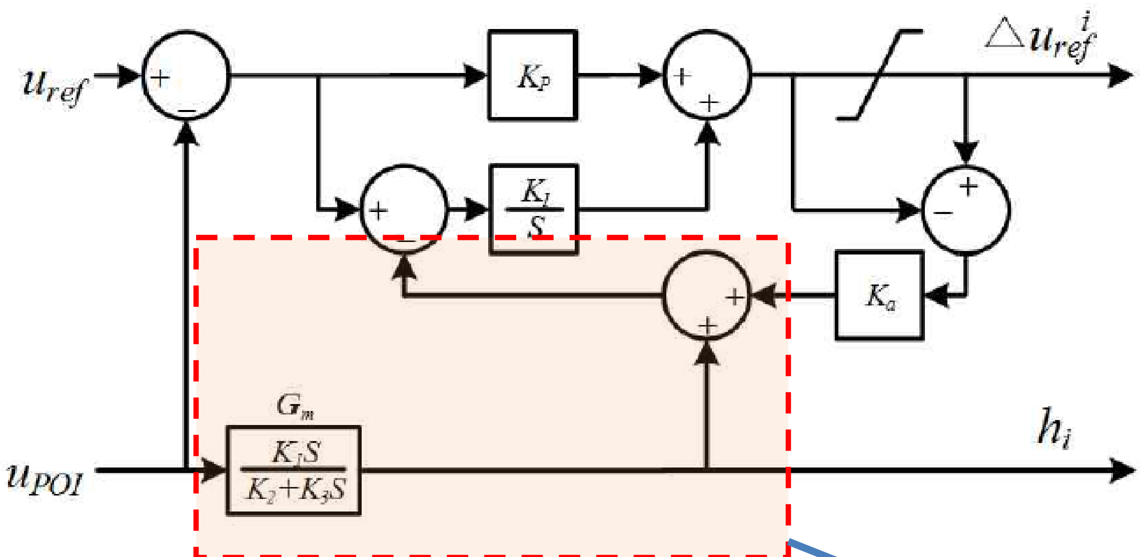
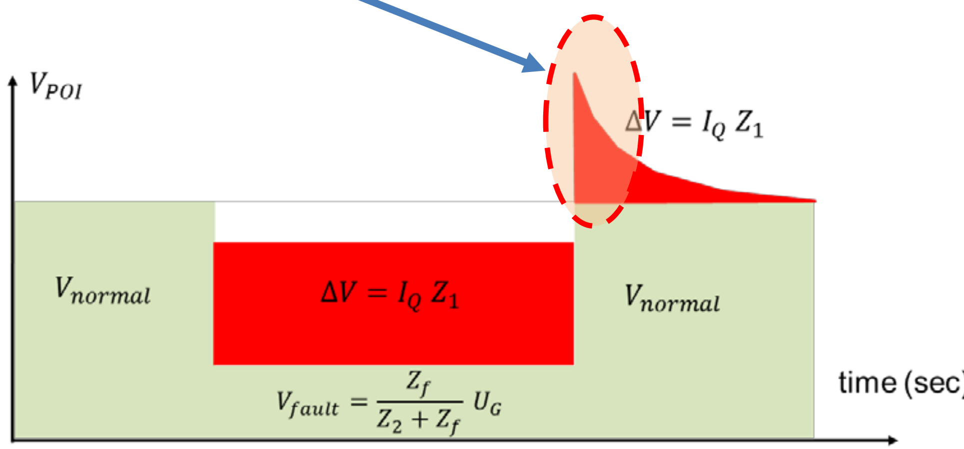
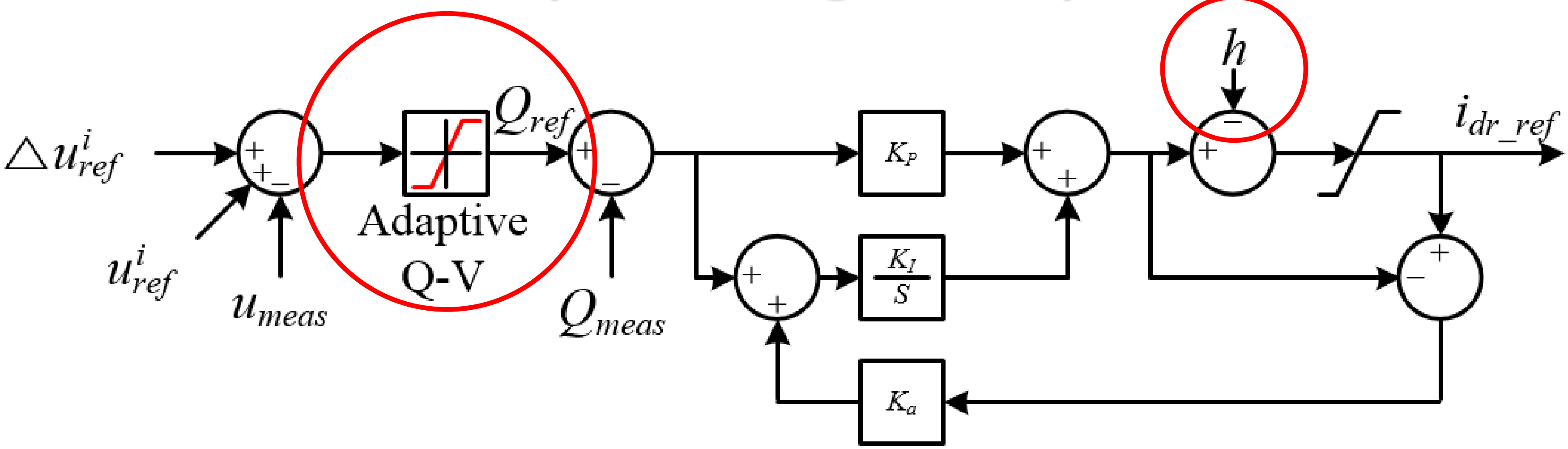


Fig. 1 WPP controller

$$G_m(s) = \begin{cases} 0 & for\ u_{POI} \le 0.90 \\ \dfrac{s}{s+d} & for\ u_{POI} > 0.90 \end{cases}$$



Turbine Level Controller (including OVCF)



During a fault event

- Adaptive Q-V function enables the WTGs to make use of available Q capabilities of the WTGs

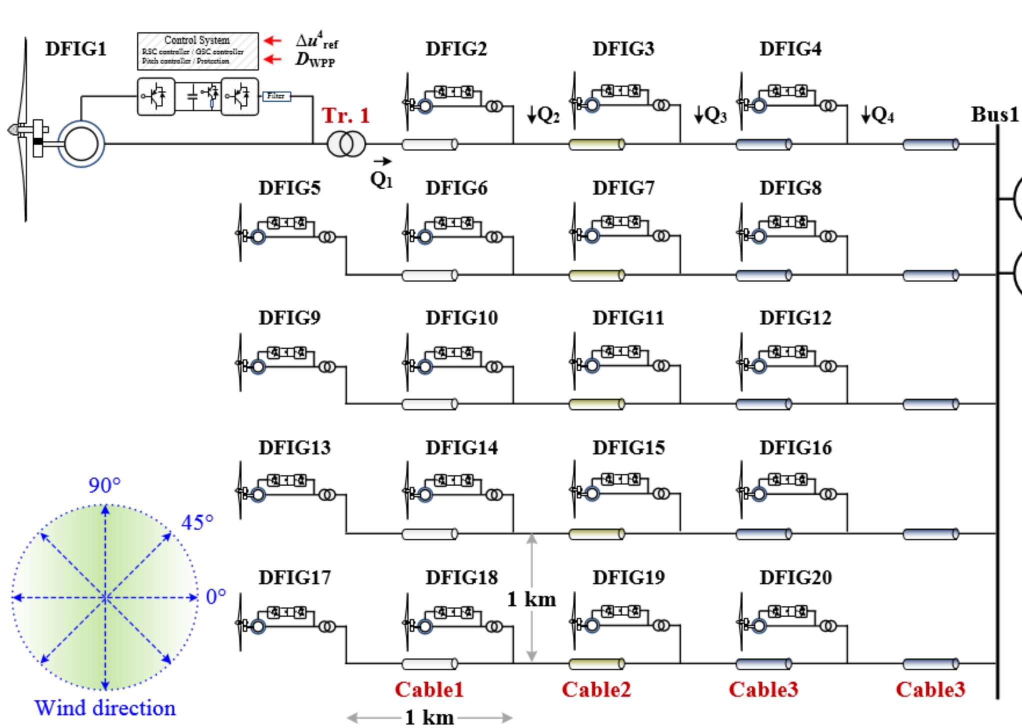
After the fault clearance

- h_i is obtained from the modified washout which passes the fast varying components of the POI voltage larger than 0.9 p.u. and it is applied to prevent the overvoltage at the POI and the terminals of the WTGs by by eliminating the accumulated values in the integrator at the moment

Simulation Verification

Case 1
- 0.5-p.u. grid fault for 300 ms, SCR of 4, a_L of 0.1, and wind speed of 12 m/s with direction of 45°

Case 2
- 0.5-p.u. grid fault for 300 ms, SCR of 4, a_L of 0.1, and wind speed of 10 m/s with direction of 45°



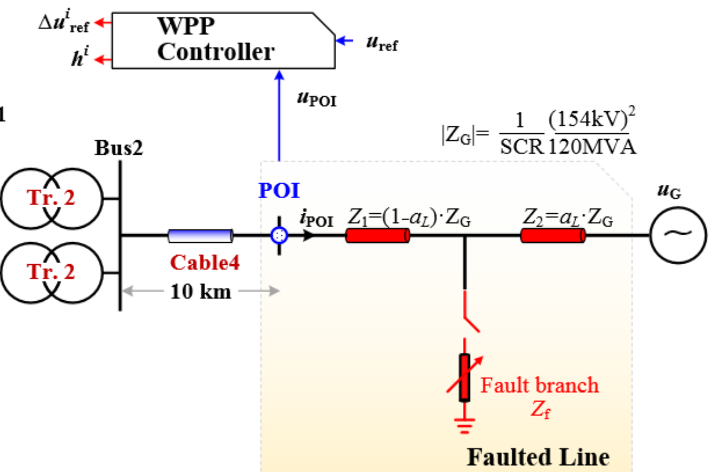
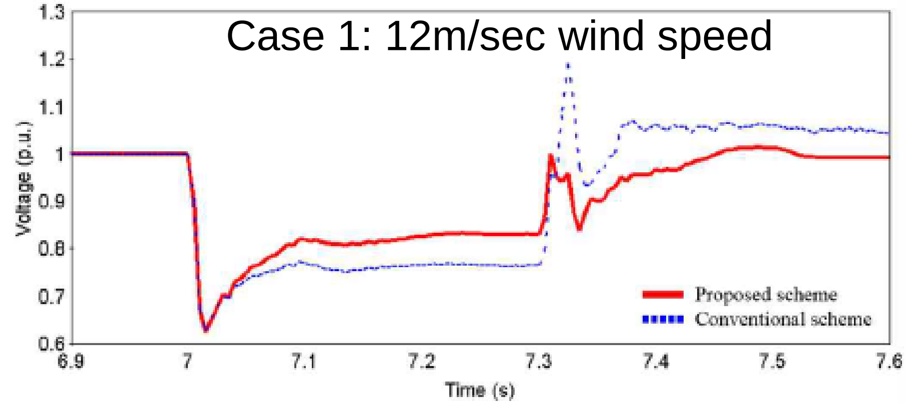


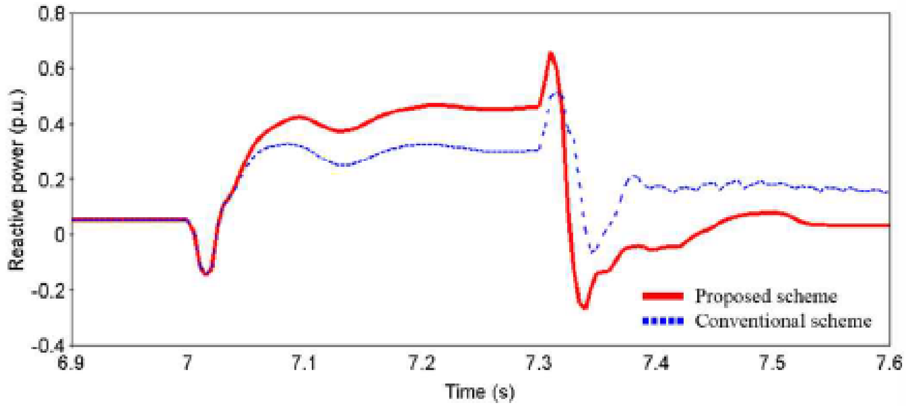
TABLE I

WIND SPEEDS (IN M/S) AT ALL WTGS IN THE WPP

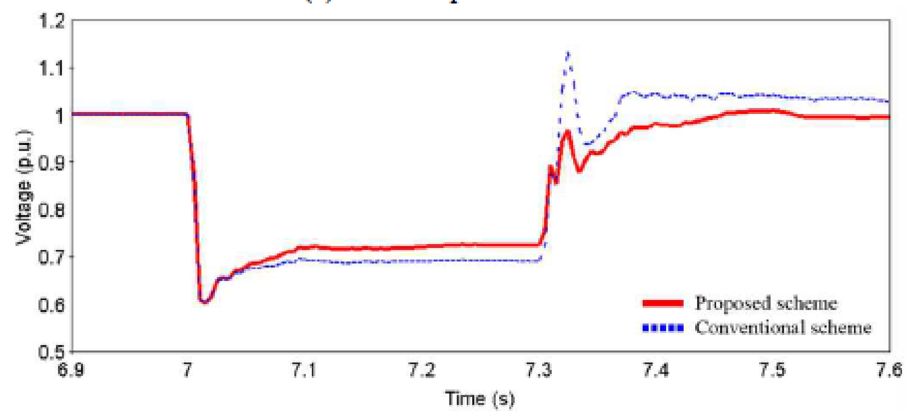
12 m/s, Direction 45° for Case 1				10 m /s, Direction 45° for Case 2			
Col. 1	Col. 2	Col. 3	Col. 4	Col. 1	Col. 2	Col. 3	Col. 4
12.00	10.04	9.85	9.80	10.00	8.36	8.21	8.17
12.00	10.04	9.85	9.80	10.00	8.36	8.21	8.17
12.00	10.04	9.85	9.85	10.00	8.36	8.21	8.21
12.00	10.04	10.04	10.04	10.00	8.36	8.36	8.36
12.00	12.00	12.00	12.00	10.00	10.00	10.00	10.00



(a) Voltage at POI

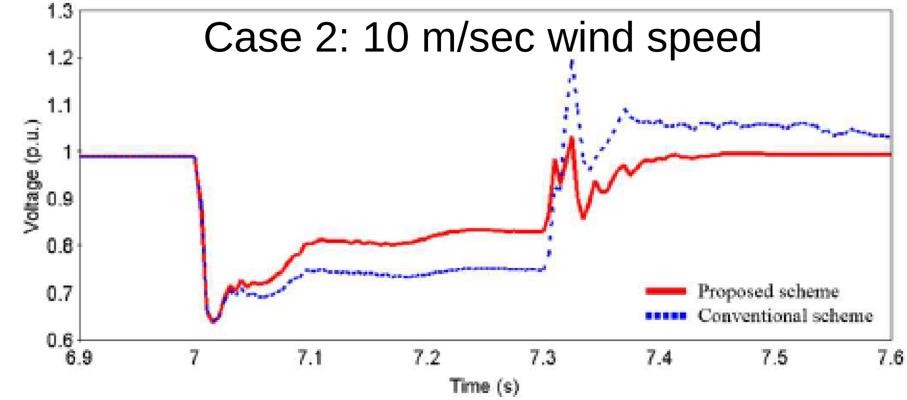


(b) Reactive power at POI

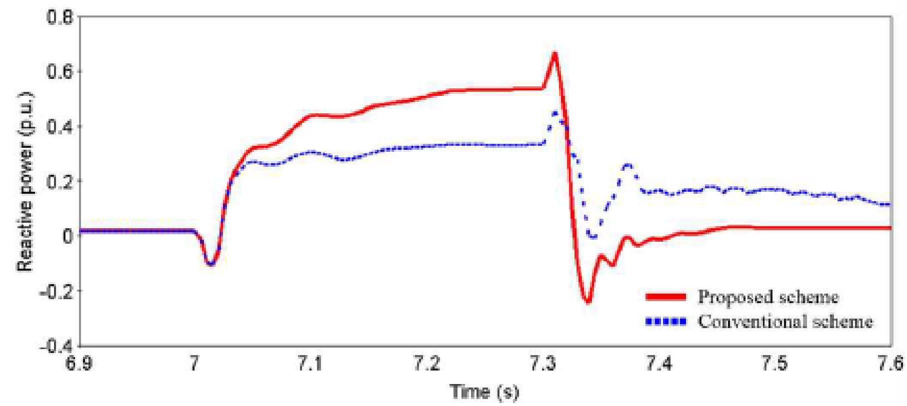


(a) Voltage at WTG

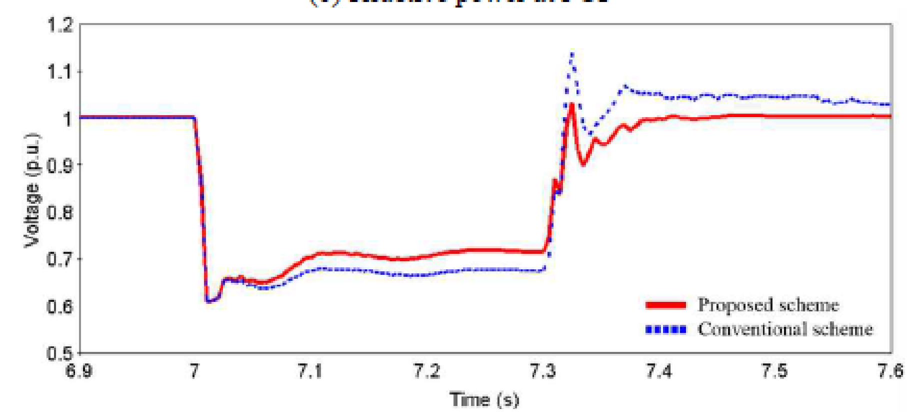
Fig. 5. Results for Case 1



(a) Voltage at POI



(b) Reactive power at POI



(c) Voltage at WTG

Fig. 6. Results for Case 2

Conclusions

- An advanced voltage control scheme a WTG and WPP was explored
- Normal condition and transient condition due to disturbance are considered.
- It takes into account the diversity within the WPP (wind resource and electrical network)
- To prevent an overvoltage after the fault clearance Over Voltage Control Function (OVCF) is included in the WPP and WTG controllers.
- The controllers are implemented and the results show that the proposed scheme can secure more *Q* reserve of a WPP, which can be injected to support the point of interconnection (POI) voltage during the fault.