Implications of the DC Voltage Control Strategy on the Dynamic Behavior of Multi-terminal HVDC following a Converter Outage

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I. Outline

I. Introduction

II. Control Strategies for MTDC Networks Operation

(i) Inner-Fast Current Controller, (ii) DC Voltage Controller, (iii) AC Voltage Controller, (iv) Active Power Controller, (v) Reactive Power Controller.

III. DC Voltage Control: Methods
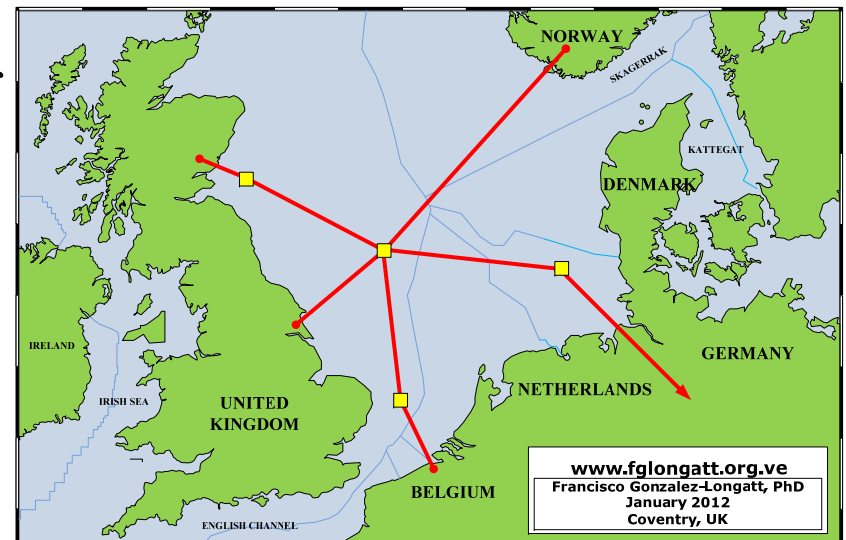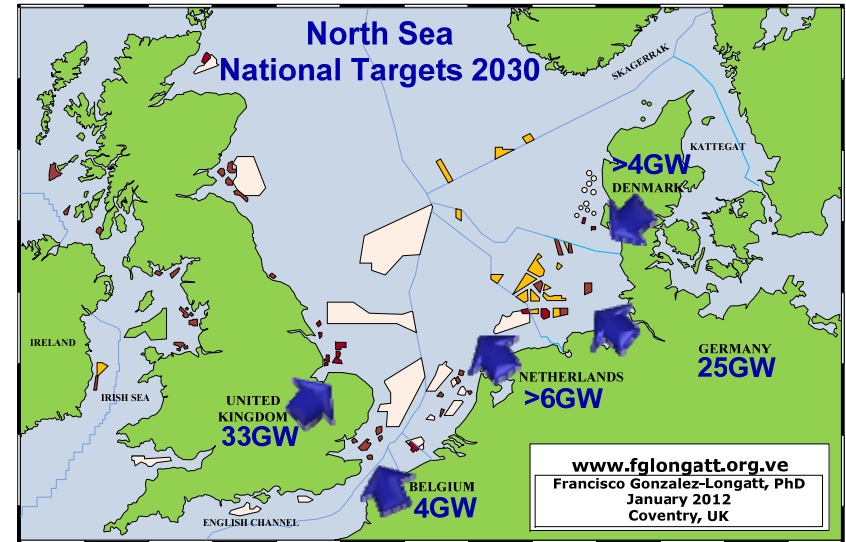
(i) Direct Voltage-Droop Method (ii) Voltage-Margin Method

IV. Simulations and Results

(i) *Case I*: Sudden load increase, (ii) *Case II*: One Converter Outage

V. Conclusions

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I. Introduction (1/2)

- The *EU* and the *G8* Heads of Government committed their countries in 2009 to an *80 % reduction in Green House Gas emissions by 2050.*

- International consensus to reach this target requires the EU to achieve a *'nearly zero-carbon power supply'*.

- *Supergrid* is the name of this future electricity system that will enable Europe to undertake *a once-off transition to sustainability.*

- *Multi-terminal HVDC (MTDC)* using *Voltage Source Converter (VSC)* is the most appropriate technology to enable the concept of Supergrid.

North Sea
National Targets 2030

>4GW DENMARK

GERMANY 25GW

NETHERLANDS >6GW

UNITED KINGDOM 33GW

BELGIUM 4GW

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I. Introduction (2/2)

- The power injections (P_i) in a DC grid are controlled by the converters.

- On a MTDC grid as Supergrid, the power flow into, or out of, each converter can be dynamically changed without any reconfiguration of the HVDC grid.

- Although Supergrid should allow the full control of active power on all converters, several control challenges arise from this condition.

- *The purpose of this paper is to analyze the potential implications of the DC Voltage Control Strategy on the dynamic behavior of Multi-terminal HVDC following a Converter Outage.*

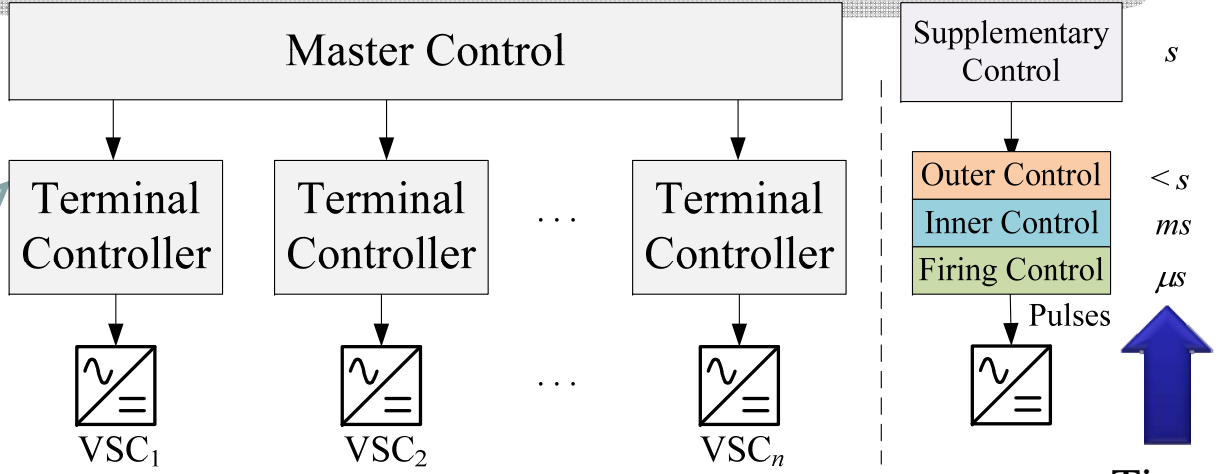Francisco M. Gonzalez-Longatt, www.fglongatt.org.ve
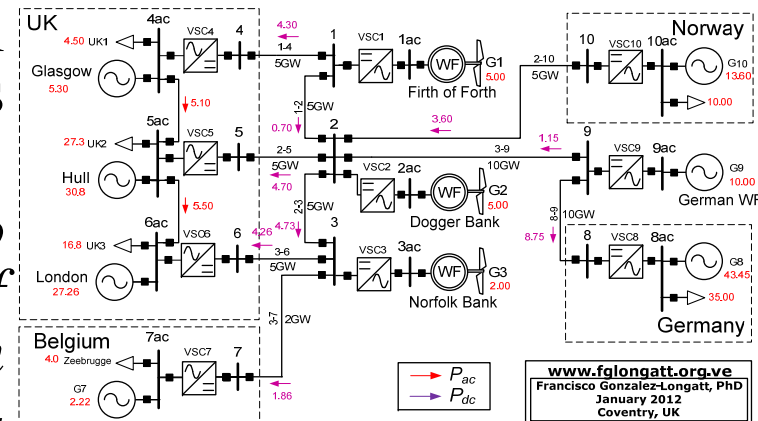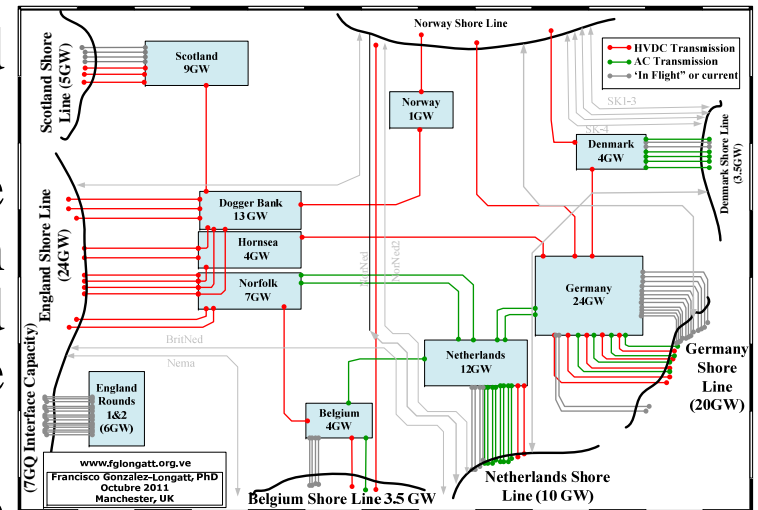
II. Control Strategies for MTDC (1/3)

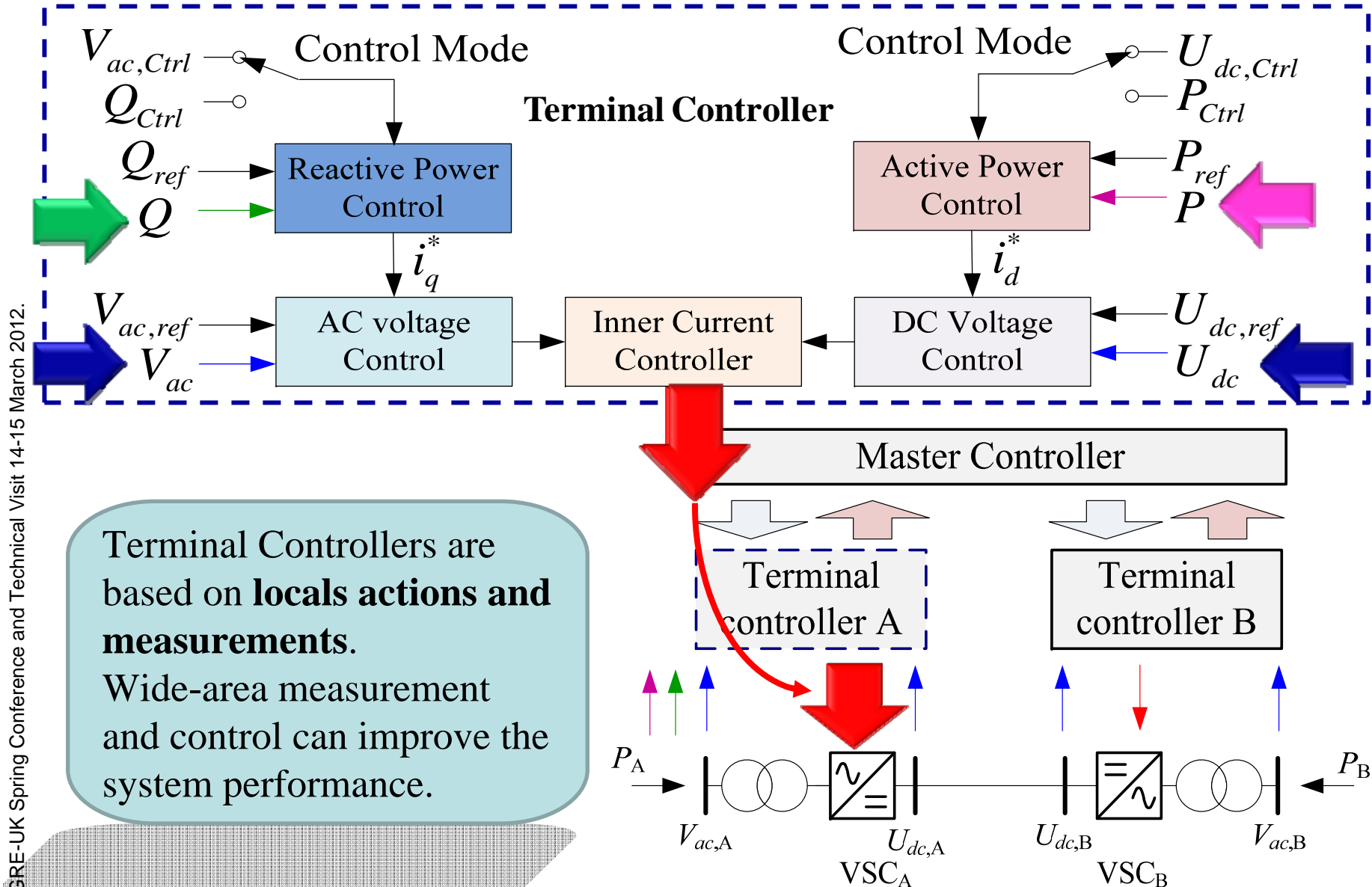## Schematic representation of MTDC control system hierarchy
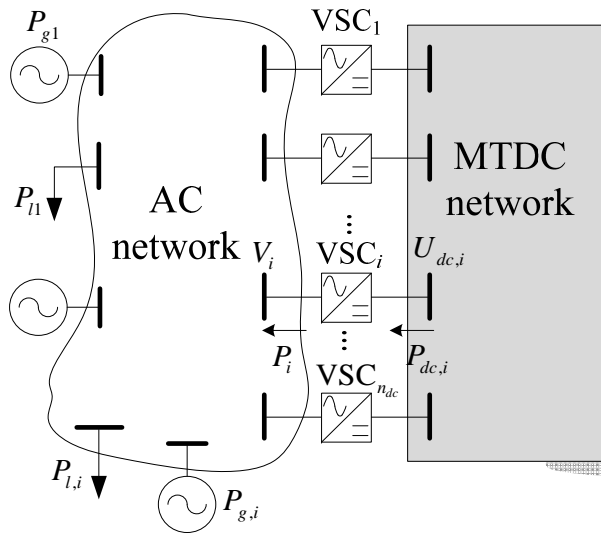
The master control **optimizes the overall performance** of the MTDC by regulating the DC side voltage.

It is provided with the **minimum set of functions necessary for coordinated operation of the terminals** in the DC circuit, i.e. start and stop, minimization of losses, oscillation damping and power flow reversal, black start, AC frequency and AC voltage support.

The terminal controllers determine the behavior of the converter at the system bus.

They are designed for the main functions for controlling: active power (P), reactive power (Q), AC and the DC voltage (V_{ac}, U_{dc})
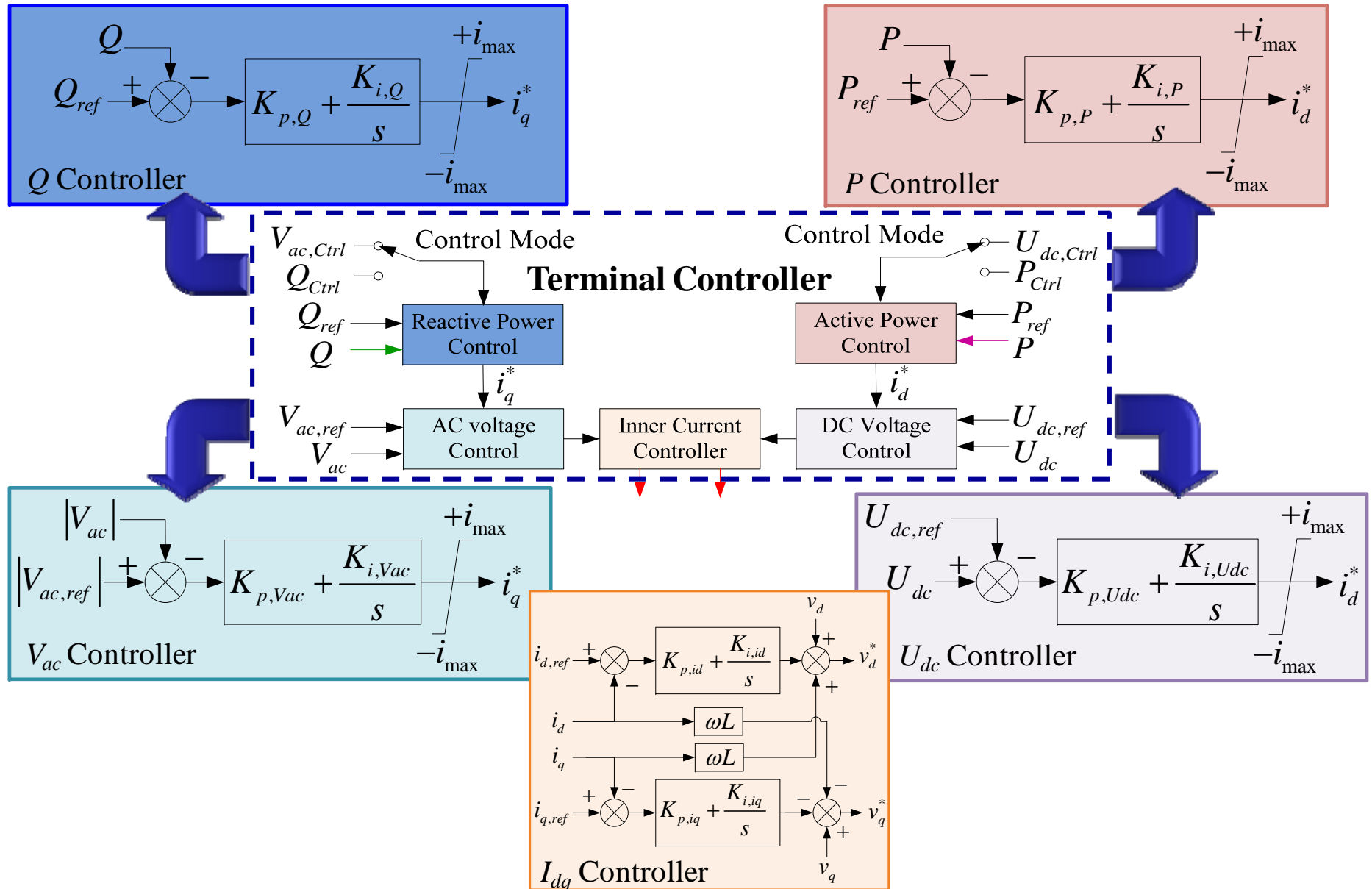
II. Control Strategies for MTDC (2/3)

Terminal Controller

$V_{ac,Ctrl}$ — Control Mode — $U_{dc,Ctrl}$
Q_{Ctrl} — — P_{Ctrl}

Q_{ref} → Reactive Power Control ← P_{ref}
Q → — P

i_q^* — i_d^*

$V_{ac,ref}$ → AC voltage Control — Inner Current Controller — DC Voltage Control ← $U_{dc,ref}$
V_{ac} → — U_{dc}

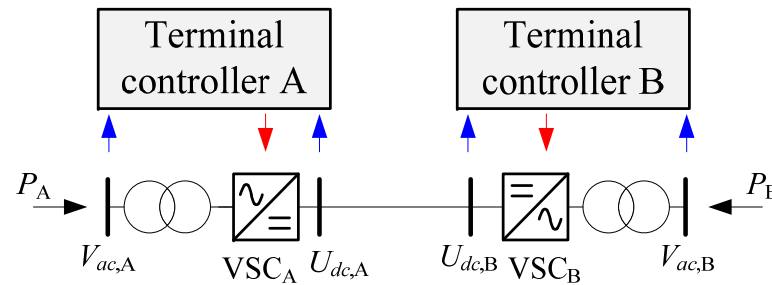Master Controller

Terminal controller A — Terminal controller B

Terminal Controllers are based on **locals actions and measurements**.
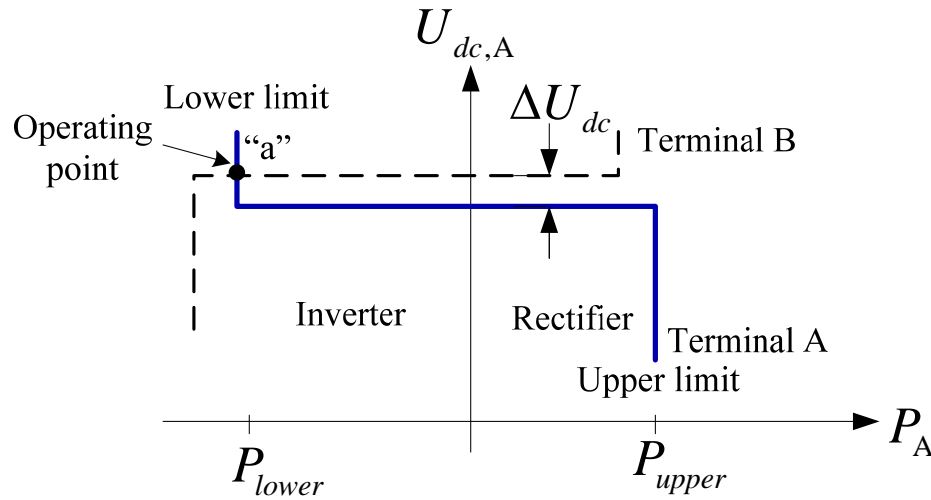Wide-area measurement and control can improve the system performance.

P_A → — ← P_B

$V_{ac,A}$ — $U_{dc,A}$ — $U_{dc,B}$ — $V_{ac,B}$

VSC_A — VSC_B

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II. Control Strategies for MTDC (3/3)

Q Controller

$$Q_{ref} \; + \; \underset{-}{\otimes} \longrightarrow \boxed{K_{p,Q} + \frac{K_{i,Q}}{s}} \longrightarrow \begin{array}{c} +i_{max} \\ \diagup \\ -i_{max} \end{array} \longrightarrow i_q^*$$

P Controller

$$P_{ref} \; + \; \underset{-}{\otimes} \longrightarrow \boxed{K_{p,P} + \frac{K_{i,P}}{s}} \longrightarrow \begin{array}{c} +i_{max} \\ \diagup \\ -i_{max} \end{array} \longrightarrow i_d^*$$

Terminal Controller

Control Mode — $V_{ac,Ctrl}$ / Q_{Ctrl}

Q_{ref}, Q → Reactive Power Control → i_q^*

$V_{ac,ref}$, V_{ac} → AC voltage Control

Inner Current Controller

Control Mode — $U_{dc,Ctrl}$ / P_{Ctrl}

P_{ref}, P → Active Power Control → i_d^*

$U_{dc,ref}$, U_{dc} → DC Voltage Control

V_{ac} Controller

$$|V_{ac,ref}| \; + \; \underset{-}{\otimes} \longrightarrow \boxed{K_{p,Vac} + \frac{K_{i,Vac}}{s}} \longrightarrow \begin{array}{c} +i_{max} \\ \diagup \\ -i_{max} \end{array} \longrightarrow i_q^*$$

U_{dc} Controller

$$U_{dc,ref} \; + \; \underset{-}{\otimes} \longrightarrow \boxed{K_{p,Udc} + \frac{K_{i,Udc}}{s}} \longrightarrow \begin{array}{c} +i_{max} \\ \diagup \\ -i_{max} \end{array} \longrightarrow i_d^*$$

I_{dq} Controller

$$i_{d,ref} \; + \; \underset{-}{\otimes} \longrightarrow \boxed{K_{p,id} + \frac{K_{i,id}}{s}} \longrightarrow \underset{+}{\overset{v_d}{\otimes}} \longrightarrow v_d^*$$

$$i_d \longrightarrow \boxed{\omega L}$$

$$i_q \longrightarrow \boxed{\omega L}$$

$$i_{q,ref} \; + \; \underset{-}{\otimes} \longrightarrow \boxed{K_{p,iq} + \frac{K_{i,iq}}{s}} \longrightarrow \underset{+}{\overset{v_q}{\otimes}} \longrightarrow v_q^*$$

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III. DC VOLTAGE CONTROL

Terminal controller A

Terminal controller B

P_A

$V_{ac,A}$ VSC$_A$ $U_{dc,A}$ $U_{dc,B}$ VSC$_B$ $V_{ac,B}$

P_B

(i) Voltage Margin Method (VMM)

$U_{dc,A}$

Lower limit

Operating point

"a"

ΔU_{dc}

Terminal B

Inverter

Rectifier

Terminal A

Upper limit

P_{lower}

P_{upper}

P_A

(ii) Voltage-Droop Method (VDM)

$U_{dc,A}$

Lower limit

Inverter

Rectifier

Initial operating point

Slope m_c

$U_{dc,ref}^a$

"a"

ΔU_{dc}

U_{ref}^b

"b"

Upper limit

P_{lower}

P_{ref}^a

P_{ref}^b

P_{upper}

P_A

When the active power is to be transmitted from Terminal B to Terminal A ($P_A<0$, $P_B>0$), the voltage margin (ΔU_{dc}) is subtracted from the DC reference voltage for Terminal A.
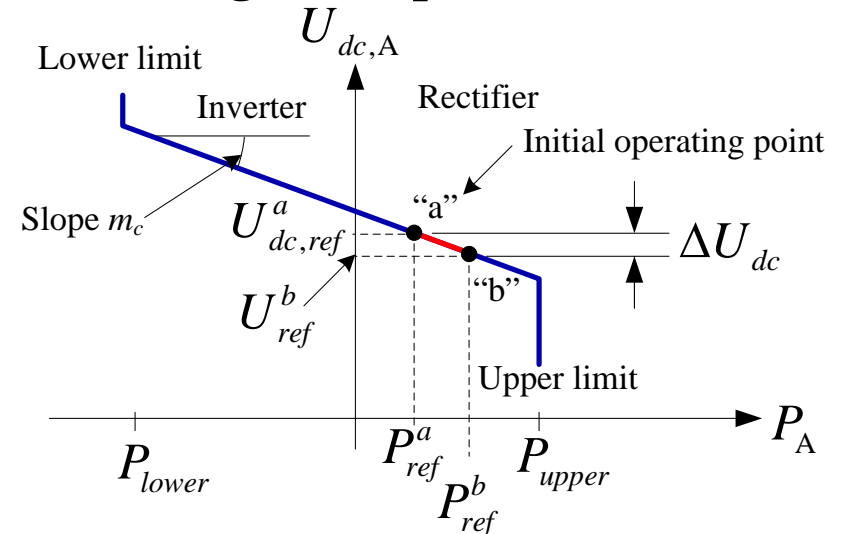
When U_{dc} drops the slack converter station (VSC$_A$) will increase the active power injection in the DC grid P_A until a new equilibrium point.

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IV. Simulations and Results (1/2)

- The dynamic behavior of AC/DC Test System is analyzed based on time-domain simulations. DigSILENT® PowerFactory™ v14.0.525.1.

DC Test System: VSC MTDC system.

AC Test System: of Stagg and El-Abiad.
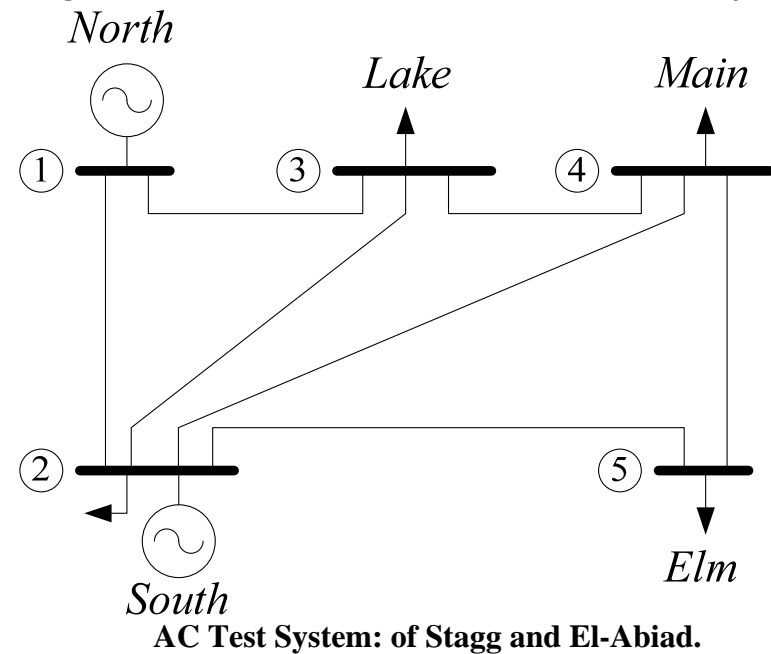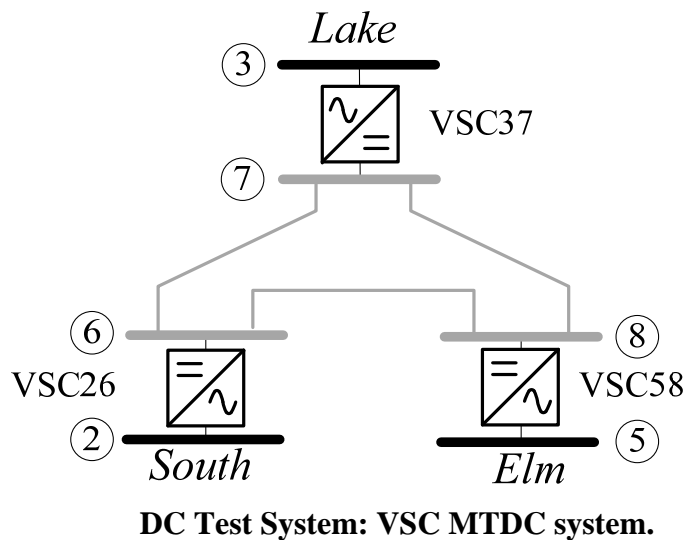
- *Case I*: The effect of sudden load increases on power flows and transient response in the AC/DC Test System.

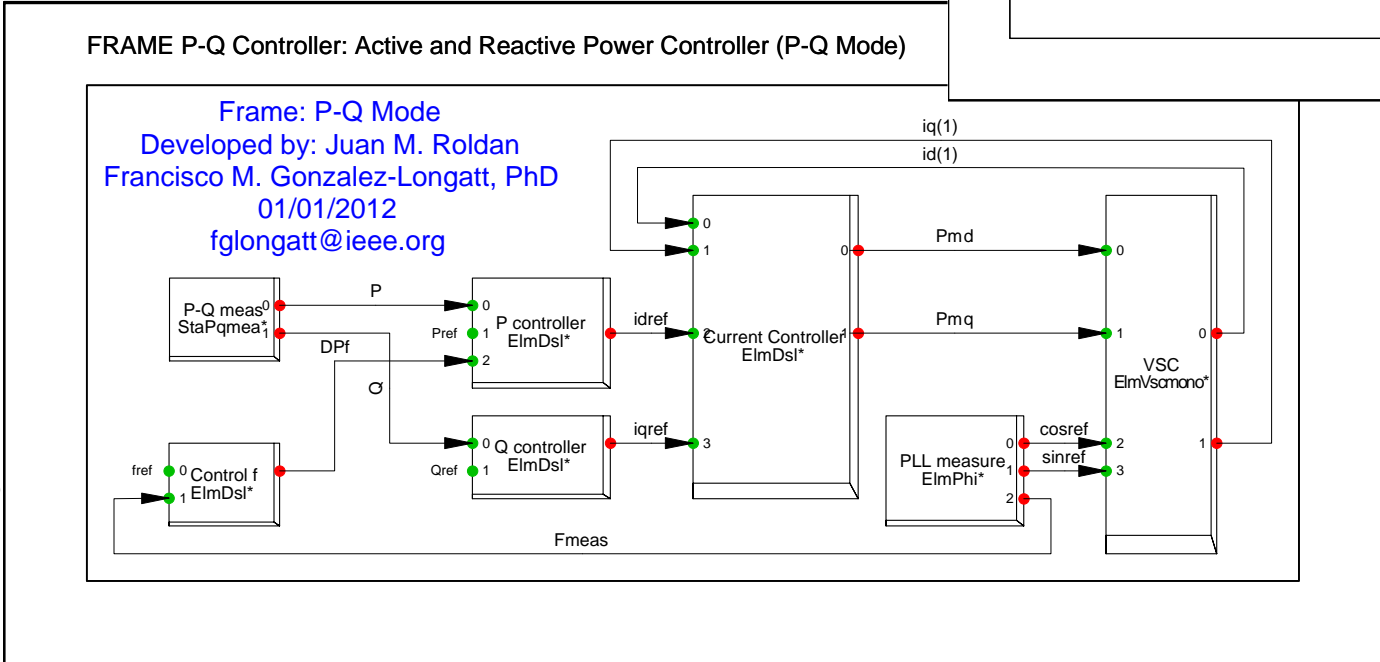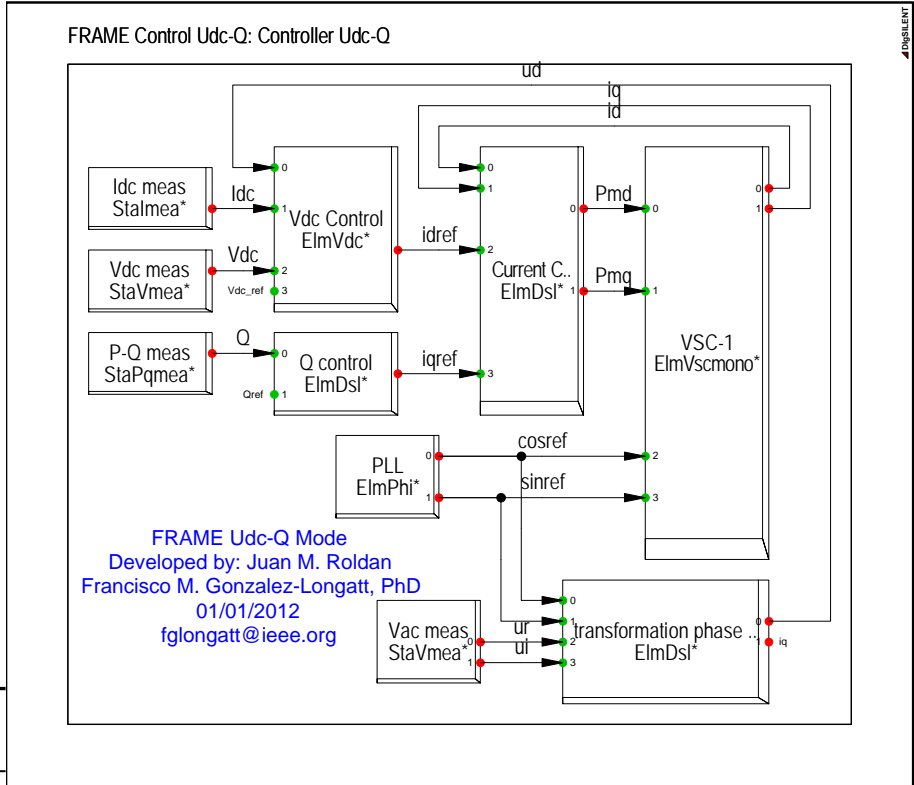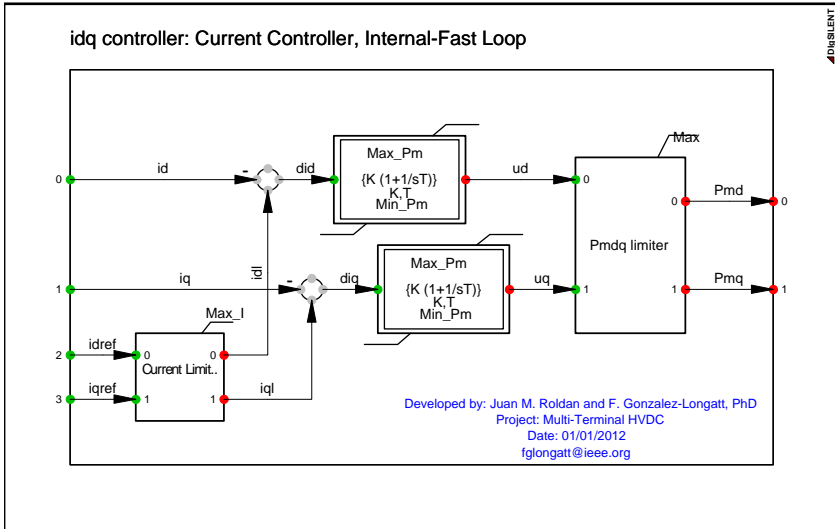- *Case II*: The effects of a converter outage on the dynamic response are also analyzed.

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IV. Simulations and Results (2/2)

- An sequential solution algorithm is used for the AC/DC power flow solution.
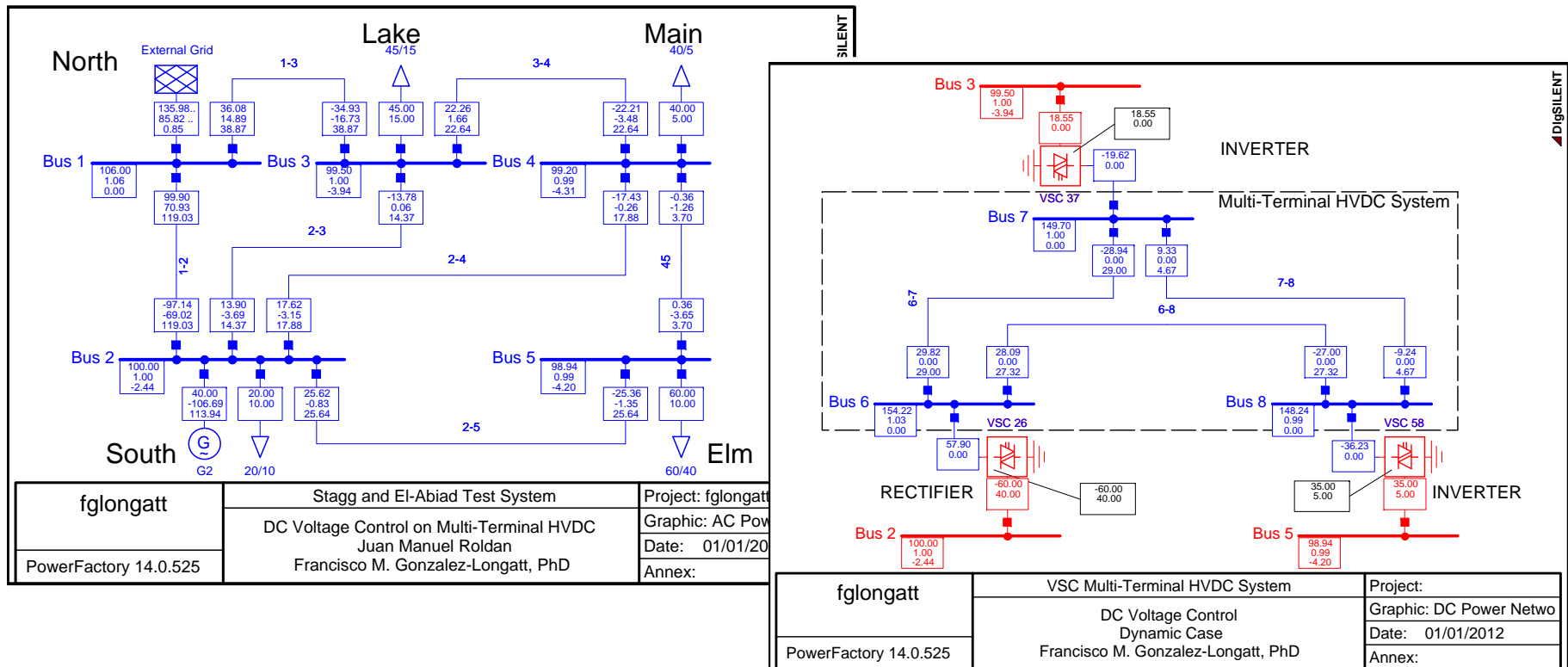
- That solution is used as initial conditions for the dynamic simluations.

Models on DSL

idq controller: Current Controller, Internal-Fast Loop

Developed by: Juan M. Roldan and F. Gonzalez-Longatt, PhD
Project: Multi-Terminal HVDC
Date: 01/01/2012
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FRAME Control Udc-Q: Controller Udc-Q

FRAME Udc-Q Mode
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FRAME P-Q Controller: Active and Reactive Power Controller (P-Q Mode)

Frame: P-Q Mode
Developed by: Juan M. Roldan
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DC Voltage Controllers: DSL Models

Udc-P droop controller: Udc Droop Controller

$$U_{dc,ref}$$
$$U_{dc}$$

$$\frac{1}{m_c}$$

$$P_{ref}$$
$$P$$

$$K_{p,Udc} + \frac{K_{i,Udc}}{s}$$

$$+i_{max}$$
$$i_d$$
$$-i_{max}$$

Pmax
I_max
Pref
Max_I
P
dP
{K (1+1/sT)}
Kp,Tp
u
Limiter with input si..
Idref
Udcref
Min_I
DV
K
Kv
KDV
Udc
Droop
Plower
I_min

Udc-P Droop Controller
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Project: Multi-Terminal HVDC
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Udc Controller: Voltage-Margin Method (VMM)

Pupper
I_max
Udc_ref
Udc
du
Max_I
{K (1+1/sT)}
Ku,Tu
Min_I
o1
U
Limiter with input signals
Idref
Idc
o12
Constant1/mc
u1
o11
Ud
Plower
I_min

Udc-P Voltage-Margin Method
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CIGRE-UK Spring Conference and Technical Visit 14-15 March 2012.

Case I: Sudden Load Increase (1/2)

$\Delta P = 40 MW$

Sudden Load Increase
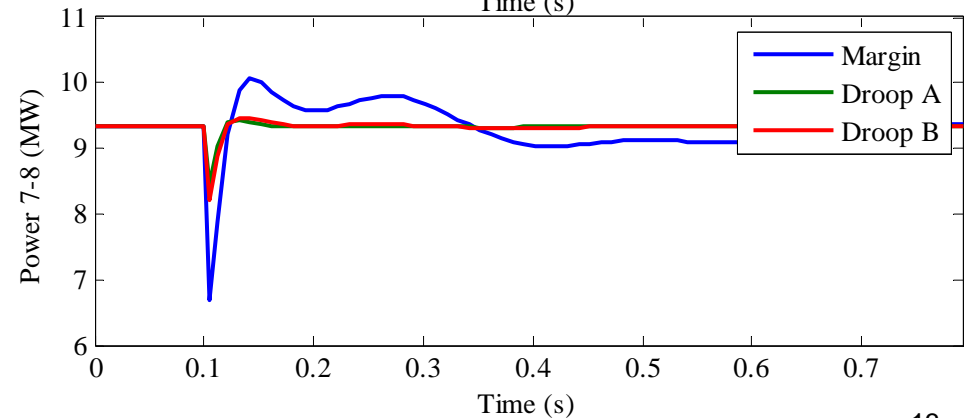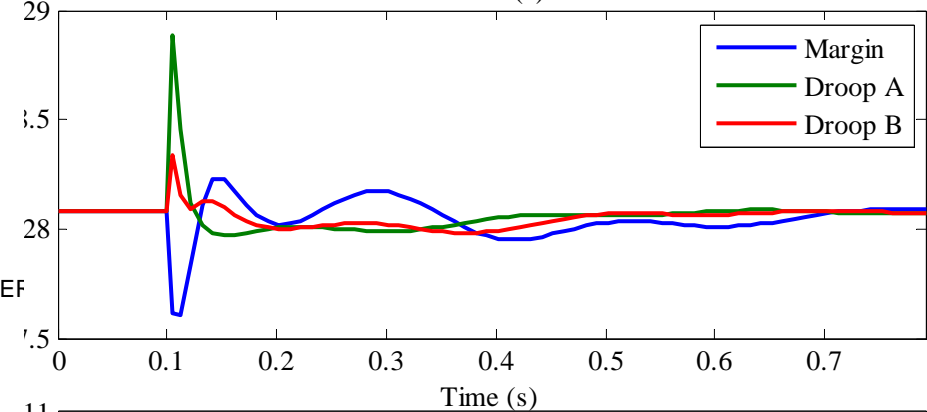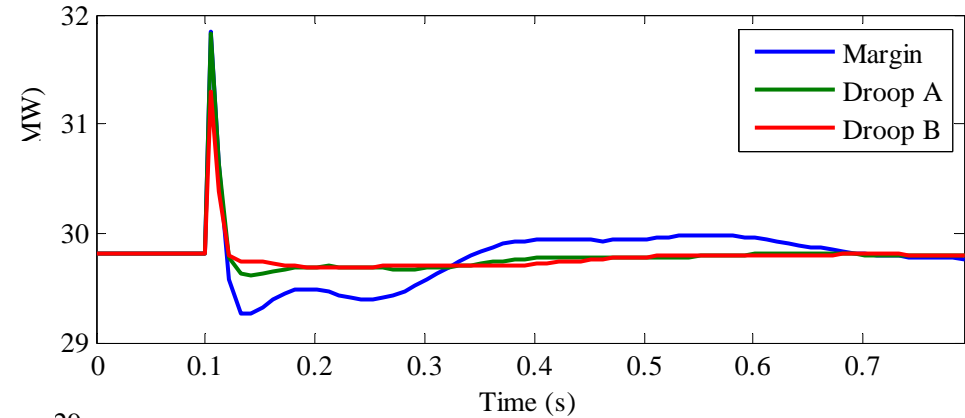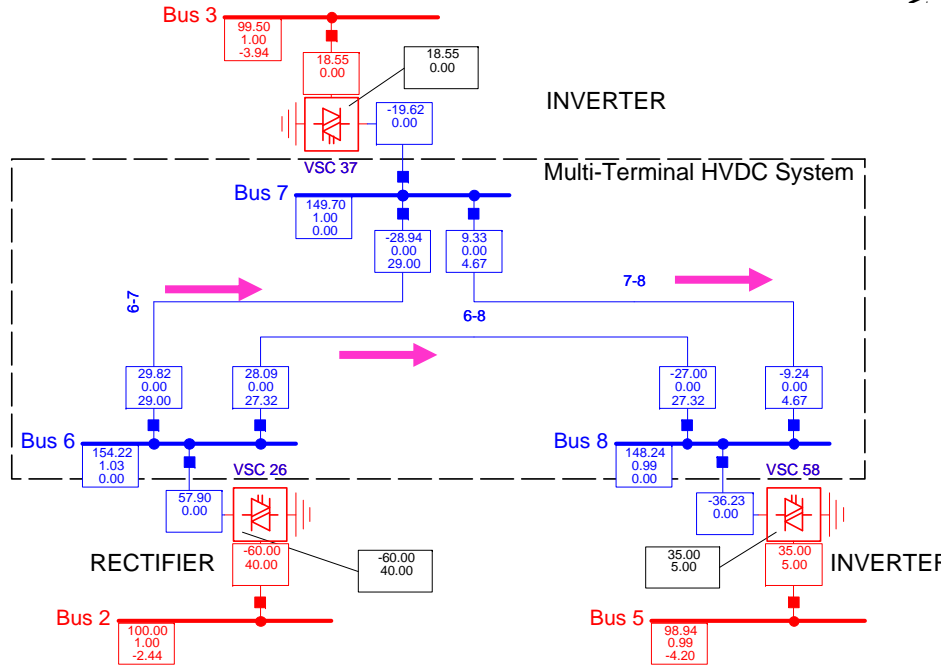
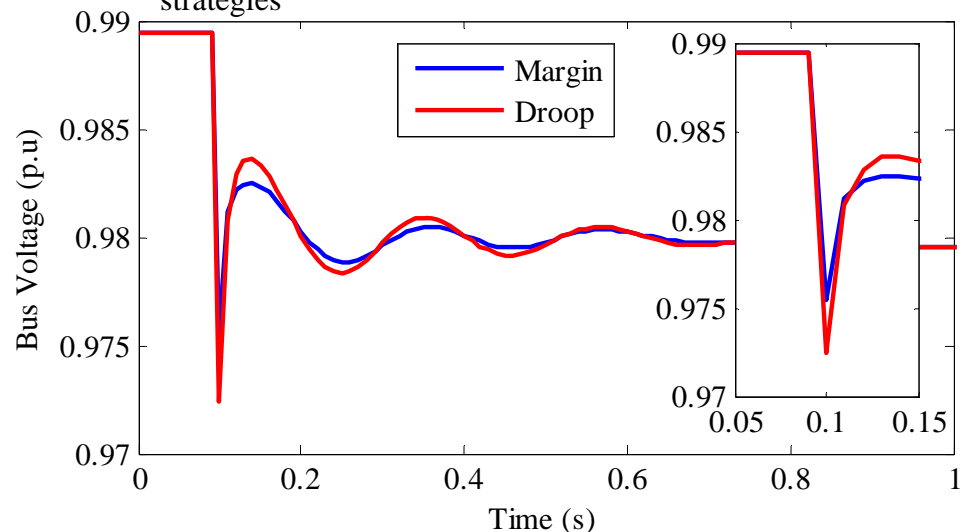Voltage margin method produces the *smallest stress on AC system.*

Voltage-Droop method increases power transfer during initial response.

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Case I: Sudden Load Increase (2/2)

- The blue line shows the bus voltage's response with only one voltage controller operating, voltage margin method.

- The red line represents the dynamic response when a voltage droop controller (m_c = -0.1) is operating on converter station VSC26.

- The transient over-voltages and under-voltages are reduced as expected using the droop control.

- The slopes of the voltage-droop controller considered in this simulation are $1/m_c$= -10.0, -8.0, -2.0 p.u. for converters VSC26, VSC37, VSC58 respectively.

Bus 6, DC voltage transient with margin and droop control strategies

Bus 5, AC voltage transient with margin and droop control strategies

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Case II: Converter Outage (1/2)
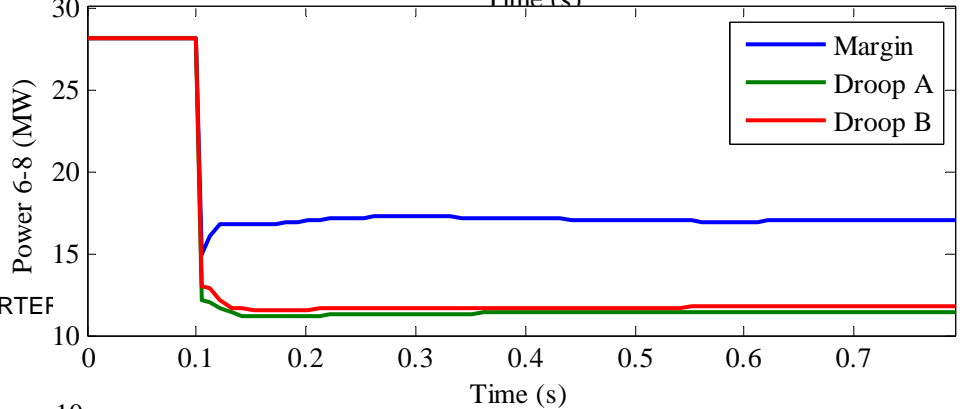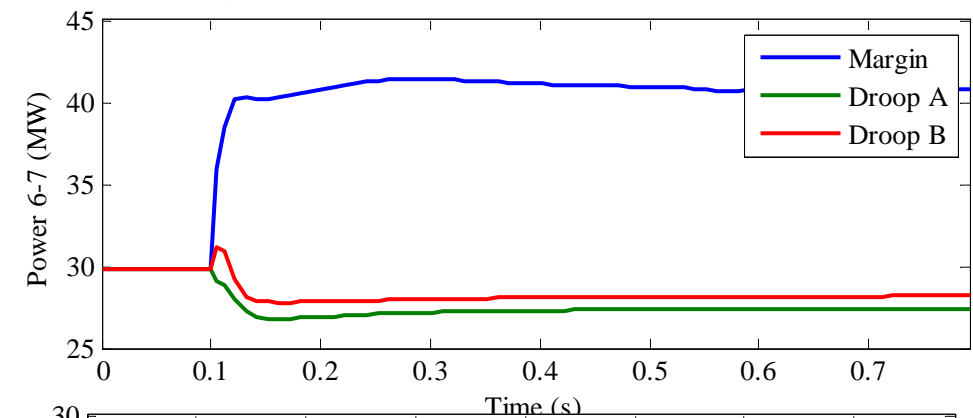

Converter outage can create reverse power flows, overload on undersea cables and converter stations is a real possibility.

Voltage-Droop method performs better.
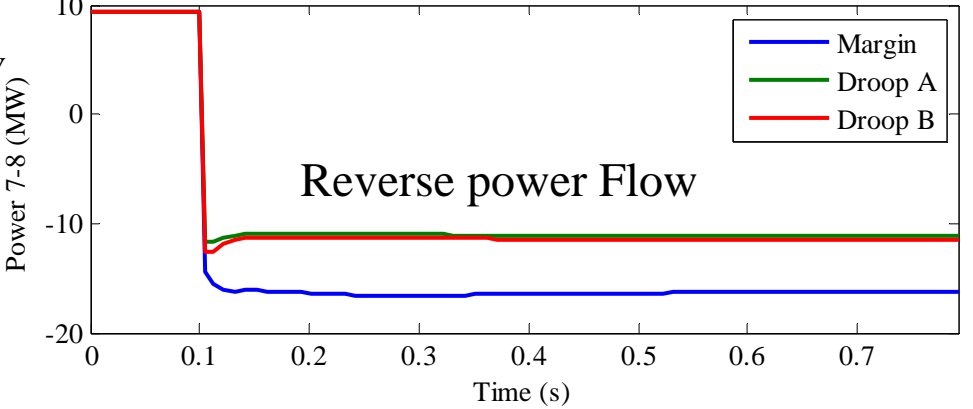
Case II: Converter Outage (2/2)

- This simulation results are used to investigate the effect of a distributed voltage droop control on bus 2 (VSC26).

- The response of bus voltage at bus 6 considering a perturbation based on the outage of VSC58 demonstrates how an incorrect selection slope value may causes transient responses with greater over-voltages on the DC bus (Droop B, green line).

- If voltage-droop slope is correctly selected it can assist the main the voltage at slack bus 3 and the system can handling transients caused by one converter station outage
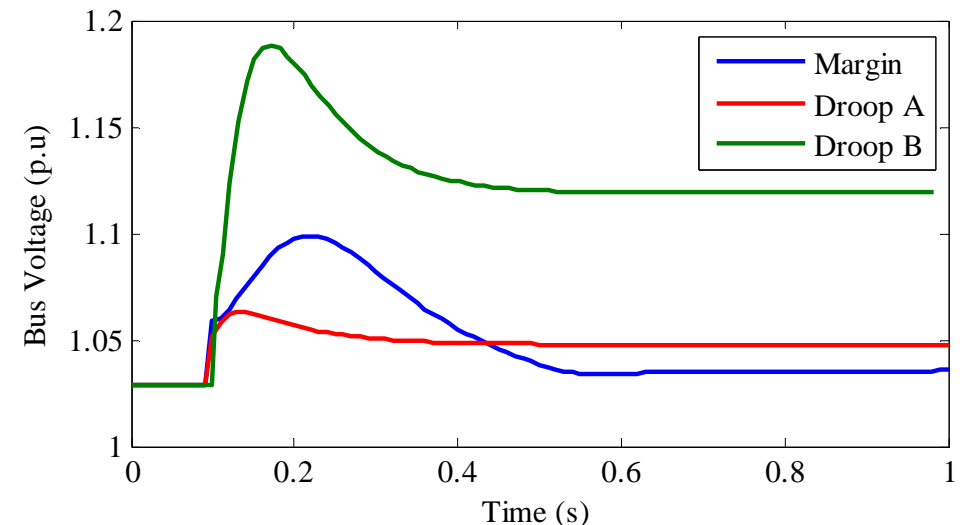
Bus 6, DC voltage transient with margin and droop control strategies
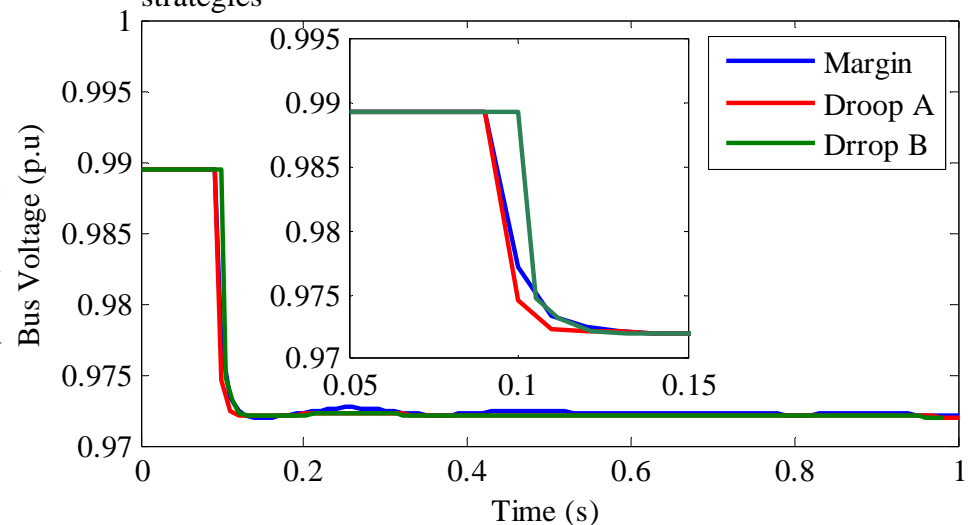
Bus 5, AC voltage transient with margin and droop control strategies

Conclusions

- This paper presents simulation results show the effect of DC Voltage control strategy on the dynamic behavior of bust voltages at multi-terminal HVDC following a converter-station outage: (i) *voltage margin method* and (ii) *voltage-droop method.*

- When two converters on the MTDC operate with DC voltage droop characteristic, it appears a "*collaborative scheme*" for the DC voltage support, sharing the task of controlling the DC voltage.

- Simulation results demonstrate *the voltage margin control is capable to survive a converter outage just if this converter is operating on constant power mode.*

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Any questions?

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