The University of Manchester

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

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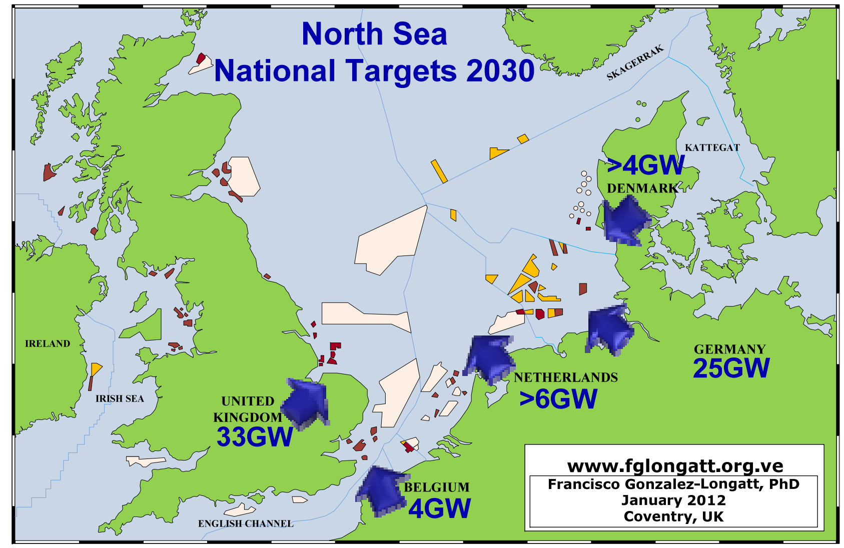
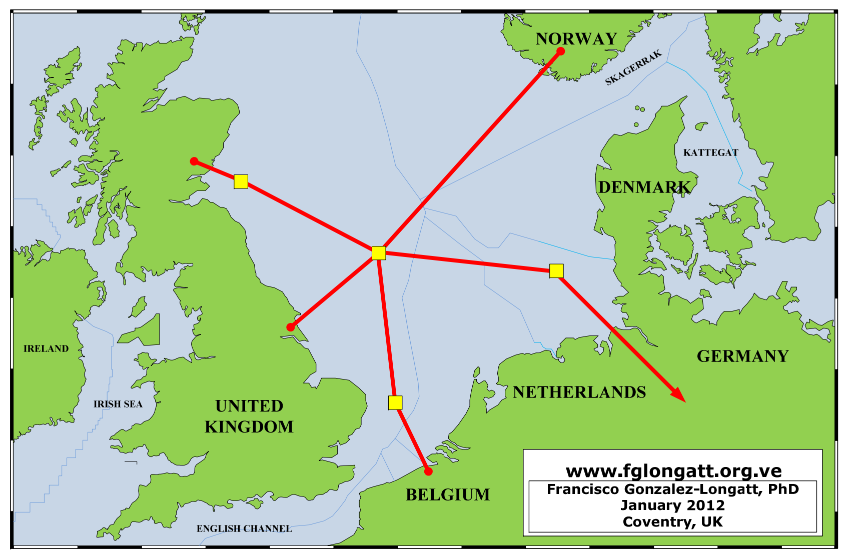
I. Introduction (1/2)

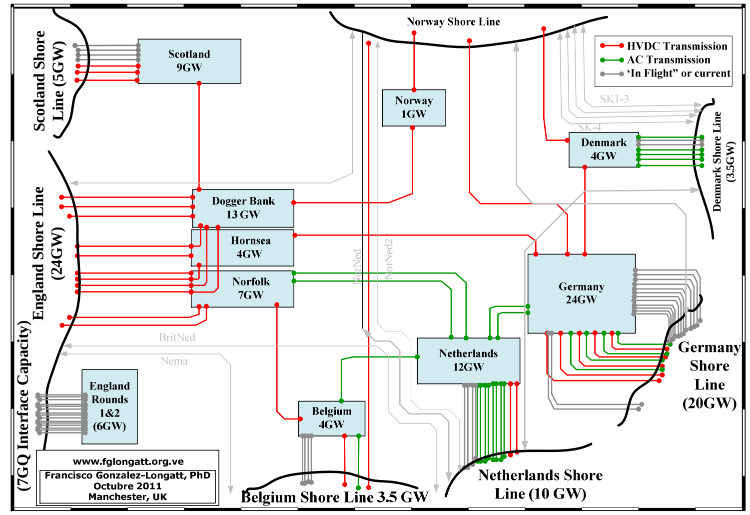
- The *EU* and the *G8* Heads of Government committed their countries in 2009 to an *80 % reduction in Green House Gas emissions by 2050.*
- International consensus to reach this target requires the EU to achieve a *'nearly zero-carbon power supply*'.
- *Supergrid* is the name of this future electricity 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.

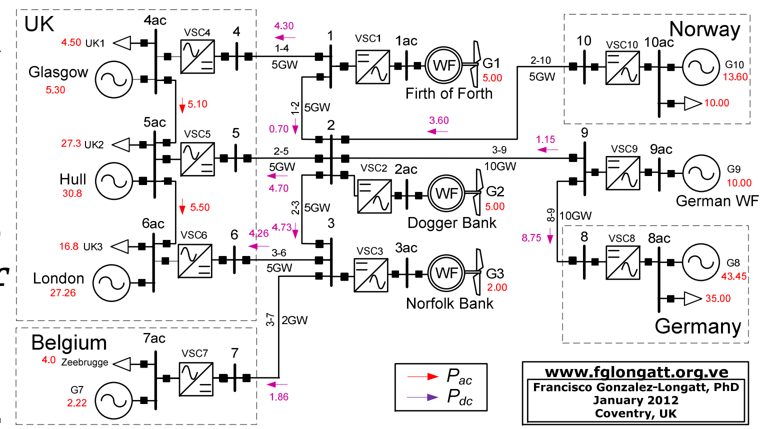




I. Introduction (2/2)

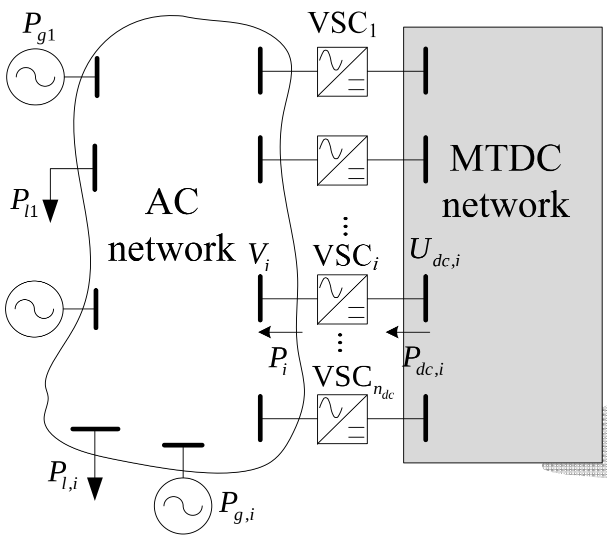
- The power injections (P_i) in a DC grid are controlled by the converters.
- On a MTDC grid as Supergrid, the power flow into, or out of, each converter can be dynamically changed without any reconfiguration of the HVDC grid.
- Although Supergrid should allow the full control of active power on all 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.*



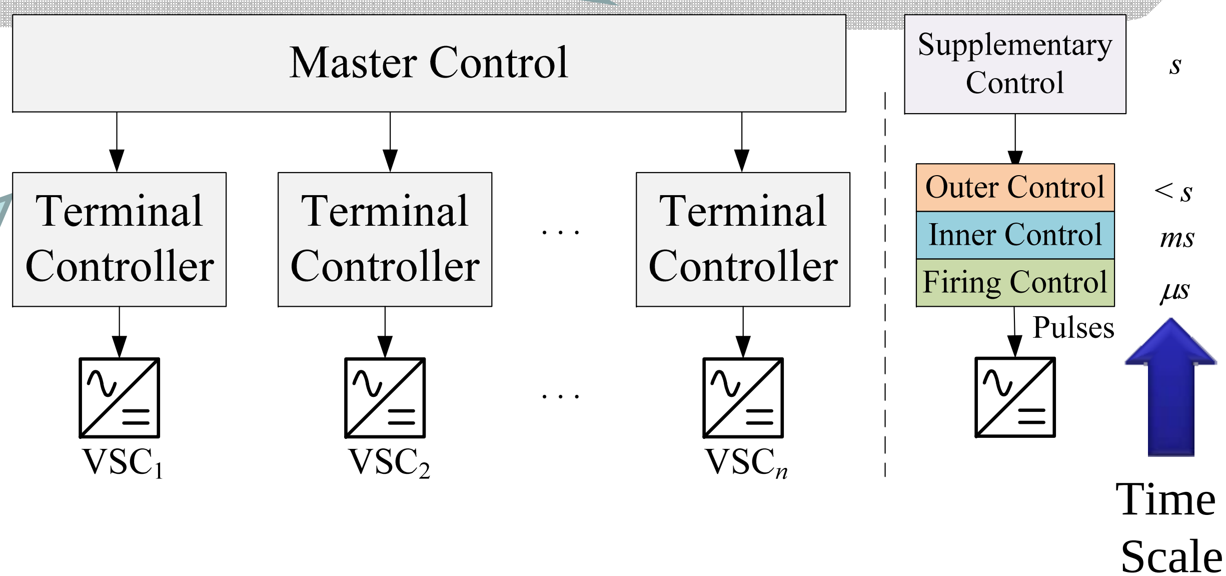


II. Control Strategies for MTDC (1/3)

Schematic representation of MTDC control system hierarchy



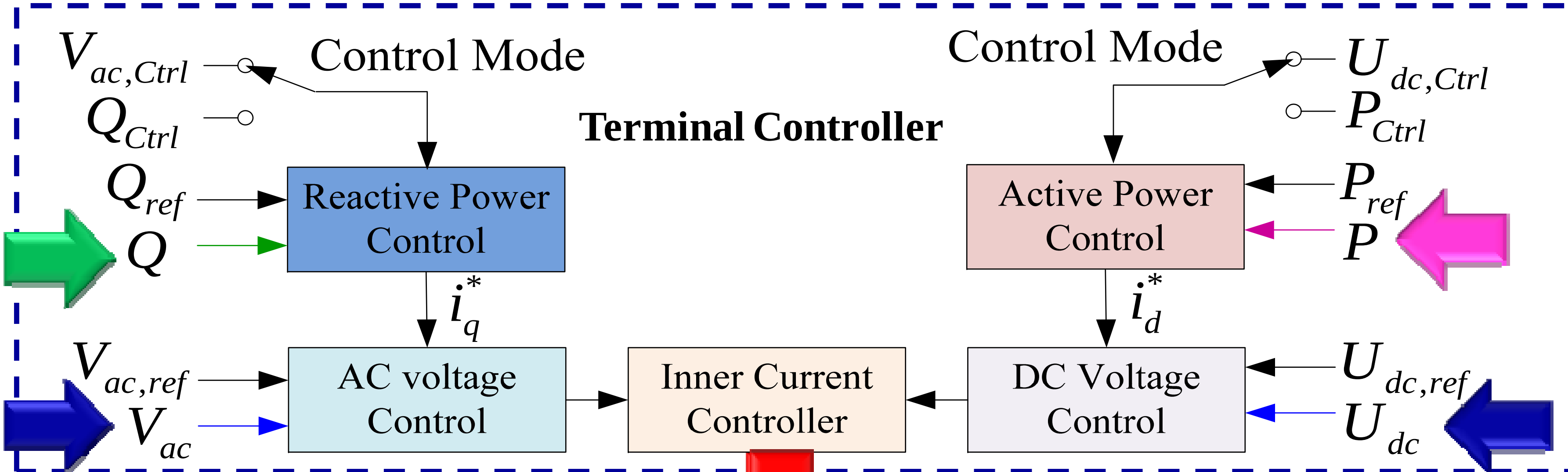
The master control **optimizes the overall performance** of the MTDC by regulating the DC side voltage.
It is provided with the **minimum set of functions necessary for coordinated operation of the terminals** in the DC circuit, i.e. start and stop, minimization of losses, oscillation damping and power flow reversal, black start, AC frequency and AC voltage support.

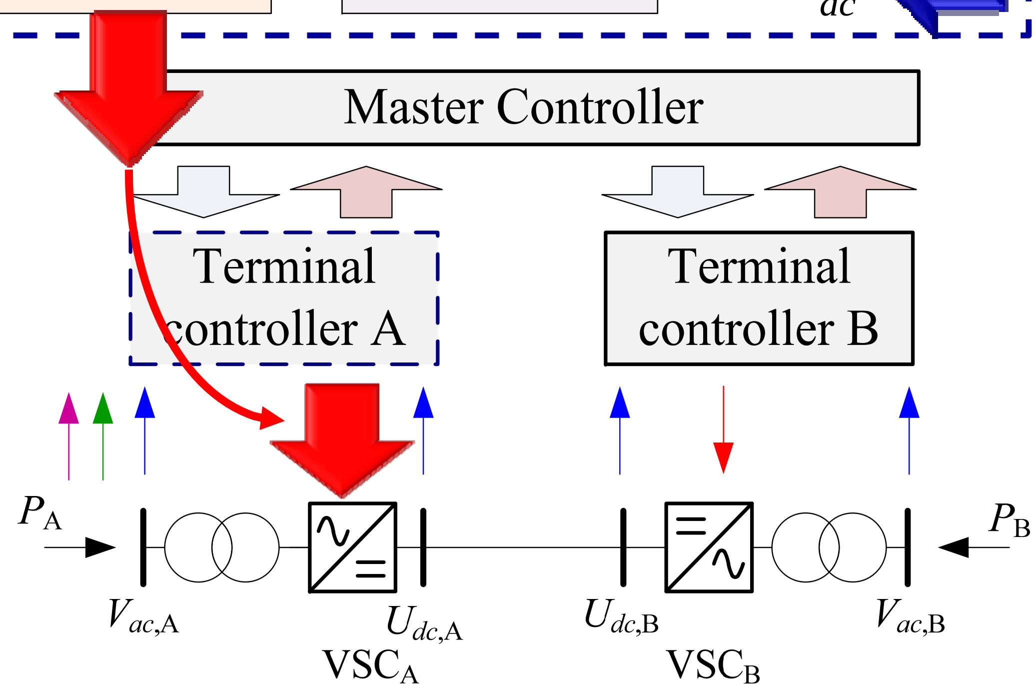


The terminal controllers determine the behavior of the converter at the system bus.

They are designed for the main functions for controlling: active power (P), reactive power (Q), AC and the DC voltage (V_{ac}, U_{dc})

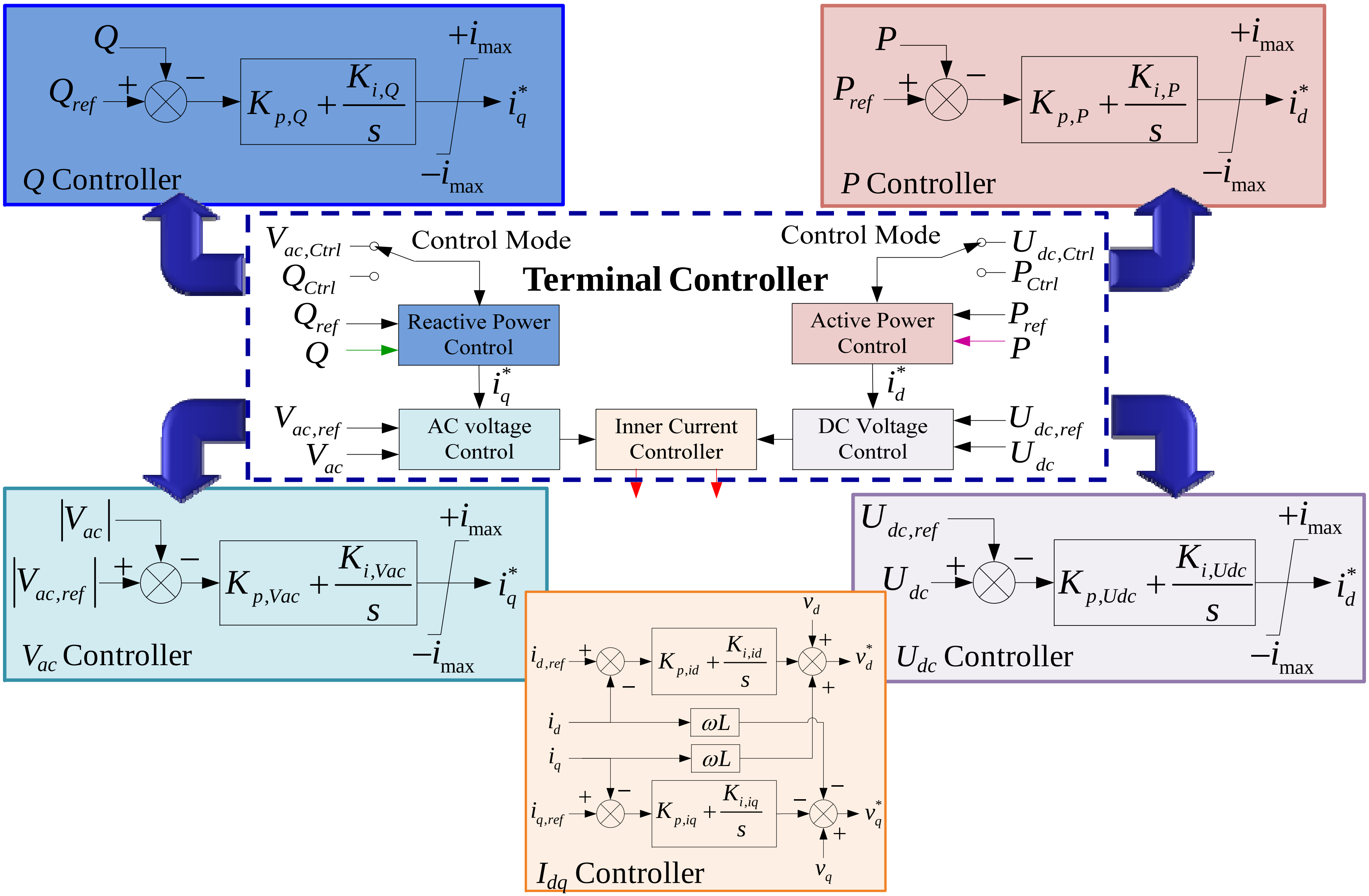
II. Control Strategies for MTDC (2/3)



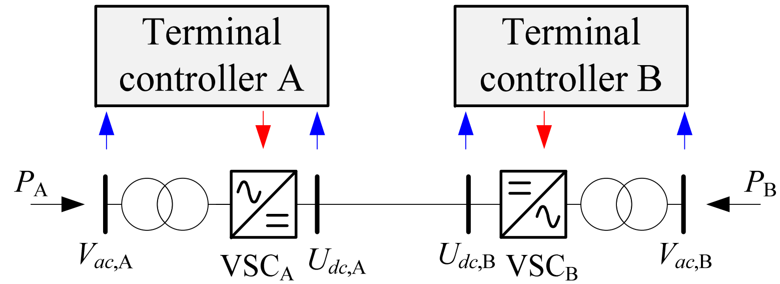


Terminal Controllers are based on **locals actions and measurements.**
Wide-area measurement and control can improve the system performance.

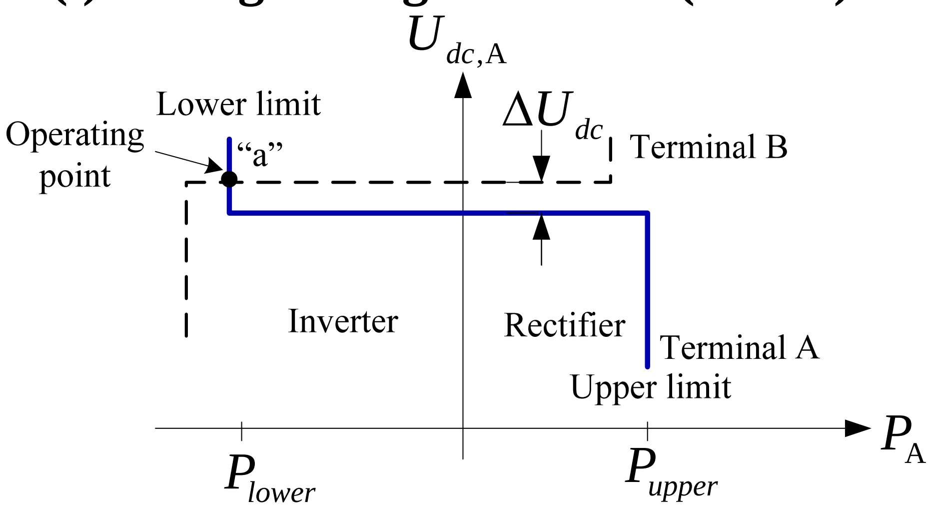
II. Control Strategies for MTDC (3/3)



III. DC VOLTAGE CONTROL

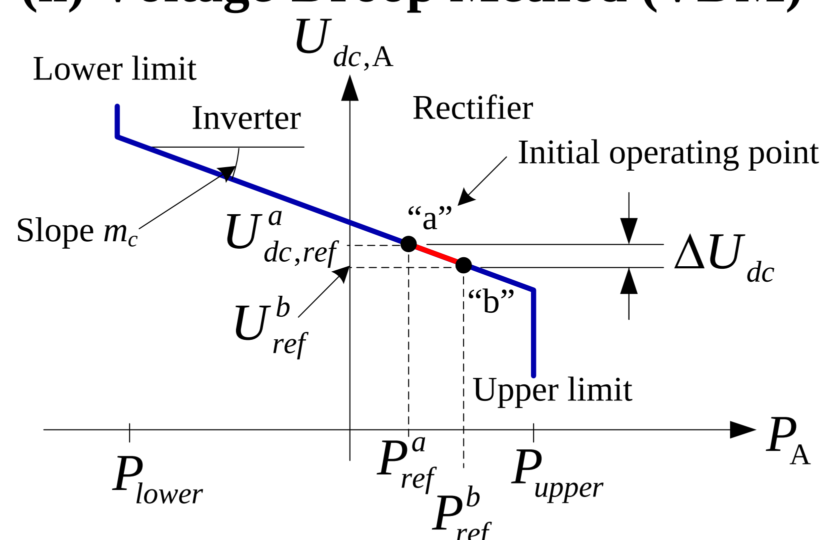


(i) Voltage Margin Method (VMM)



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.

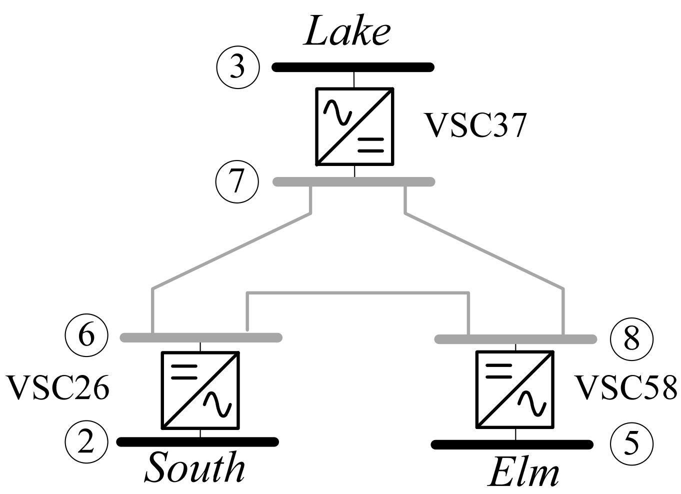
(ii) Voltage-Droop Method (VDM)



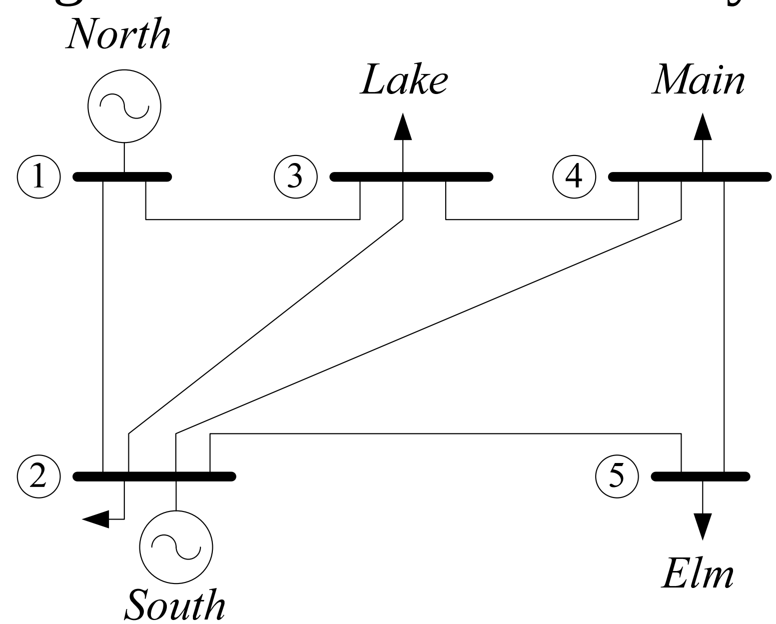
When U_{dc} drops the slack converter station (VSC_A) will increase the active power injection in the DC grid P_A until a new equilibrium point.

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.

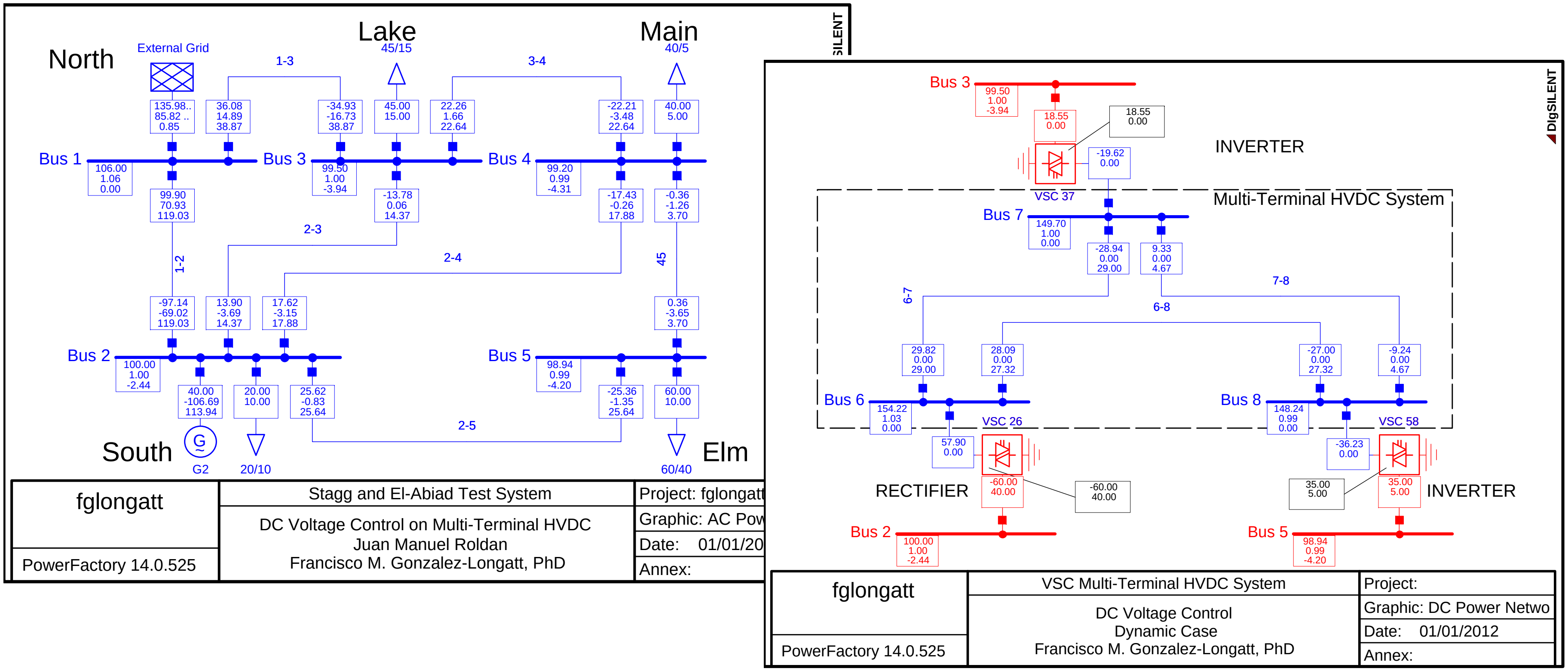


AC Test System: of Stagg and El-Abiad.

- *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.

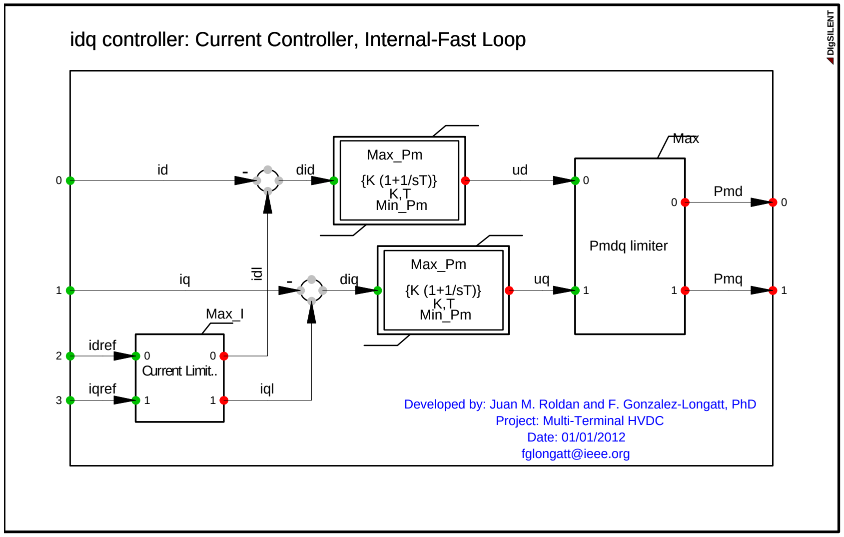
IV. Simulations and Results (2/2)

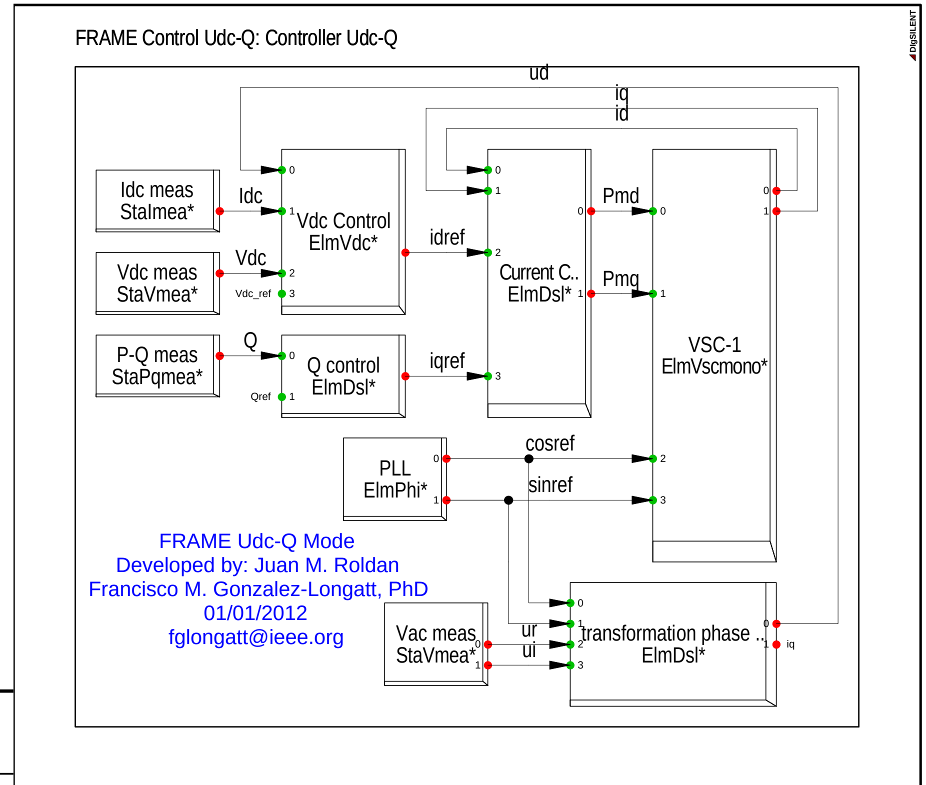
- An sequential solution algorithm is used for the AC/DC power flow solution.

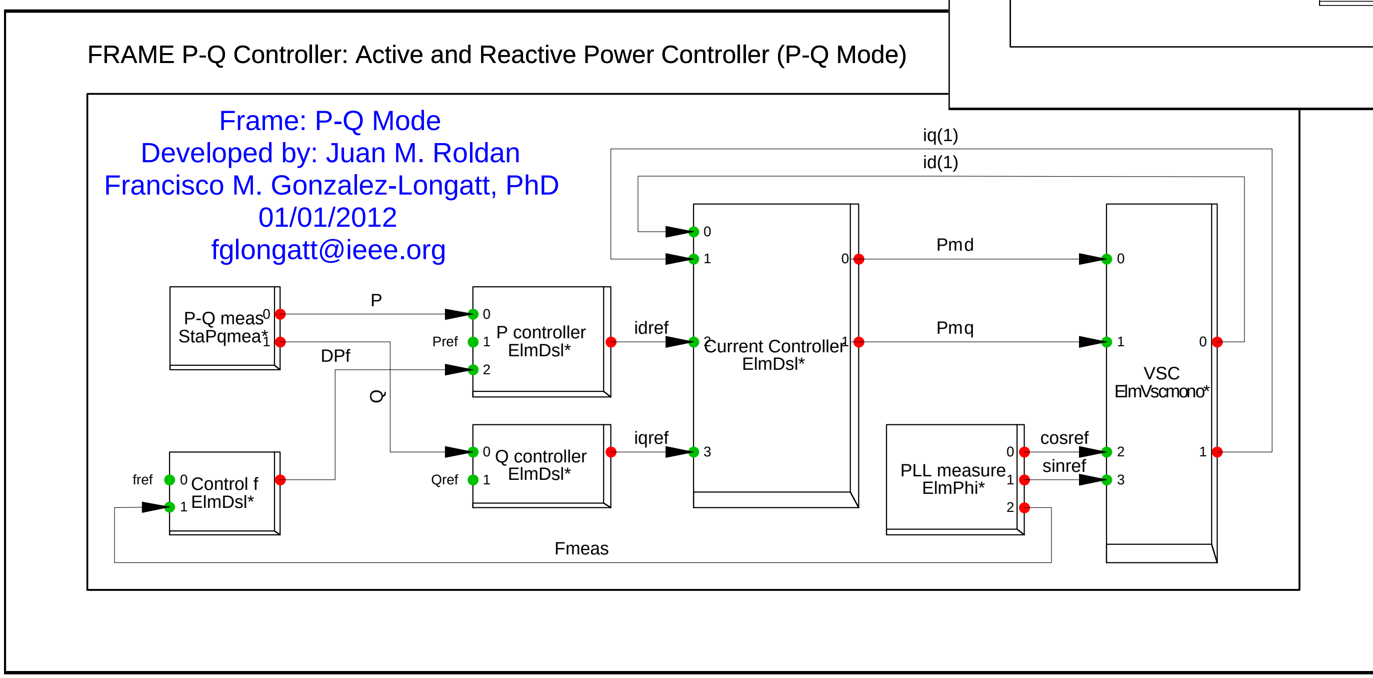


- That solution is used as initial conditions for the dynamic simluations.

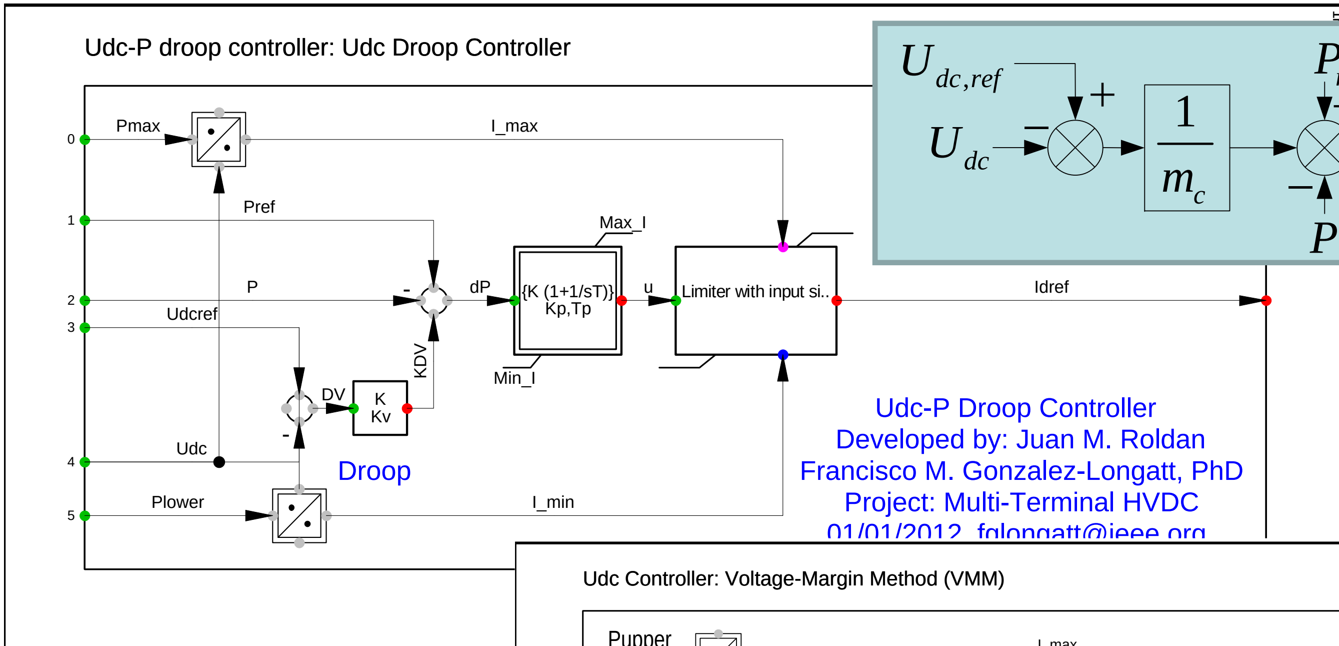
Models on DSL

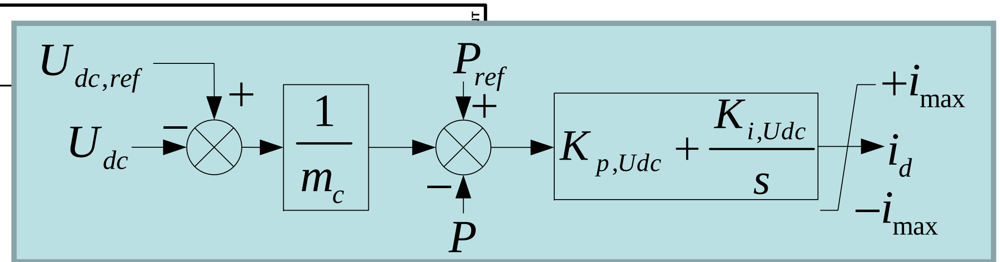


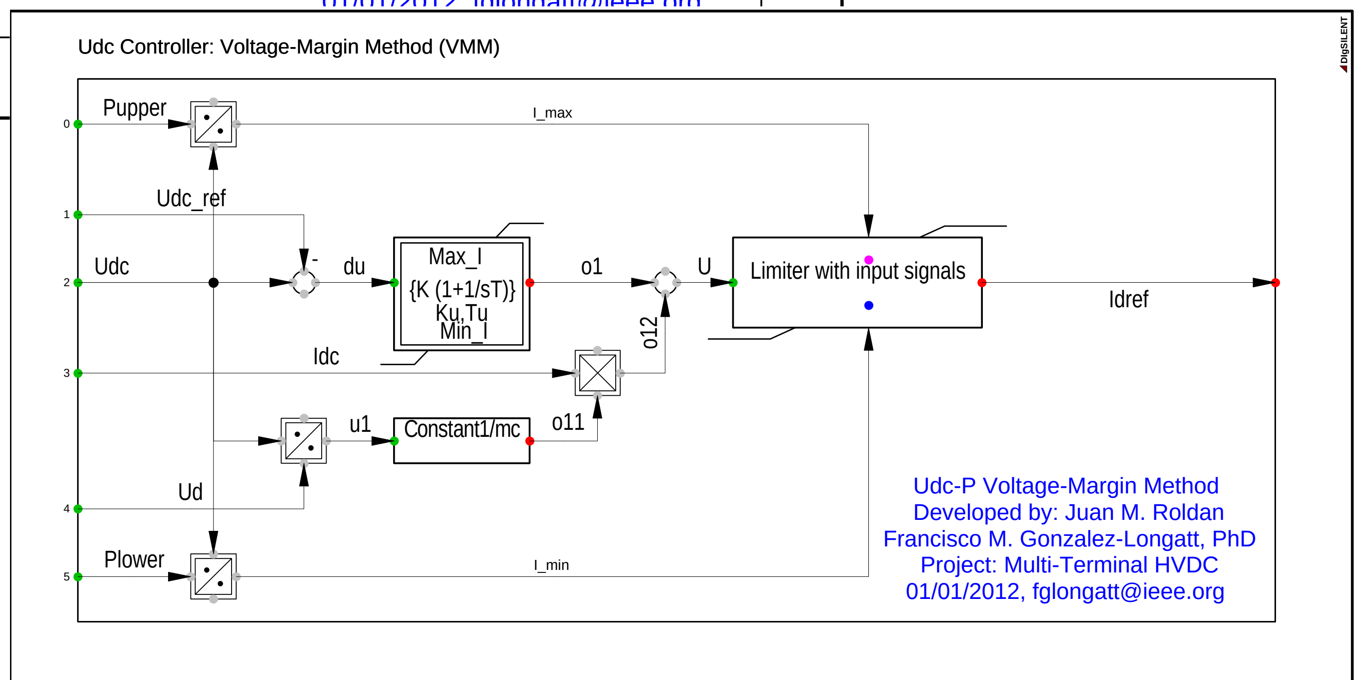




DC Voltage Controllers: DSL Models



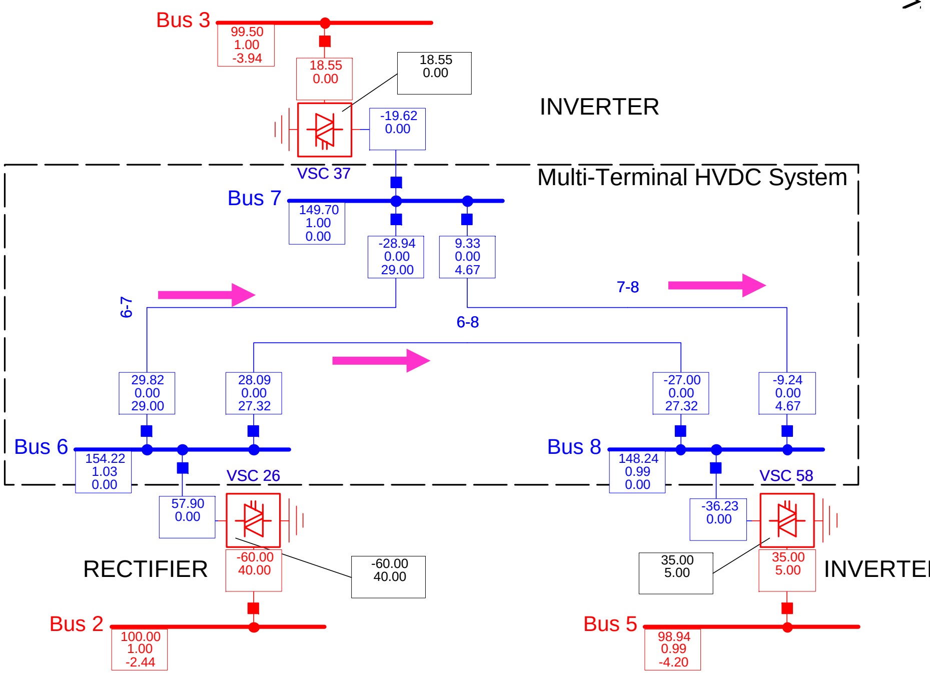


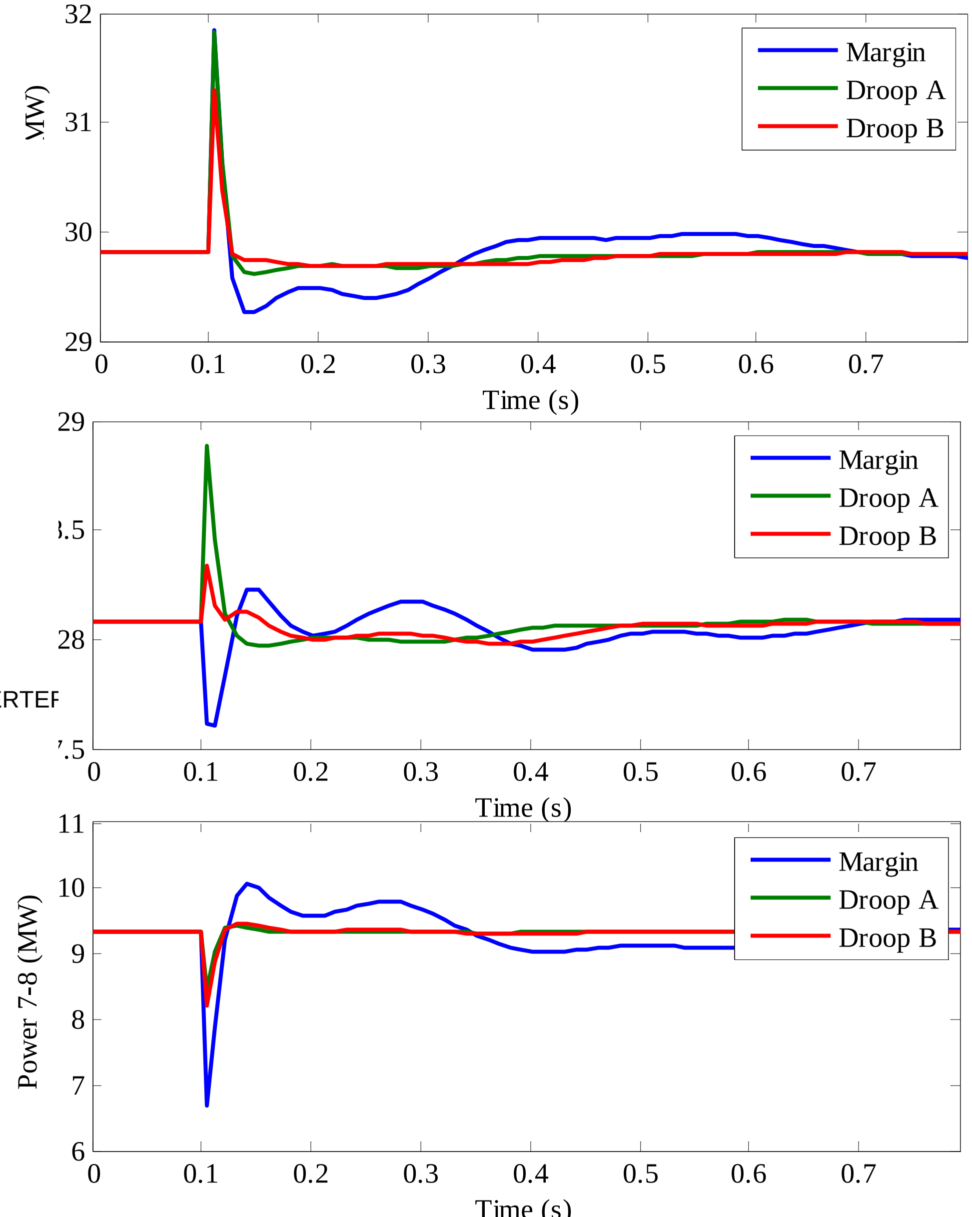


Case I: Sudden Load Increase (1/2)

$\Delta P = 40MW$

Sudden Load Increase



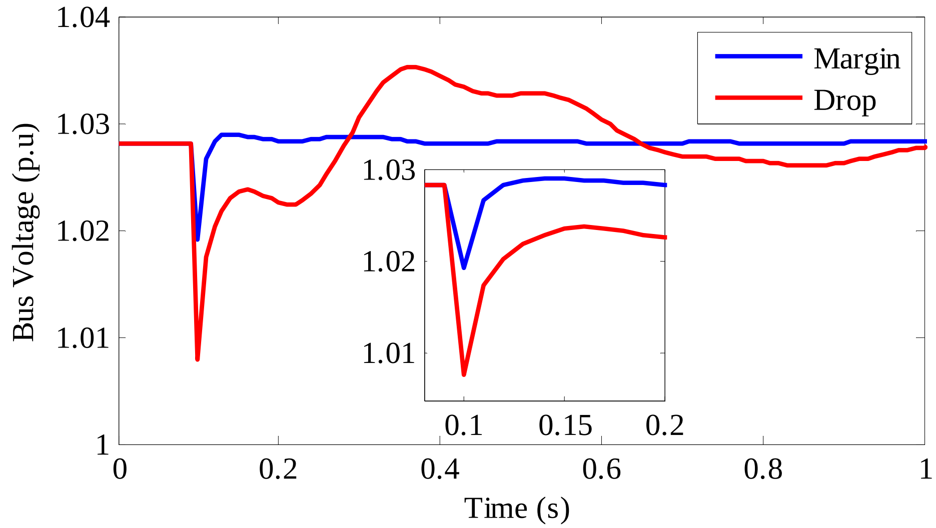


Voltage margin method produces the *smallest stress on AC system.*

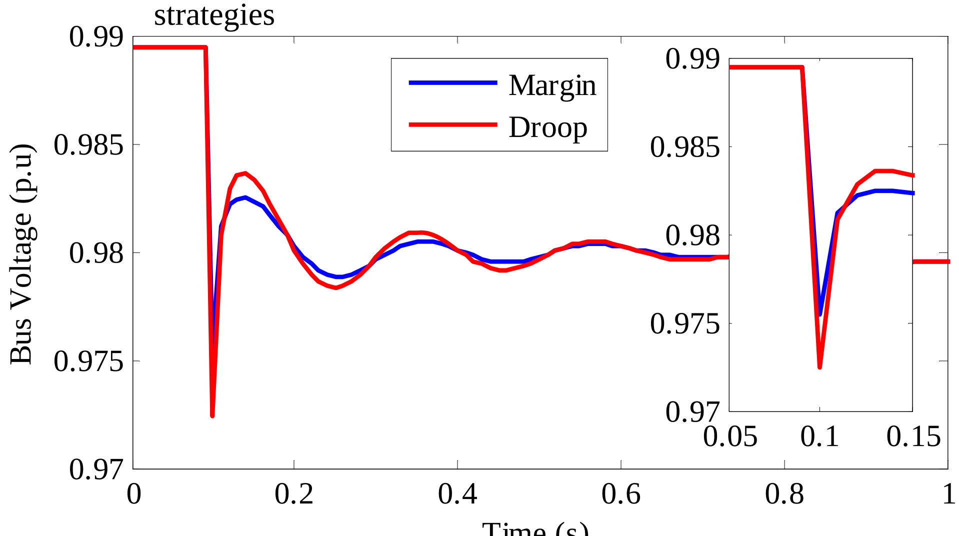
Voltage-Droop method increases power transfer during initial response.

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.

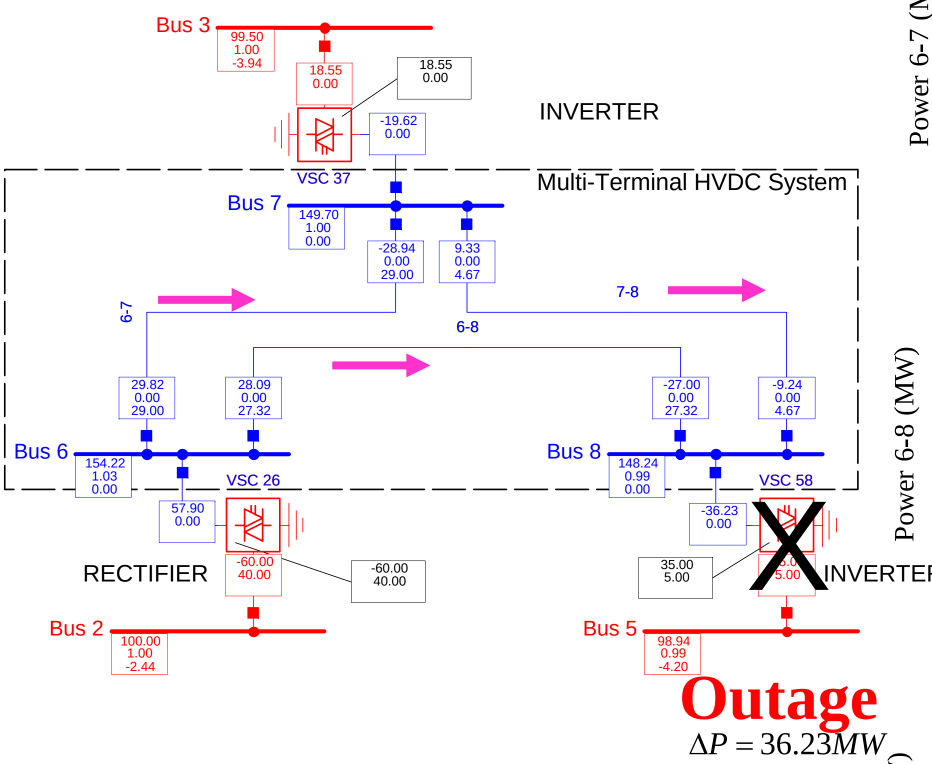


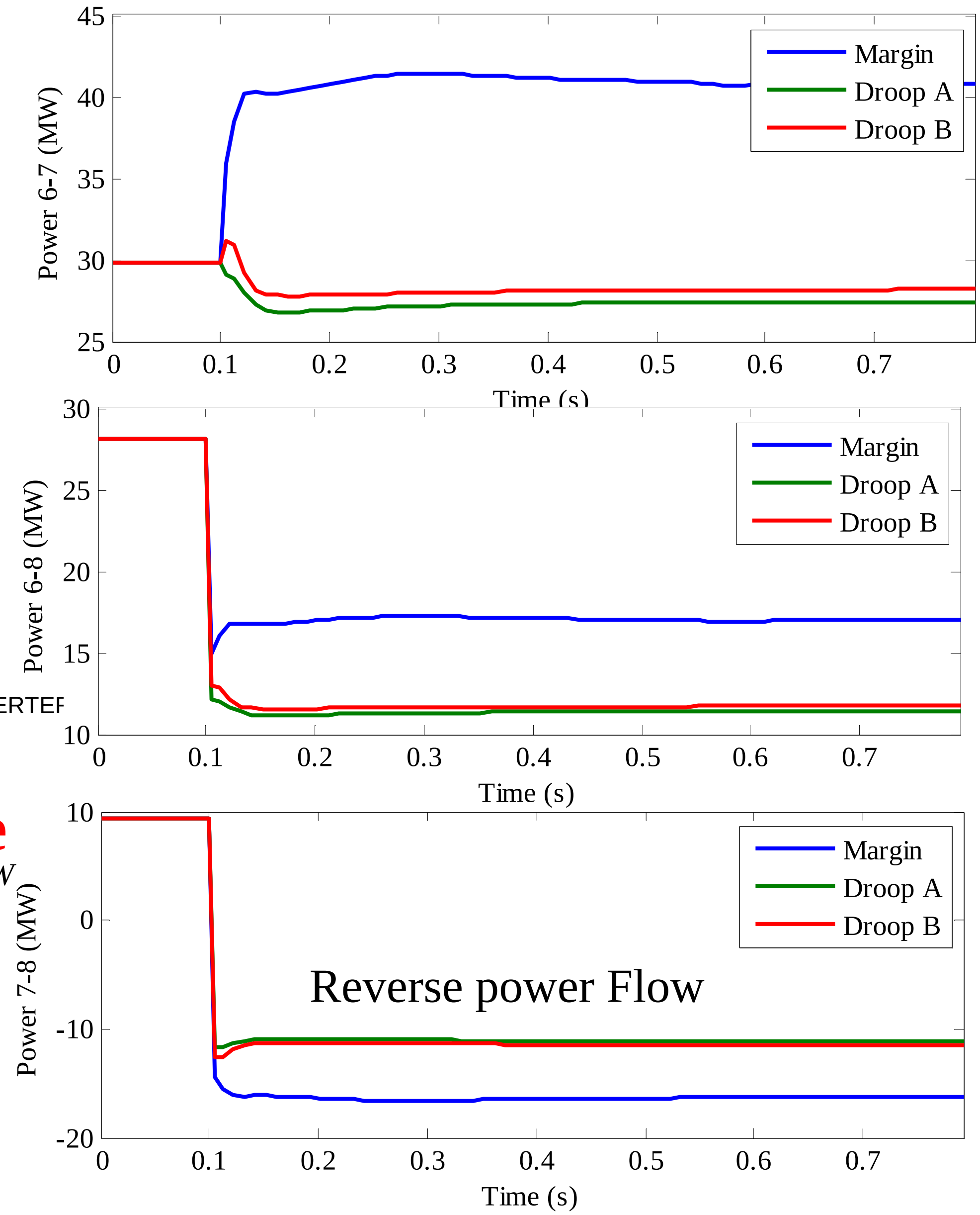
Bus 6, DC voltage transient with margin and droop control strategies



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

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.

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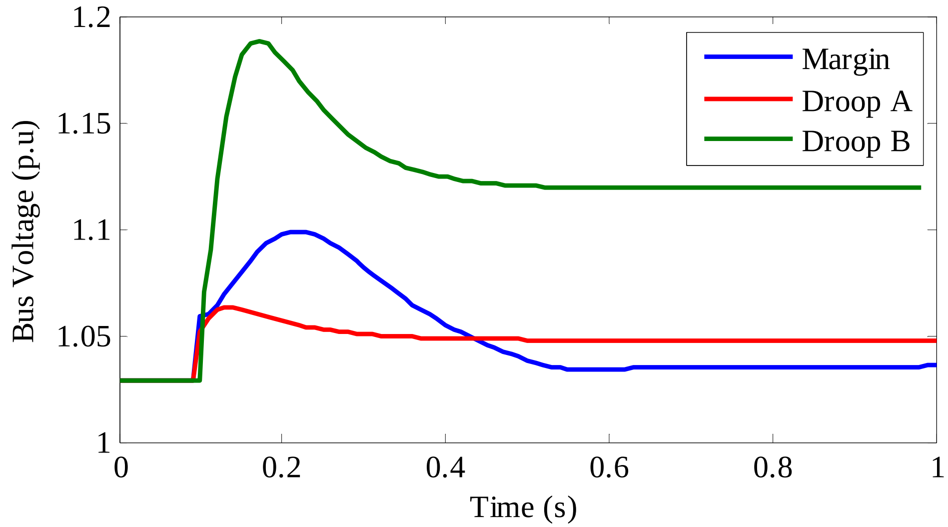
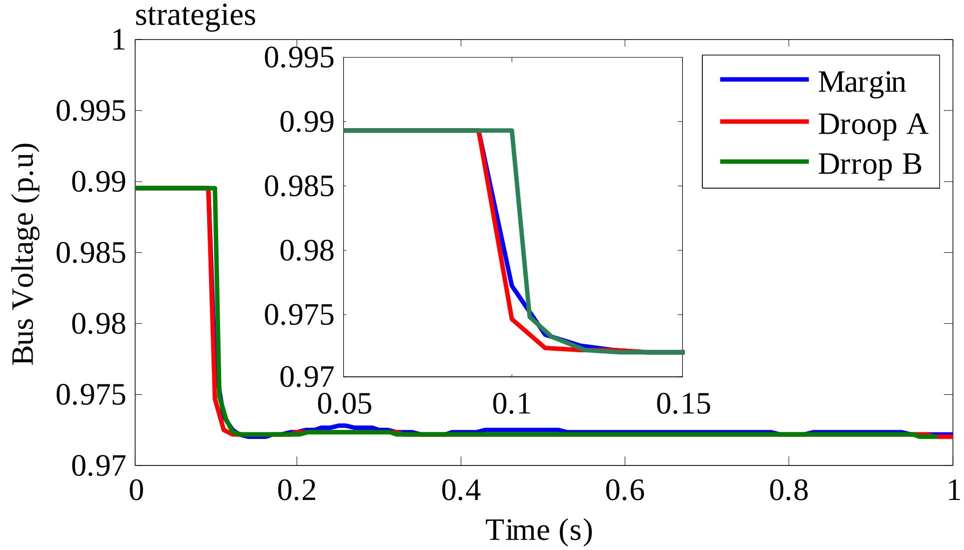
Case II: Converter Outage (2/2)

- 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*.

Any questions?

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