EMTP Europe User Conference - June 21st, 2019 - Perpignan

Influence of HVDC control on the transient stability of synchronous machine

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Agenda

01

Study background

Study background

Network evolution

THE SHARE OF PED* IS INCREASING IN THE NETWORK

- More and more HVDC interconnections
- Increase of PE based renewable energy (Wind + Solar)
- Storage

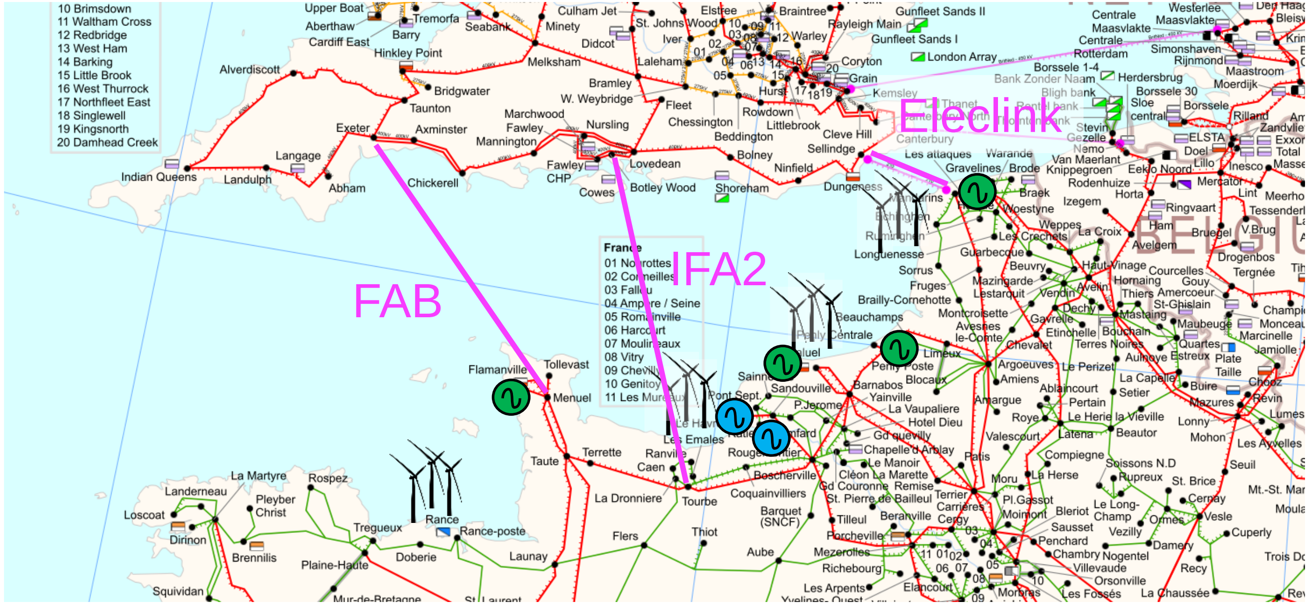
PEDS AFFECT THE BEHAVIOUR OF THE POWER SYSTEM DURING TRANSIENT.

WHAT IS THE IMPACT ON SYNCHRONOUS MACHINE?

* PED: Power Electronic Devices

Study background

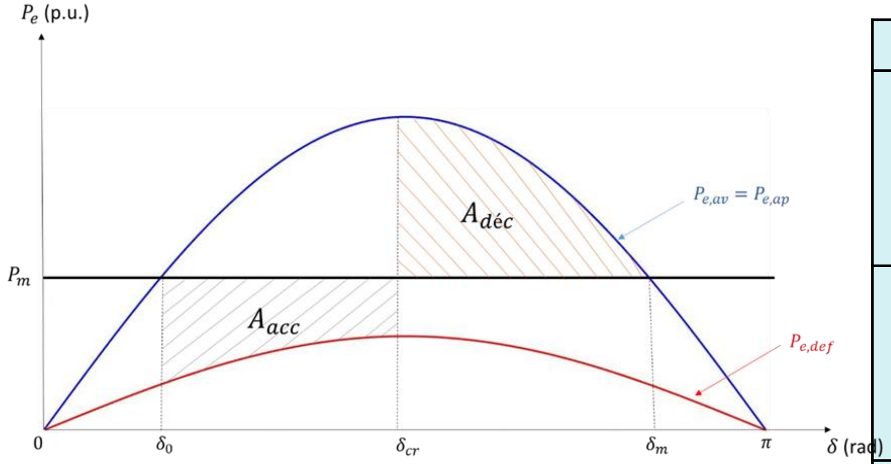
North of France – Power System is moving



Study background

Determination of δ_{cr}

➢ **Illustration of the area theory**



P_m	Mechanical power of the turbine (p.u.), before the fault
$P_{e,def}$	▪ Electrical power (p.u.) during the fault ▪ $P_{e,def} = \frac{3\|E'\|\|V_{bus\ eq\ def}\|}{\|Z_{eq,def}\|} sin\delta$
$P_{e,ap}$	▪ Electrical power after the fault (p.u.) after the fault clearance ▪ $P_{e,ap} = \frac{3\|E'\|\|V_{bus\ eq\ ap}\|}{\|Z_{eq,ap}\|} sin\delta$
A_{acc}	Speed up Area
$A_{déc}$	Speed down Area
δ_0	Angle of the SM before the fault
δ_m	Maximal angle at the fault clearance

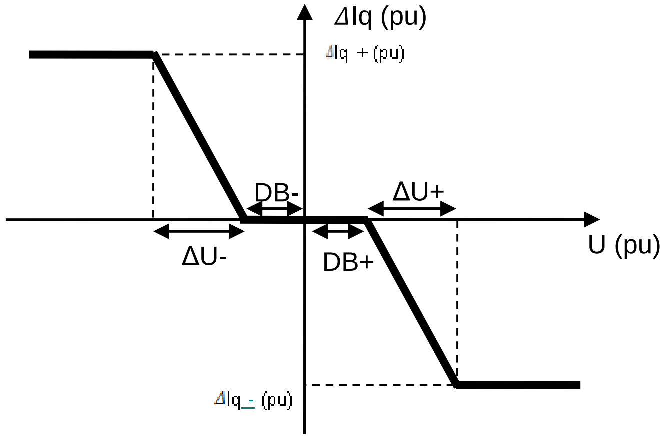
➢ **The critical clearing time = stability limit**

- $A_{acc} = A_{dec}$
- $\delta_m = \pi - \delta_0$

Study background

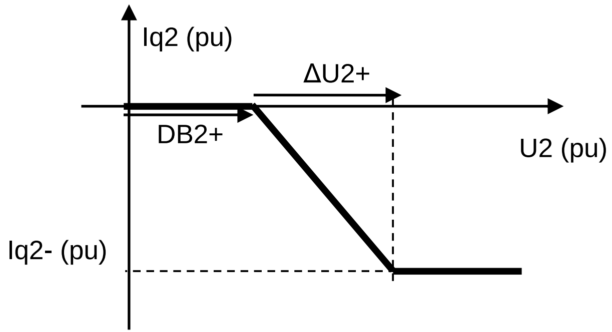
Grid Code: FRT control functions

Positive sequence current



- Positive sequence reactive current is injected to support the positive sequence voltage

Negative sequence current



- Negative sequence current is injected to reduce negative sequence voltage

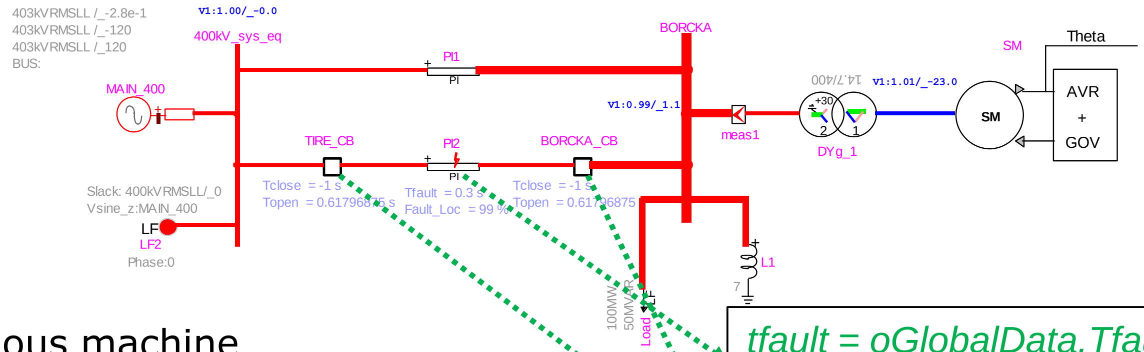
02

Transient stability analyses - Sweeping toolbox

Transient stability analyses - Sweeping toolbox

Illustration with the EMTP example

- Example 1: find the critical clearing time for a simple case



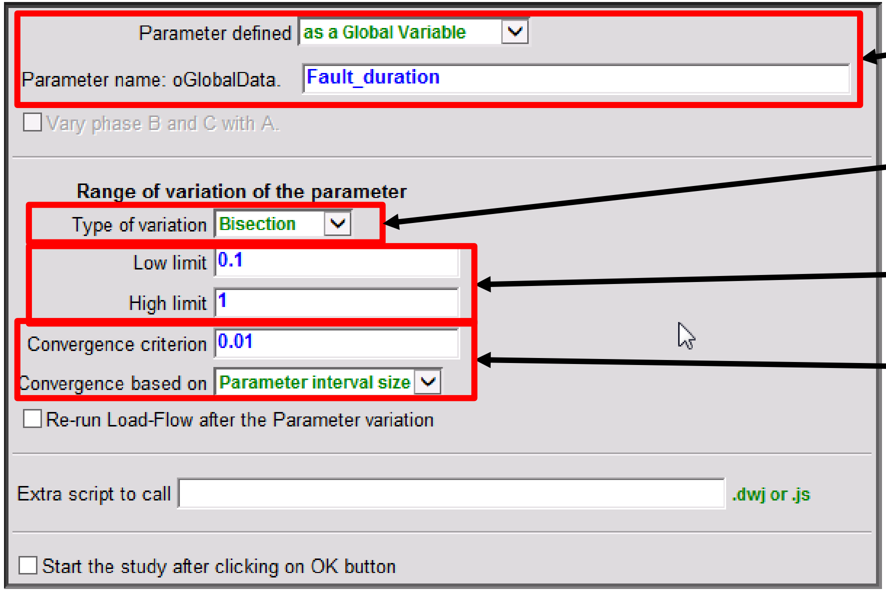
tfault = oGlobalData.Tfault; //s
Fault_duration = oGlobalData.Fault_duration //s

D=oGlobalData.Fault_Loc // fault location in %
Tfault = oGlobalData.Tfault // Fault instant

- Synchronous machine
  - 14.7 kV
  - 175 MVA
  - AVR + Governor
- 2 overhead lines in parallel (0.19 H / 3.75Ω)
- Load (100 MW 50 Mvar)
- Reactor (7 H)
- Network equivalent (25 GVA)

Transient stability analyses - Sweeping toolbox

Configuration of the sweeping parameter mask

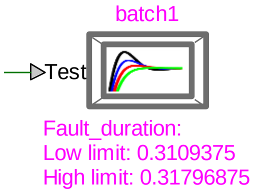


Name of the global variable to be updated (fault duration)

Choose Bisection as optimisation method

Define limits
Low limit: SM is stable
High limit: SM is unstable

Convergence criterion

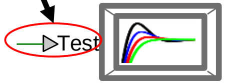


Transient stability analyses - Sweeping toolbox

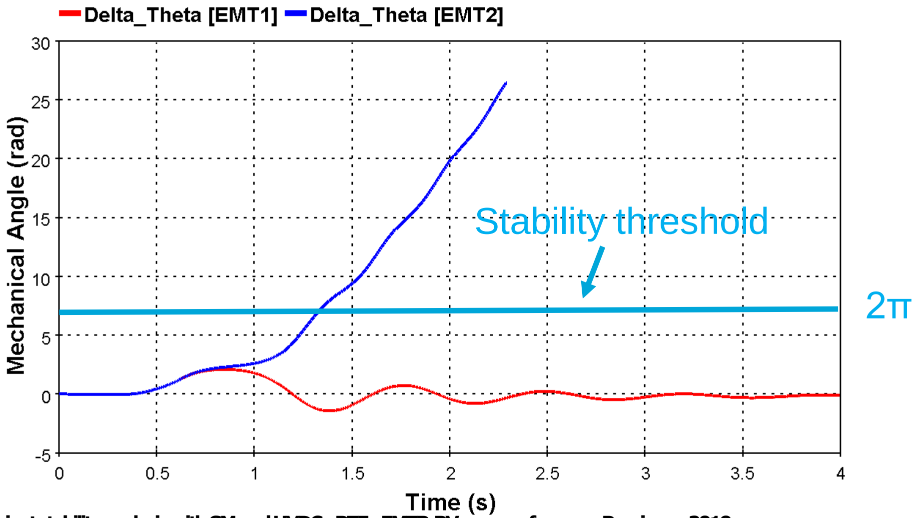
Find stability criteria

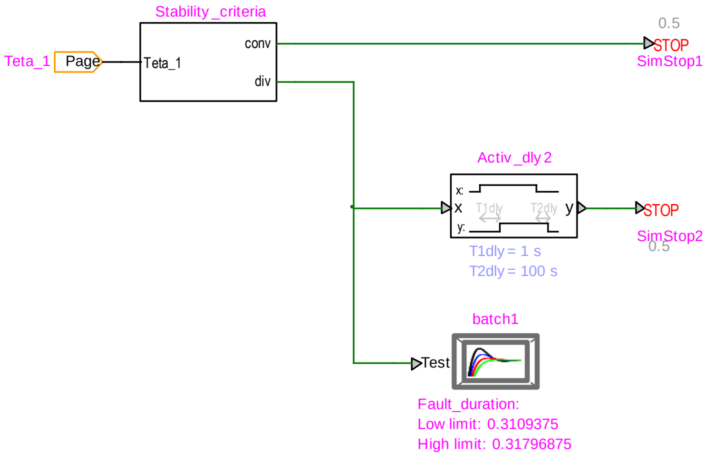
Stability criteria (Binary)

batch1



Normalized mechanical angle of the turbine-generator set (rotor shaft vs stator)

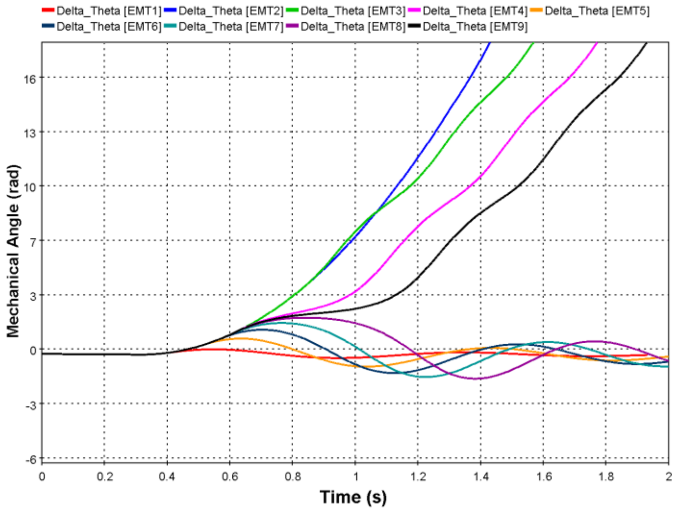




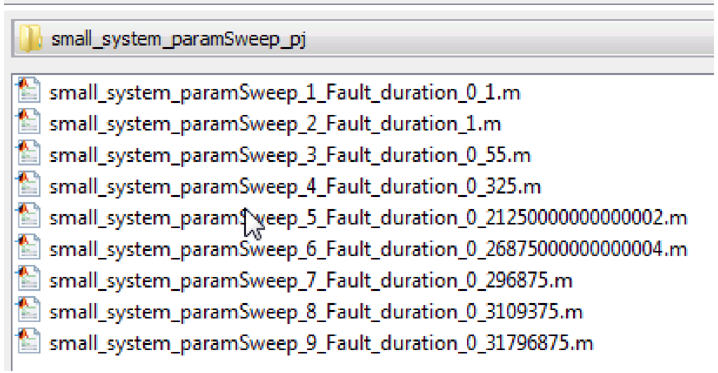
Transient stability analyses - Sweeping toolbox

Simulation results

Fault duration
Low limit : 0.1 s
High limit : 1 s

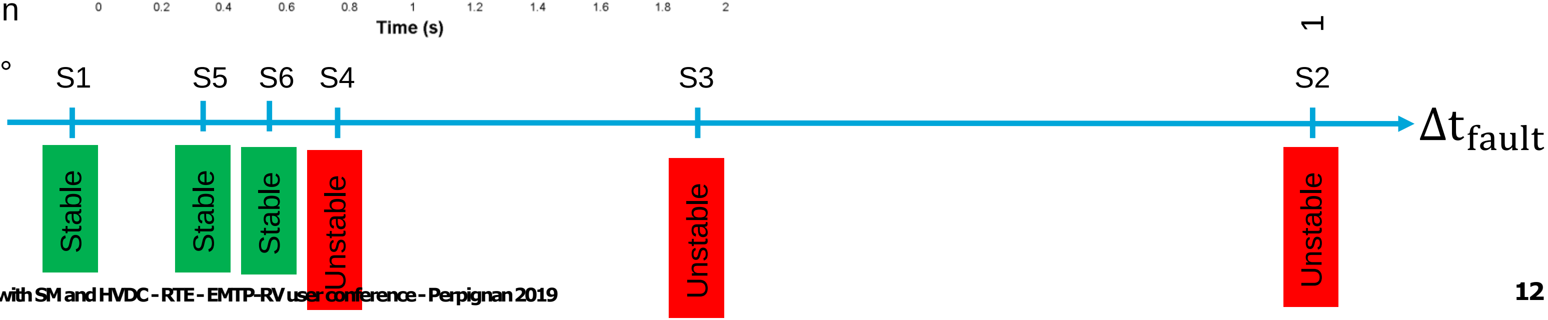


2π



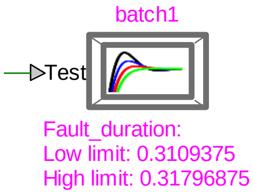
Fault duration

Simulation n°



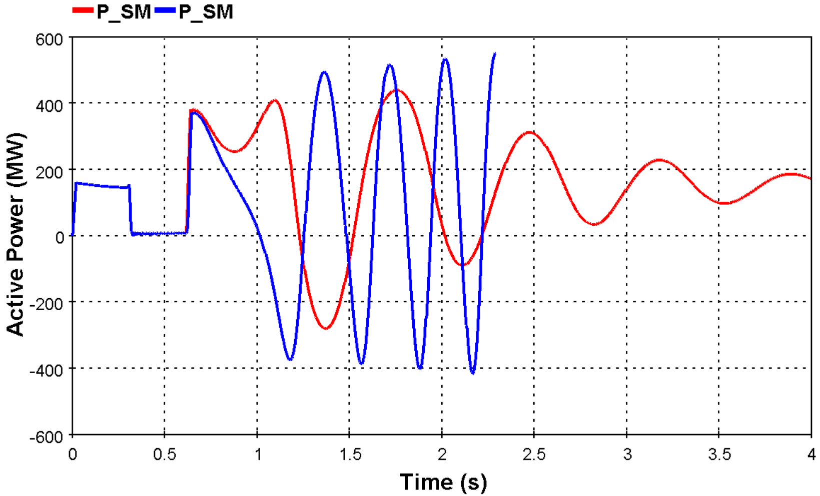
Transient stability analyses - Sweeping toolbox

Simulation results

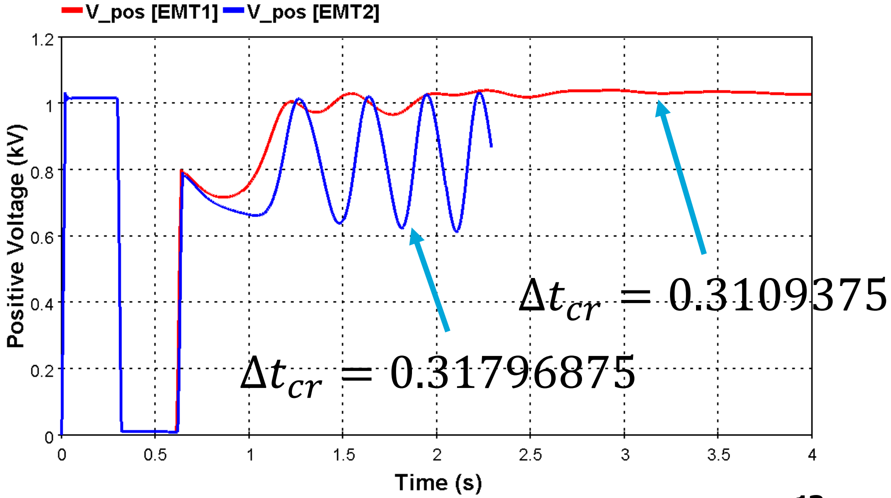


Fault duration
Low limit : 0.3109375 s
High limit : 0,31796875 s

SM active power

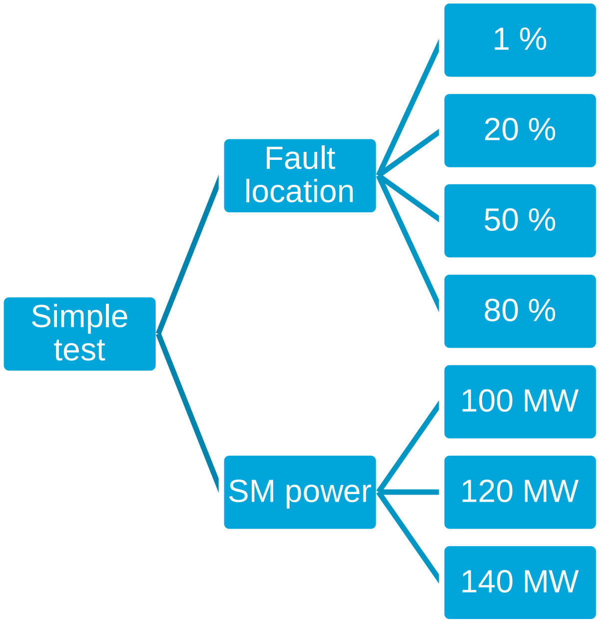


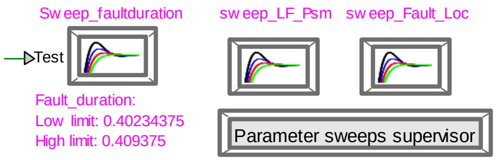
Substation positive voltage

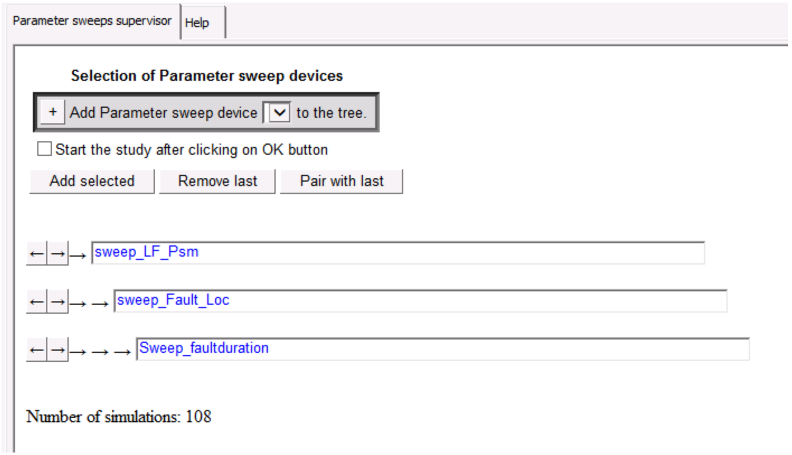


Transient stability analyses - Sweeping toolbox

Parametric case



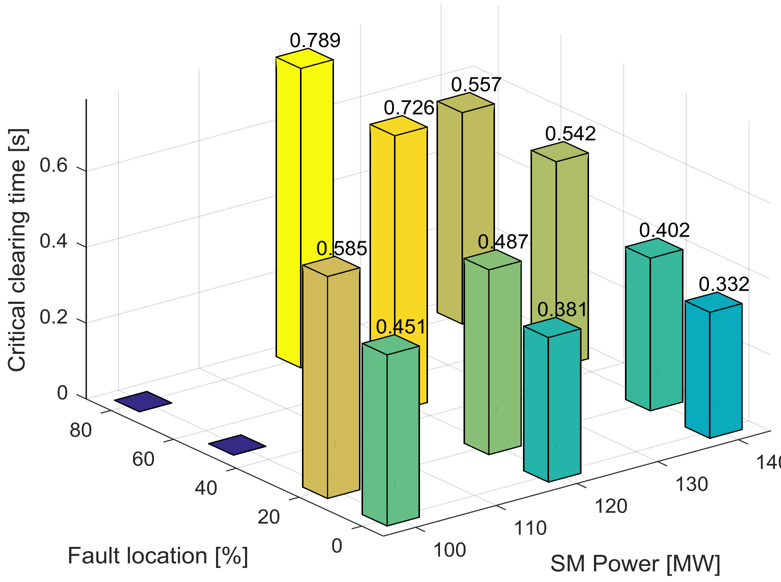




Transient stability analyses - Sweeping toolbox

Parametric case

LF_P [MW]	Fault Loc [%]	Critical clearing time [s]
100	1	0.452
100	20	0.585
100	50	
100	80	
120	1	0.381
120	20	0.487
120	50	0.726
120	80	0.789
140	1	0.332
140	20	0.402
140	50	0.543
140	80	0.557

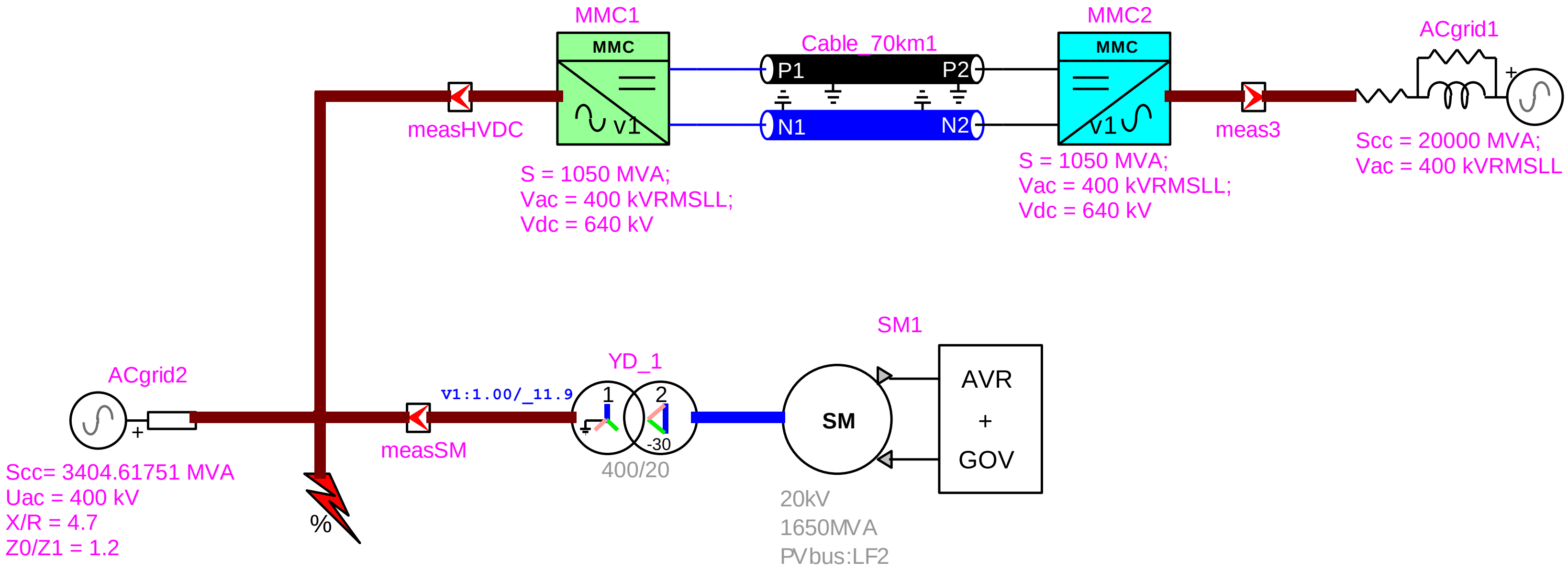


03

Study on a benchmark for transient stability with HVDC

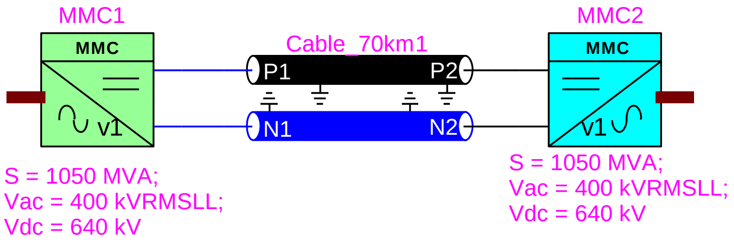
Benchmark for transient stability with HVDC

Benchmark description - EMTP



Benchmark for transient stability with HVDC

HVDC Link



MMC characteristics	
Converter type	MMC / symetrical monopolar
Rated power	1050 MVA
AC voltage	400 kV
Frequency	50 Hz
Converter bus voltage	320 kV
DC voltage	±320 kV
Number of SM	400

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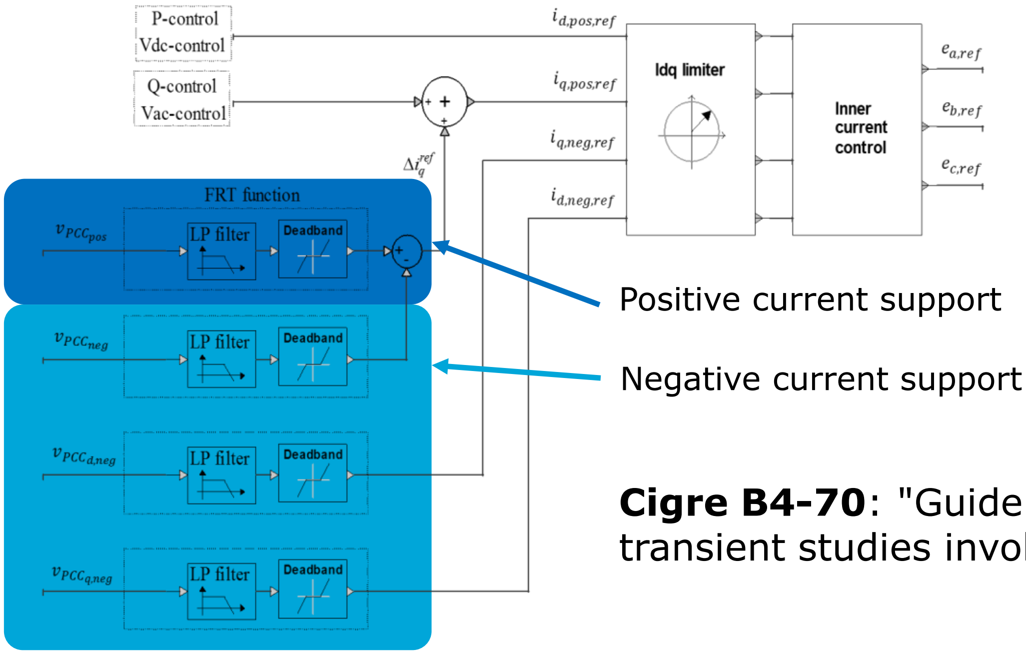
MMC characteristics	
Transformer leakage reactor	0.18 pu
Arm reactor	0.15 pu
SM energy	33 kJ/MVA

Cigre TB604: ”Guide for the Development of Models for HVDC Converters in a HVDC Grid”, 2014

Benchmark for transient stability with HVDC

HVDC Link – reactive current support



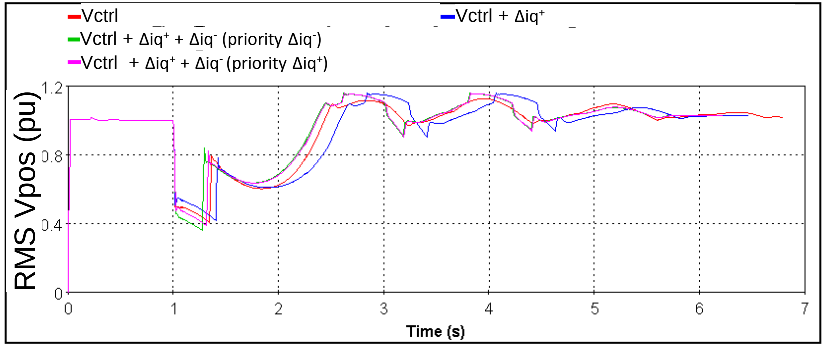
Cigre B4-70: "Guide for electromagnetic transient studies involving VSC converters"

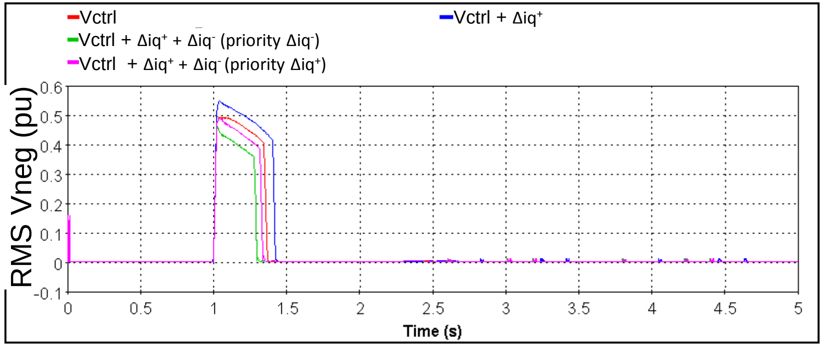
[1] S. Beckler et al "On Dynamic Performance Analysis for MMC-HVDC Systems during AC faults", Cigre symposium, Aalborg, 2019

Benchmark for transient stability with HVDC

Phase to phase faults

Voltage at the HVDC point of common coupling





Fault type	Remaining voltage (%)	Control	Critical clearing time (s)
2-phase	0%	Vctrl	0.346 s
		Vctrl + Δiq^+	**0.402s**
		Vctrl + Δiq^+ + Δiq^- (priority Δiq^-)	0.275 s
		Vctrl + Δiq^+ + Δiq^- (priority Δiq^+)	0.312 s
	10%	Vctrl	0.402 s
		Vctrl + Δiq^+	**0.487 s**
		Vctrl + Δiq^+ + Δiq^- (priority Δiq^-)	0.346 s
		Vctrl + Δiq^+ + Δiq^- (priority Δiq^+)	0.393 s
	20%	Vctrl	0.493 s
		Vctrl + Δiq^+	**0.606 s**
		Vctrl + Δiq^+ + Δiq^- (priority Δiq^-)	0.451 s
		Vctrl + Δiq^+ + Δiq^- (priority Δiq^+)	0.493 s

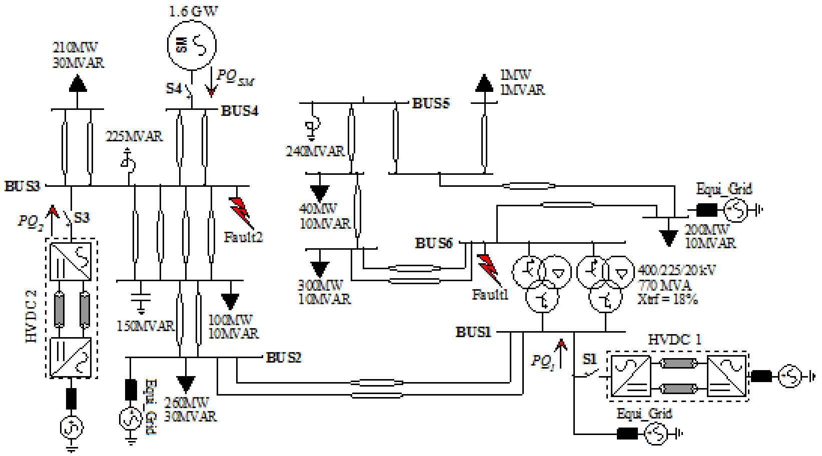
- For unbalanced fault, injection of negative reactive current deteriorate slightly the transient stability

04

Study on the northern France Network

Study on the northern France network

Objective: "Evaluate the impact of HVDC project on existing power plant stability"



EMTP Model:

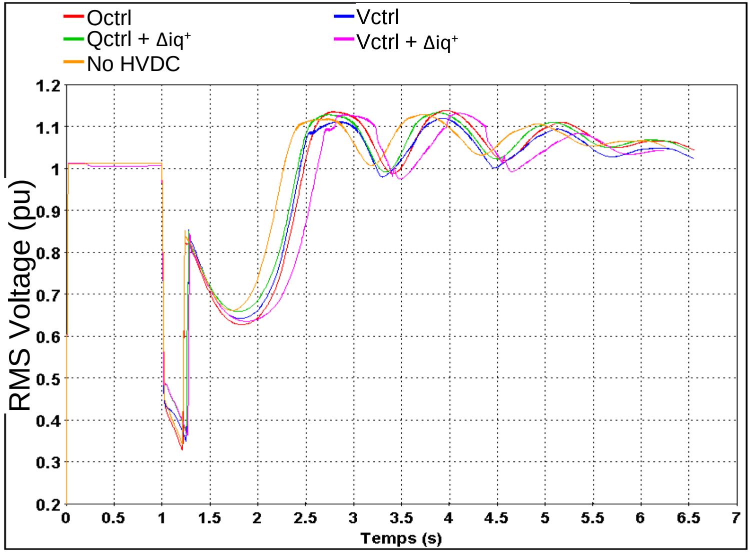
- One part of the 400 et 225 kV are modelled
- 4 Thevenin equivalent represent the rest of the network
- The HVDC is connected at different locations according to the current projects
- The HVDC inject the maximum power into the AC grid
- Faults is simulated at different substation or line with protection relay activation

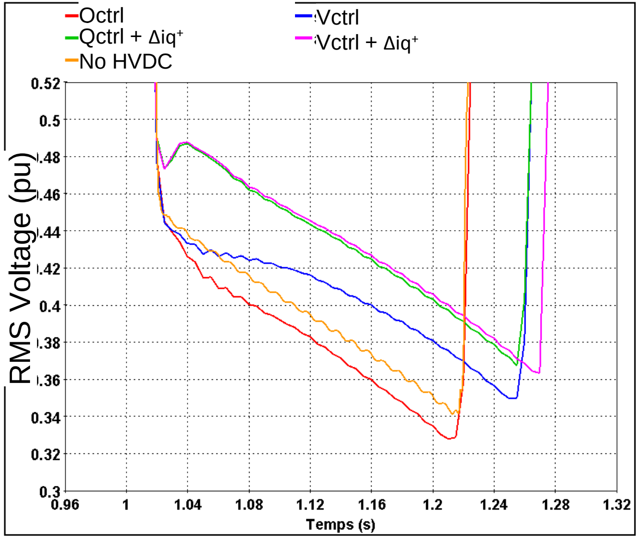
[2] H. Saad et al, "AC Fault dynamic studies of islanded grid Including HVDC links operating in VF-control", IET ACDC, Coventry, 2019

Study on the Northern France network

3-phase fault

Voltage at the HVDC point of common coupling





Study on the Northern France network

3-phase fault

HVDC	reactive current support	Reactive controller of the HVDC	Critical clearing time
No HVDC	-	-	0.21 s
With HVDC	NO	Q control	0.212 s
		Vac control	0.25 s
	YES	Q control	0.256 s
		Vac control	0.269 s

- For balanced fault, injection of positive reactive current improve slightly the stability

05

CONCLUSIONS

Conclusions

Transient stability studies with HVDC and Synchronous Machines

- Realistic synchronous machine data and control
- Accurate modelling in EMT tool
- Detail MMC-HVDC with sequence control
- Investigation on the different FRT strategy and parameters

Preliminary results

- VSC-HVDC does not deteriorate the transient stability of SMs
- Positive reactive current support improve slightly the transient stability
- Negative current support might slightly degrade the transient stability

Perspectives

- Analyse the impact of temporary valve blocking

Thanks for your attention

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