HVDC WEBINAR
FIRST SESSION

SIEMENS

General overview of EMT tools and approach to assess interaction studies.

Practical case studies

THE SPEAKERS

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INTRODUCTION

Several power electronic devices; as HVDC links, wind farms and FACTS projects are currently planned or constructed worldwide

Power electronic installations are embedded in a meshed AC network

- Relatively new aspect
- Such devices may have abnormal interaction and also impact on the performance of the AC network

This presentation focuses on the risk assessment of interactions between power electronic devices embedded in an HVAC network

- Overview on the interaction phenomena
- Approaches to investigate the risk of interaction during project phases

INTRODUCTION

Definitions of interactions in power systems

- "An interaction is a reciprocal action exerted by a system on one or several systems"
- "An interaction is the response deviation from normal operation when the elements of the system are excited by faults or disturbances"

Interactions might have a different effect on the system

- Positive: increase of network stability
- Negative: deterioration of the network stability

There are several interactions phenomena

- Control loop interactions
- Interactions due to non-linear functions
- High frequency interactions i.e. harmonic emissions and resonances

INTRODUCTION (SIEMENS)

EMT Multi-infeed Interaction Study

Control Loop Interaction Study

Purpose of the study:

- To evaluate control functions such as voltage, frequency & modulation control
- Co-ordination of control functions between power electronic devices (if possible)

Non-Liner Functions

Purpose of the study:

- To demonstrate robustness of the HVDC control during fault performance, line switching and so on

Harmonic & Resonance interaction

Purpose of the study:

- To evaluate the harmonics at PCC
- Possible resonances between the converters

INTERACTION PHENOMENA

1. Control loop interactions

- Generally speaking, several control loops are used in a power electronics equipment
- Stability margin may be affected (ex: SSCI, SSTI,etc) due to the gain values of a control loop (i.e. PID control, droop control, etc)
- Commonly studied in literature
- These types of interactions can be analyzed using small-signal, modal analysis or parametric studies in EMT-type tools
- Example : Interaction between 2 HVDC-VSC links (1000MW/±300MVar)

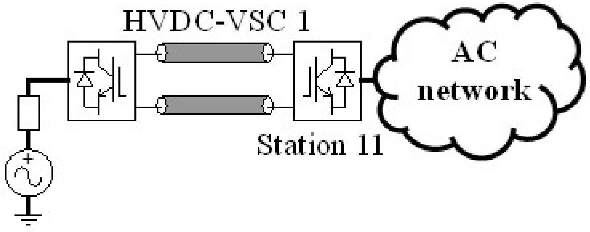
INTERACTION PHENOMENA

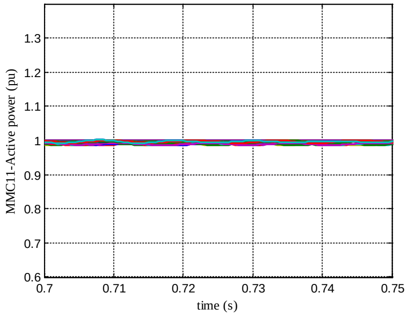
1. Control loop interactions

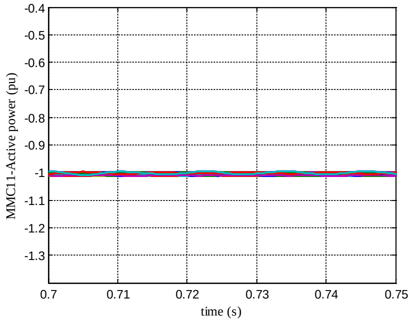
Step #1

Parametric study in EMT time domain is performed to adjust the gains of the control loop of HVDC-VSC 1 without the inclusion of HVDC-VSC 2

Parametric variations: AC network configurations, active/reactive power direction and control gains (432 simulations)







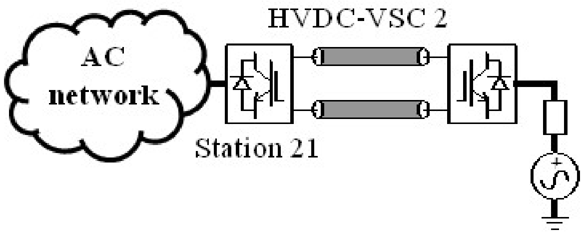
- ➢ Kp value of active power control must be < 1.5

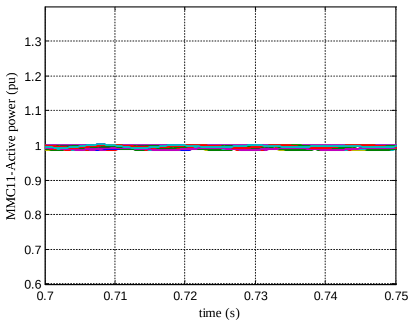
INTERACTION PHENOMENA

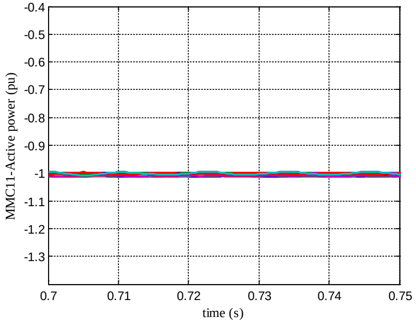
1. Control loop interactions

Step #2

Assuming that the HVDC-VSC 2 is inserted into the network without taking into account the HVDC-VSC 1 -> Kp value of active power control must be < 2





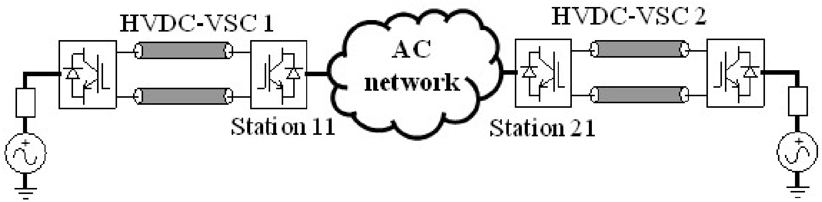


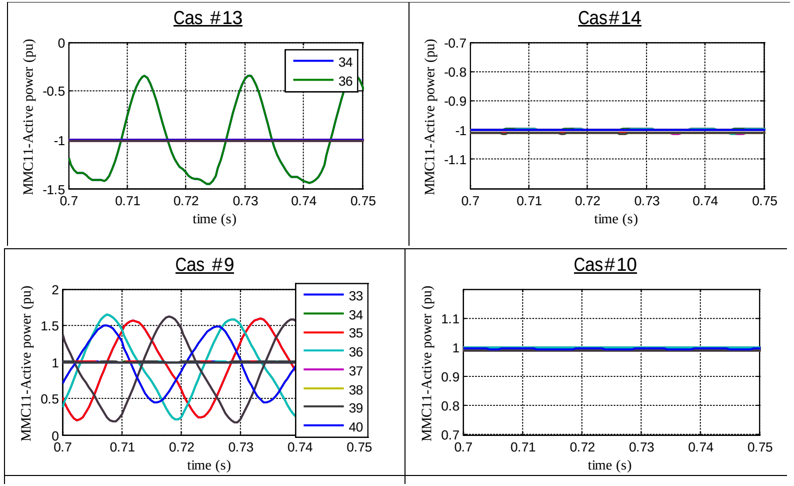
INTERACTION PHENOMENA

1. Control loop interactions

Step #3

Insertion of the two HVDC links in the network



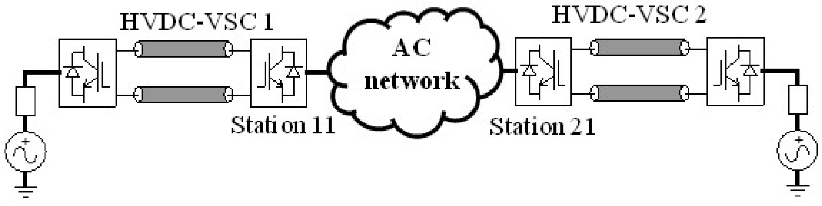


INTERACTION PHENOMENA (SIEMENS)

1. Control loop interactions

Step #3

Investigation of Voltage support between two HVDC



Instability due to strong voltage control interaction

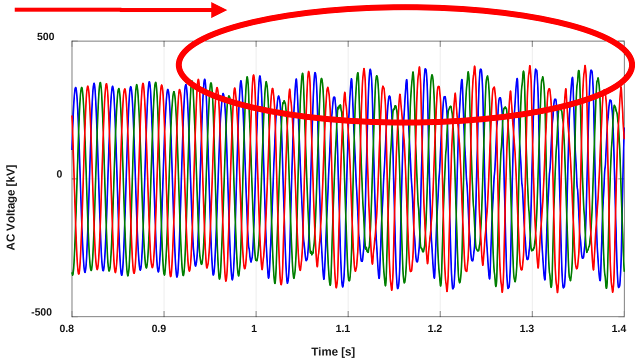


Fig: Example illustration of AC voltage control impact on AC system voltage

Scenario

Oscillation present in prior to activation, HVDC 1&2 activated same time with high slope of Voltage controller.

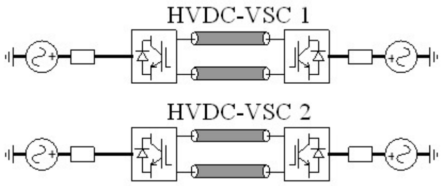
INTERACTION PHENOMENA

2. Interaction due to non-linear functions

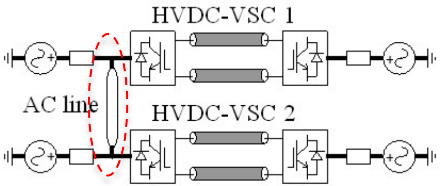
- Non-linear functions are introduced into the control and protection system as : limiters, activation of protections, etc.
- Functions are mainly activated during major disturbances or transients, such as: AC faults, DC faults, overvoltages, line energizations, etc.
- Non-linear behavior such as transformer magnetizations can also occur

Example: comparison between control loops and non-linear functions impact

In this test case, the two links and short-circuit ratio are identical (1000 MW/±300 MVar and SCR = 2.5) for both configurations. An AC overhead line is added in parallel



Two independent HVDC links

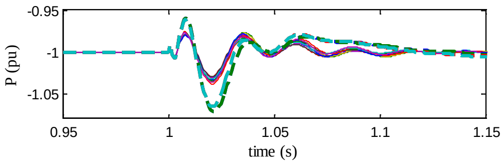


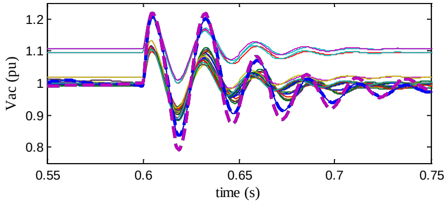
Two HVDC links connected via AC line

INTERACTION PHENOMENA

2. Interaction due to non-linear functions

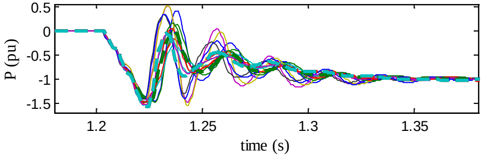
Small perturbations:
(3Ph-G fault with 1 kΩ)

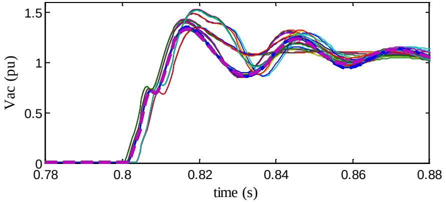




- The highest perturbation amplitudes are obtained without the presence of the ac line connected in parallel -> with AC line performances are improved

Large disruptions:
(Solid 3Ph-G fault at PCC)





- Several cases including the ac line in parallel cause higher oscillations compared to the case without the ac line in parallel -> with AC line performances are now decreased

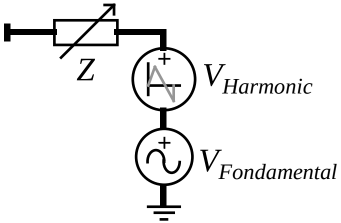
INTERACTION PHENOMENA

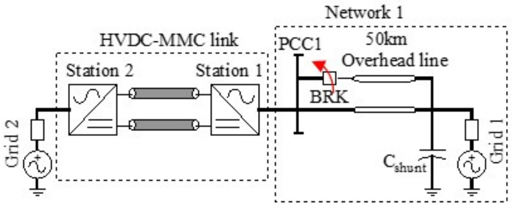
3. High frequency interactions

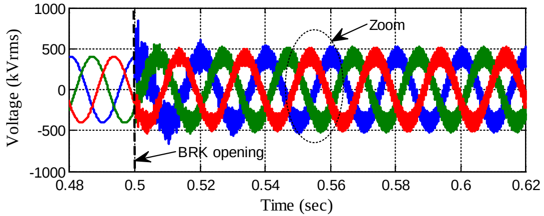
Interactions include harmonics emissions and resonances that can take place between two power electronics components :

- Harmonic emissions : associated with semiconductor switches and therefore continuously transmitted by the system which may affect the quality of the wave.
- Resonances : mainly related to the control system, filters, delays, etc. Resonances have usually higher order of magnitude with short time intervals

High frequency resonances have been reported in HVDC-VSC links and wind farms installations







Ref: H. Saad, Y. Fillion, S. Deschanvres, Y. Vernay, S. Dennetière, " On Resonances and Harmonics in HVDC-MMC Station Connected to AC grid," accepted in IEEE Transactions on Power Delivery, TPWRD-00679-2016.R2

INTERACTION PHENOMENA (SIEMENS)

3. High frequency interactions (Process)

Required inputs of the study :

- Each relevant converter station is presented as harmonic voltage source
- Characteristics of harmonic impedance required
- Black-boxed EMT model for each converters in concern

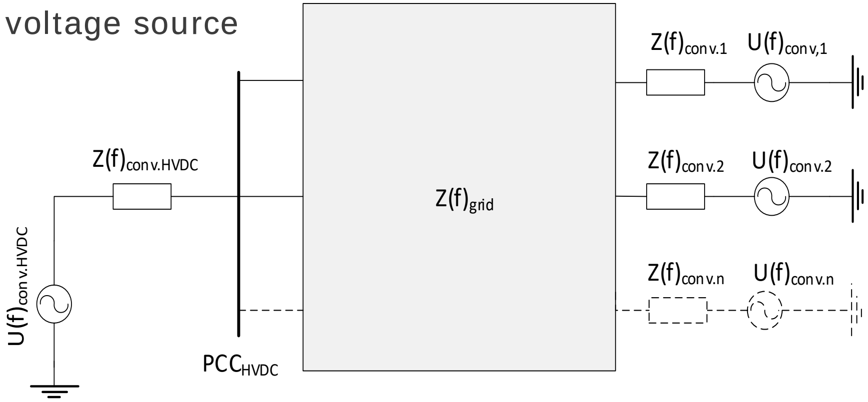


Fig: Example illustration of circuit, Siemens

AC network connecting the converter stations is modelled in frequency domain.
Different switching configuration of lines and equipment are taken into account for the study.

Output of the study:

- Magnitude of the resulting harmonic voltage according to IEC.

INTERACTION PHENOMENA (SIEMENS)

3. High frequency interactions (Process)

Required inputs of the study :

- Detail transient models of the HVDC converter control system

Demonstrated based on harmonic current sources connected at converter busbar & voltage distortions

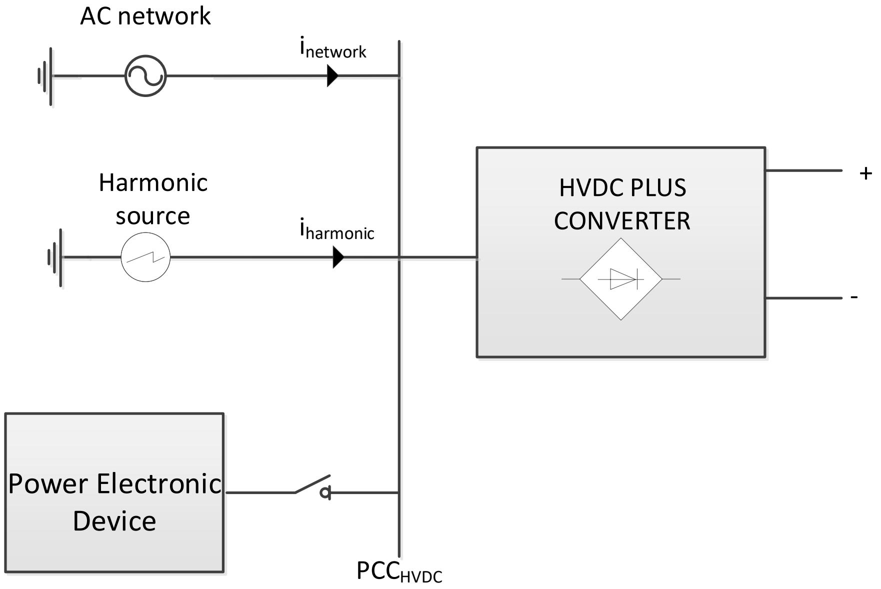


Fig: Example illustration of circuit, Siemens

Output of the study:

The performance is demonstrated with THD & according to IEC standard

INTERACTION MITIGATION

Different approaches to avoid or solve these interaction phenomena

1. **Installation of HV equipment, as filters and compensators**

- Usually expensive solution
- Delays and additional costs to the project may take place

2. **Control tuning**: since the control system dictates the behavior of the system, modification or improvement of the control system is possible

- Most suitable solution and less expensive

3. **Protections coordination:** protections thresholds can be set to mitigate the problem

- Coordination between different protection equipment may be necessary
- This approach should be used as a last resort because it can impact the life cycle of the equipment and does not solve the source of the problem

INTERACTION MITIGATION (SIEMENS)

Example Mitigation

Control tuning / mode of operation: it is possible to observe the impact of the voltage controller after fault recovery & based on change of modes the voltage profile can be improved (for two HVDC VSC connected at the same busbar)

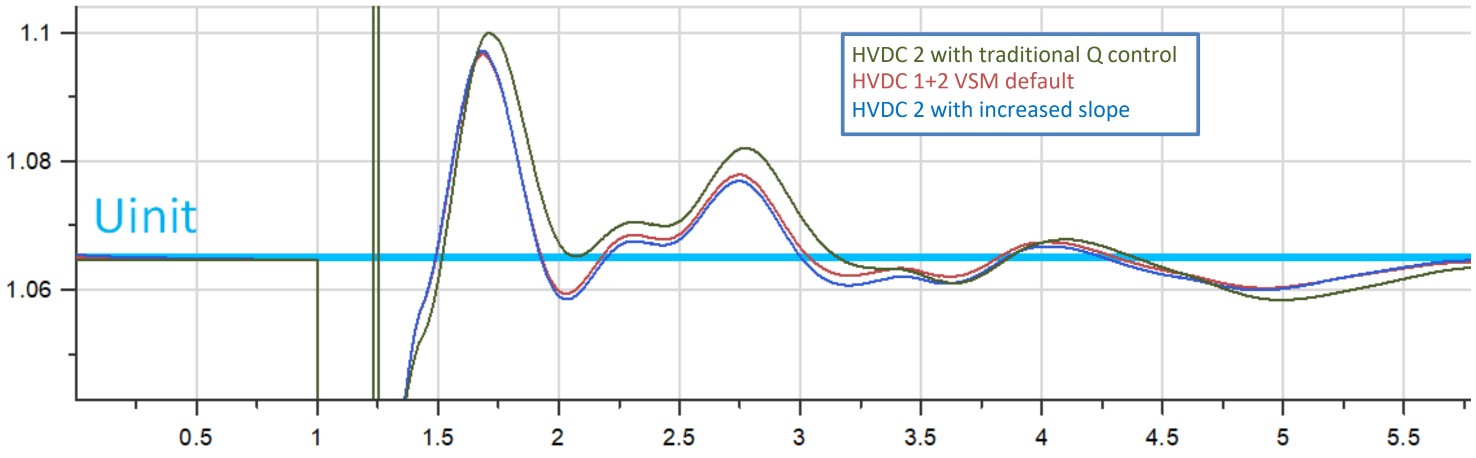


Fig: Example Voltage profile in terms of fault recovery, Siemens

INTERACTION MITIGATION (SIEMENS)

Example Mitigation

Control tuning / mode of operation: it is possible to observe the impact of the voltage controller after fault recovery & based on change of modes the voltage profile can be improved (for two HVDC VSC connected at the same busbar)

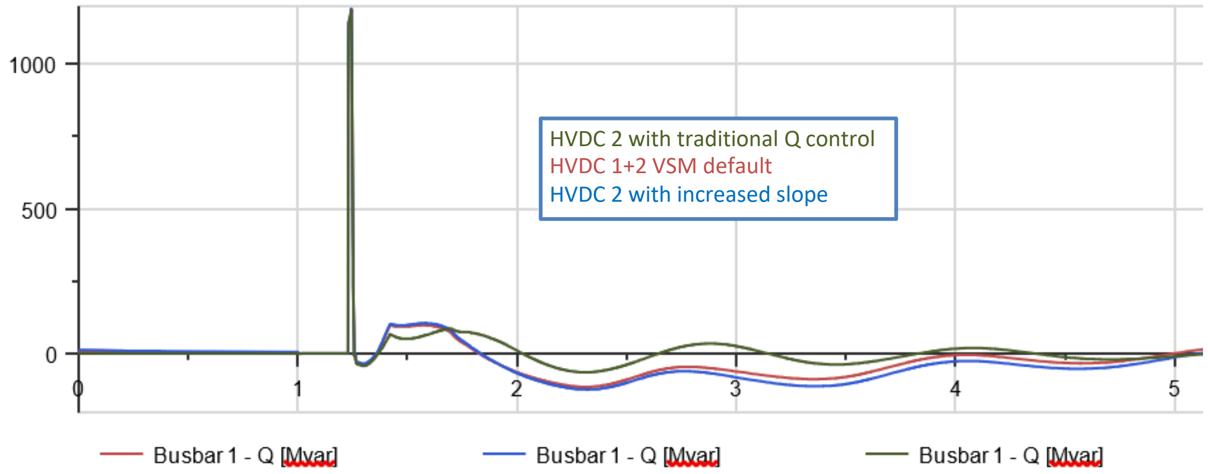


Fig: Example Reactive Power profile in terms of fault recovery, Siemens

APPROACH FOR INTERACTION STUDY

Project phases & tools

Planning

Analytical investigation to quantify interaction risk :

- SCR analysis
- MIIF
- UIF
- etc.

Determine the network area and PE devices that have potential interaction

Design

Perform generic studies in RMS tools and EMT tools
If available vendor's models are used

FAT & commissioning

- Real time simulator are performed with real cubicles
- Replicas can be used during commissioning when other PE are connected in close vicinity

Normal operation

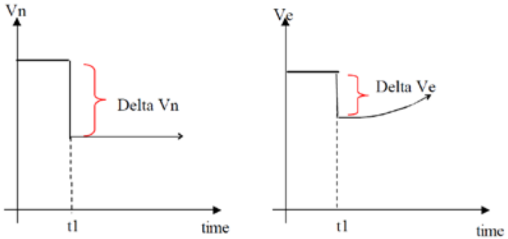
Depending on the interaction phenomena : RMS model, offline EMT tools and/or Replicas using real time simulator

ANALYTICAL CRITERIA FOR RISK ASSESSMENT

MIIF

MIIF original presented in CIGRE WG B4.41 “Systems with multiple DC Infeed” CIGRE technical brochure 364, Paris, April 2008

➢Criteria applicable only for HVDC-LCC



Weighted MIIF factor to account for components rating: $MIIF_{j,i}P_{dcj\ 0}$

Improved MIIF

➢To account for various VSC and LCC technologies

Approach based on : H. Saad, S. Dennetière and B. Clerc, "Interactions investigations between power electronics devices embedded in HVAC network," *13th IET International Conference on AC and DC Power Transmission (ACDC 2017)*, Manchester, 2017, pp. 1-7.

ANALYTICAL CRITERIA FOR RISK ASSESSMENT

Small perturbations of 1% is applied on each PCC of the power electronic equipment

MIIF amplitude

MIIF amp.	PCC#1	PCC#2	PCC#N
PCC#1	$MIIF^V_{1,1}=\frac{\Delta V_1}{\Delta V_1}$	$MIIF^V_{2,1}=\frac{\Delta V_2}{\Delta V_1}$	$MIIF^V_{N,1}=\frac{\Delta V_N}{\Delta V_1}$
PCC#2	$MIIF^V_{1,2}=\frac{\Delta V_1}{\Delta V_2}$	$MIIF^V_{2,2}=\frac{\Delta V_2}{\Delta V_2}$	$MIIF^V_{N,2}=\frac{\Delta V_N}{\Delta V_2}$
PCC#N	$MIIF^V_{1,N}=\frac{\Delta V_1}{\Delta V_N}$	$MIIF^V_{2,N}=\frac{\Delta V_2}{\Delta V_N}$	$MIIF^V_{N,N}=\frac{\Delta V_N}{\Delta V_N}$

Weighted MIIF amplitude

%	PCC #1	PCC #2	PCC #N
PCC #1	100	$MIIF^V_{2,1}\frac{Q_1}{Q_2}$	$MIIF^V_{N,1}\frac{Q_1}{Q_N}$
PCC #2	$MIIF^V_{1,2}\frac{Q_2}{Q_1}$	100	$MIIF^V_{N,2}\frac{Q_2}{Q_N}$
PCC #N	$MIIF^V_{1,N}\frac{Q_N}{Q_1}$	$MIIF^V_{2,N}\frac{Q_N}{Q_2}$	100

MIIF angle

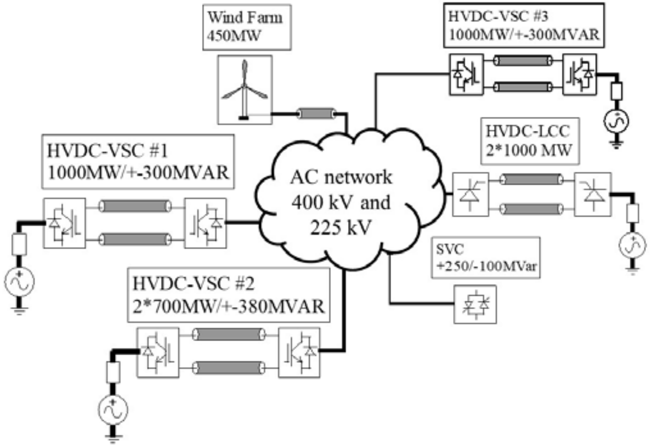
MIIF angle	PCC#1	PCC#2	PCC#N
PCC#1	$MIIF^{\partial}_{1,1}=\frac{\Delta\partial_1}{\Delta\partial_1}$	$MIIF^{\partial}_{2,1}=\frac{\Delta\partial_2}{\Delta\partial_1}$	$MIIF^{\partial}_{N,1}=\frac{\Delta\partial_N}{\Delta\partial_1}$
PCC#2	$MIIF^{\partial}_{1,2}=\frac{\Delta\partial_1}{\Delta\partial_2}$	$MIIF^{\partial}_{2,2}=\frac{\Delta\partial_2}{\Delta\partial_2}$	$MIIF^{\partial}_{N,2}=\frac{\Delta\partial_N}{\Delta\partial_2}$
PCC#N	$MIIF^{\partial}_{1,N}=\frac{\Delta\partial_1}{\Delta\partial_N}$	$MIIF^{\partial}_{2,N}=\frac{\Delta\partial_2}{\Delta\partial_N}$	$MIIF^{\partial}_{N,N}=\frac{\Delta\partial_N}{\Delta\partial_N}$

Weighted MIIF angle

%	PCC #1	PCC #2	PCC #N
PCC #1	100	$MIIF^V_{2,1}\frac{P_{dc1}}{P_{dc2}}$	$MIIF^V_{N,1}\frac{P_{dc1}}{P_{dcN}}$
PCC #2	$MIIF^V_{1,2}\frac{P_{dc2}}{P_{dc1}}$	100	$MIIF^V_{N,2}\frac{P_{dc2}}{P_{dcN}}$
PCC #N	$MIIF^V_{1,N}\frac{P_{dcN}}{P_{dc1}}$	$MIIF^V_{2,N}\frac{P_{dcN}}{P_{dc2}}$	100

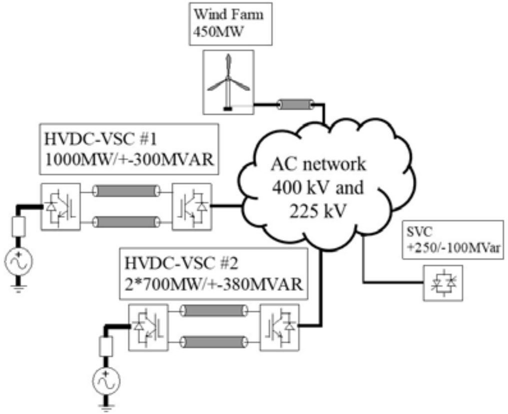
ANALYTICAL CRITERIA FOR RISK ASSESSMENT

Criteria applied on Northen France projects



Off load and Peak load
MIIF weighted

$MIIF_{ij}.Q_i/Q_j$ (%)	HVDC-IFA2	SVC-Tourbe	WPP-CSM.	HVDC-IFA2000	HVDC-FAB
HVDC-IFA2	100	50.6	40.3	10.6	66.8
SVC-Tourbe	65.9	100	78.9	8.7	47.6
WPP-CSM	48.2	72.5	100	6.4	34.9
HVDC-IFA2000	3.5	2.3	1.8	100	2.7
HVDC-FAB	38.6	21.2	17.0	4.7	100



Ref: H. Saad, S. Dennetière and B. Clerc, "Interactions investigations between power electronics devices embedded in HVAC network," 13th IET International Conference on AC and DC Power Transmission (ACDC 2017), Manchester, 2017, pp. 1-7

Based on the improved MIIF results, network reductions can be deduced

ANALYTICAL CRITERIA FOR RISK ASSESSMENT (SIEMENS)

Design Phase of Projects

Different Vendor Models in EMT with TSO

Multi-infeed study / Grid code compliance study

FAT phase

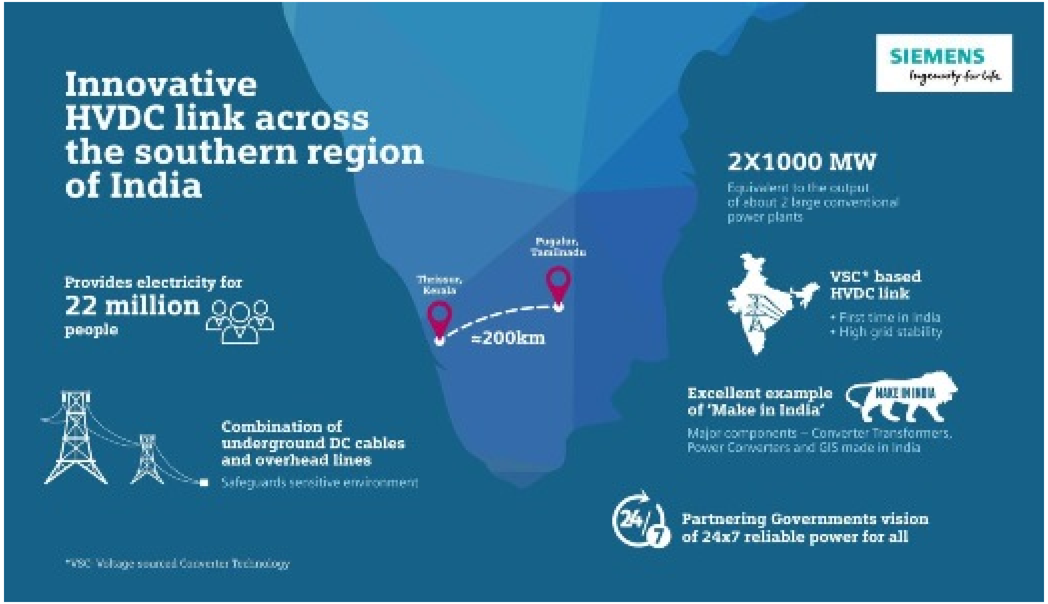


Fig: Source Siemens India

ANALYTICAL CRITERIA FOR RISK ASSESSMENT (SIEMENS)

Design Phase of Projects

Siemens HVDC Systems

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Multi-infeed study / Grid code compliance study

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Mitigation Measures & FAT

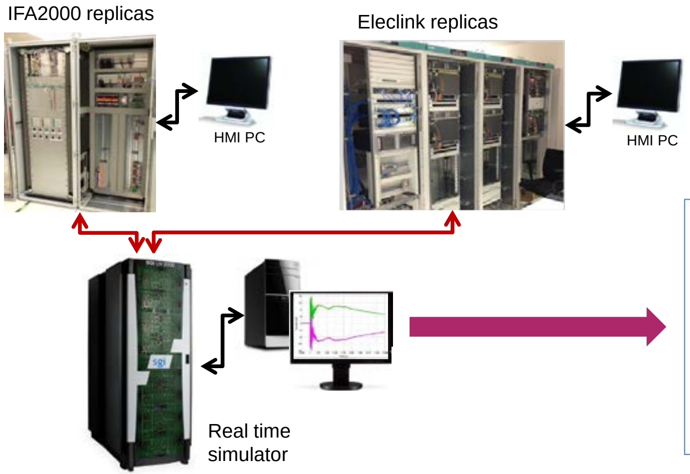
Fig: Source Transnet BW

FROM OFFLINE TO REAL-TIME SIMULATION

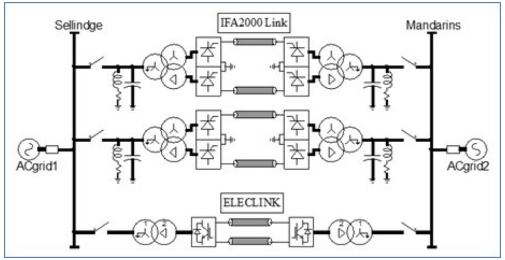
Interaction studies between IFA2000 and Eleclink

IFA 2000 Link (GE)	ELECLINK (Siemens)
• HVDC-LCC technology • Bipolar configuration • 12 pulse bridge • 2,000 MW • DC voltage ±270kV	• HVDC-VSC technology • Monopole configuration • MMC with half-bridge submodules • 1,000 MW • DC voltage ±320kV

- Different vendors
- Converter stations installed in the same substation as IFA2000
- Replicas are used to study and prevent interaction issues between power electronics devices
- Studies are performed between IFA2000 and ELECLINK replicas



AC network model + HVDC links



HVDC WEBINAR | FIRST SESSION

General overview of EMT tools and approach to assess interaction studies.
Practical case on French transmission grid.

Questions & Answers