DFIG operation in weak grids

10/02/2020

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- Aim : Why DFIG functionalities should be improved
- Approach: Modal analysis
- Sub-synchronous interaction
- Inter-area oscillation

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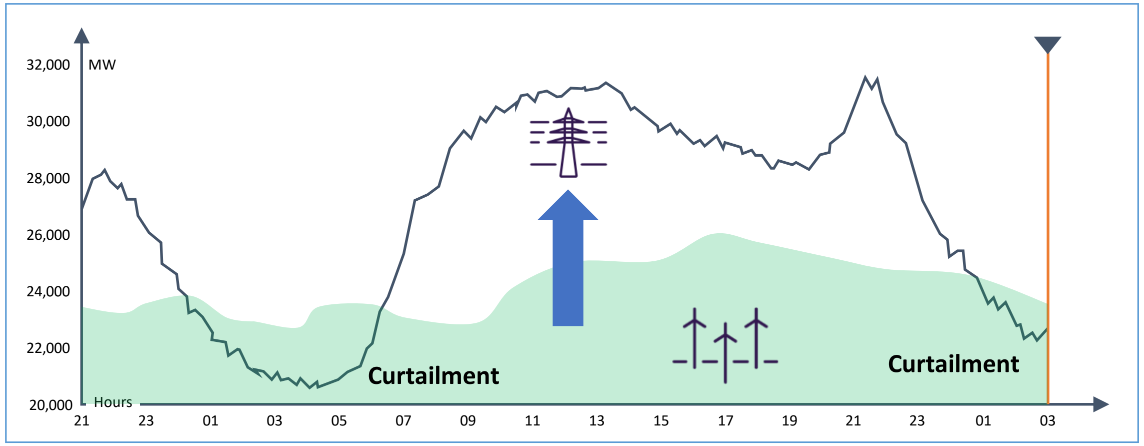
Weak grids

Synchronous generators are being displacement worldwide by renewable generators, especially wind turbines



Wind turbines should face the challenge of being installed in ‘weak’ systems

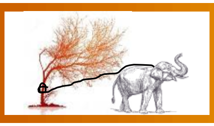
Weak grid

Low inertia
High short-circuit impedance (**SCR**)

SCR = $\frac{\text{SCMVA of the system at the device interconnection point}}{\text{Power rating of the device}}$

Extremely low ratio < SCR 2 < **Very low ratio** < SCR 4 < **Weak networks** < SCR 10 … SCR 25 < **Strong networks**

Extremely weak network



Operational limits interactions

Strong networks

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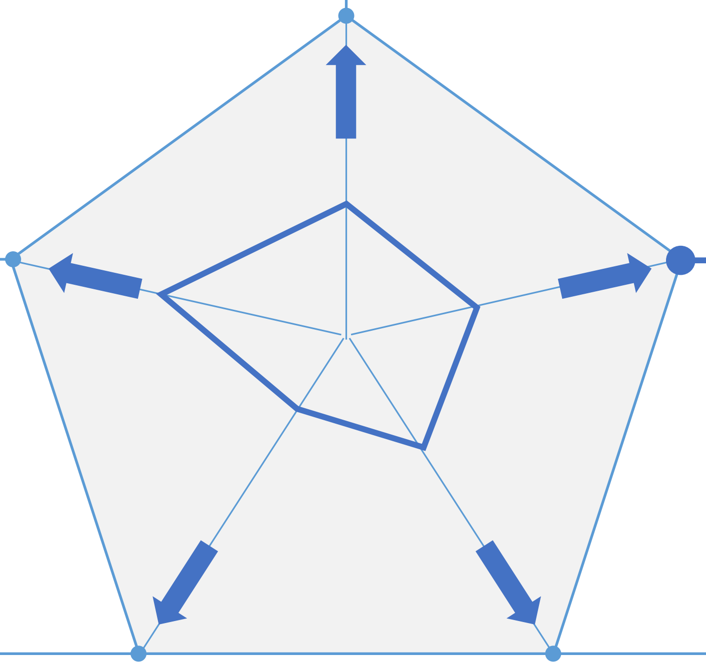
Holistic approach

For facing these challenges functionalities should be enhanced

Expanding our boundaries

Operational conditions detection

It is essential to not be ‘blind’ to the grid



Optimal hardware sizing

Supplementary controllers

- **Harmonics**
- **Inter-area/inter plant oscillations**
- **Sub-synchronous interaction**
- Frequency control
- Voltage control

Advanced synchronization method

- Synchronized control (voltage source converter)
- Advanced PLL (current source converter)

Robustness analysis

Robustness may be not enough and adaptive schemes should be evaluated

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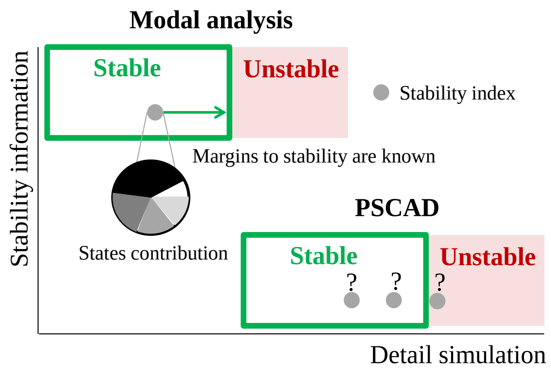
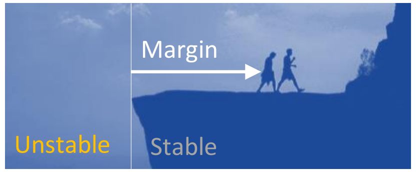
Modal analysis

How can clear stability indexes be used in the optimal design?



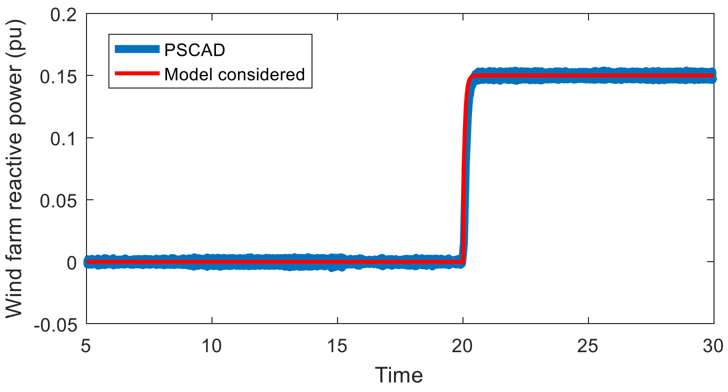


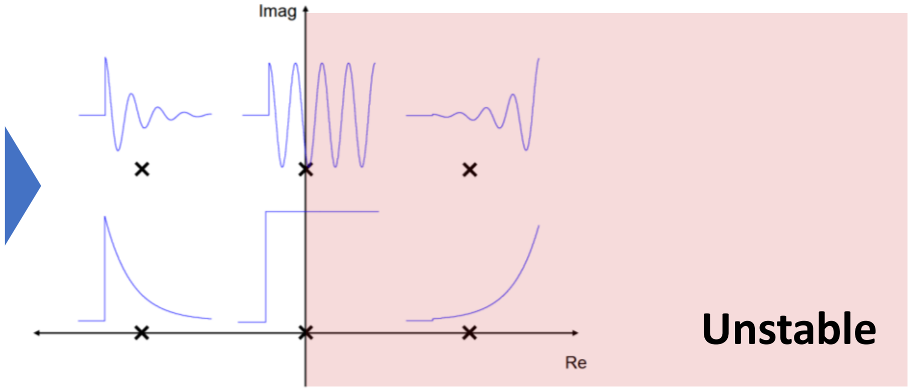
The Eigenvalues, eigenvector and participations of the dynamic model state matrix are calculated

- Right eigenvectors (vi) indicate the relative participation of each variable in i mode
- Left eigenvalues (wi) weight initial condition in i mode
- The participation of j variable in i mode is obtained multiplying left and right eigenvectors (j component)

Clear stability index, employed in any controller design

- For obtaining reliable results modal analysis model must be totally equivalent to PSCAD model
- Once solutions are designed they should be validated in a detailed model





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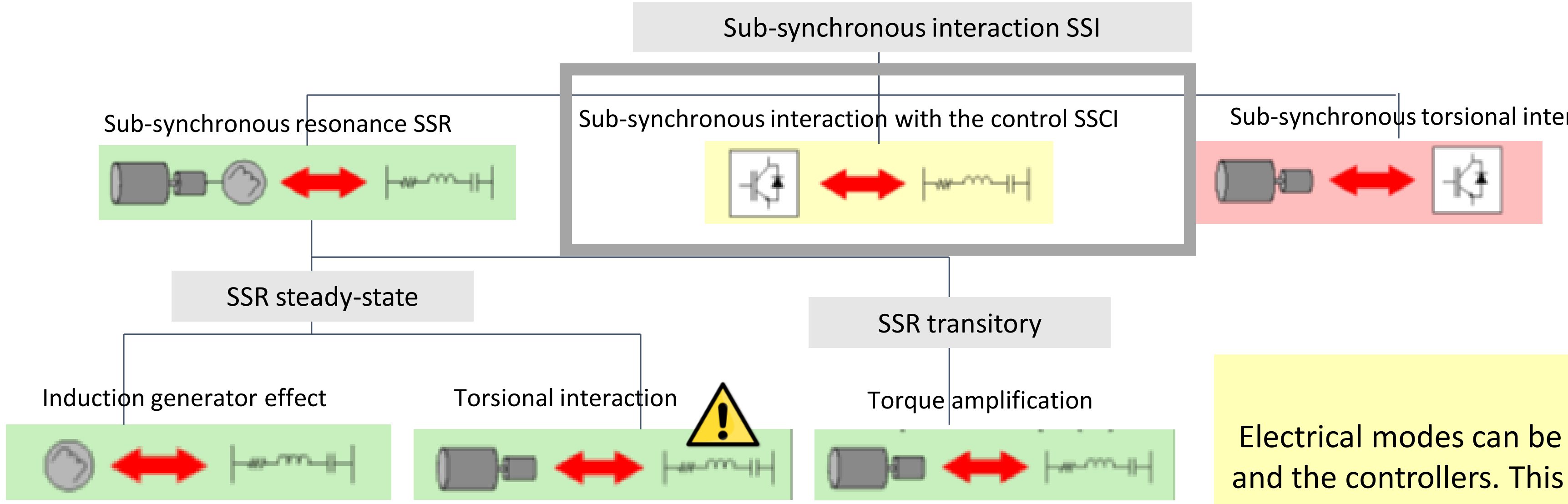
Sub-synchronous interaction



Interaction between the mechanical system and the controller

Electrical modes can be affected due to interaction between the grid and the controllers. This phenomenon was behind Zorrillo Gulf event. First evidence of sub-synchronous interaction in a DFIG

Purely electrical

Appears if the rotor reactance (negative value at sub-synchronous frequencies) is higher than grid resistance

Purely mechanical
When the induced sub-synchronous torque in the generator, is electrically close to one of the natural frequencies of the drive train.

System disturbance

If the frequency of these oscillations with one of the drive train natural frequencies, large torques will be experienced.
Around 1Hz

	Induction machine	DFIG	Full converter
SSR	Possible	Possible	No evidences
SSCI	Not possible	Possible	Possible
SSTI	Possible	No evidences	Not possible

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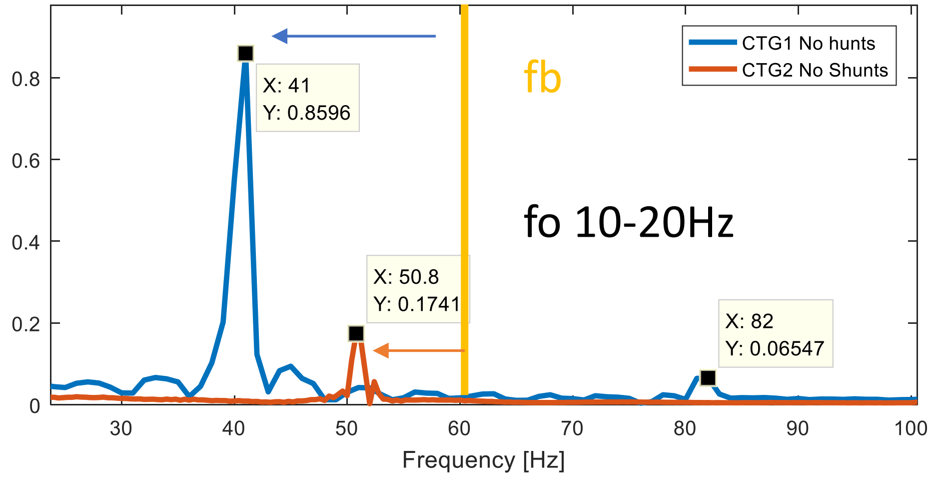
Sub-synchronous interaction

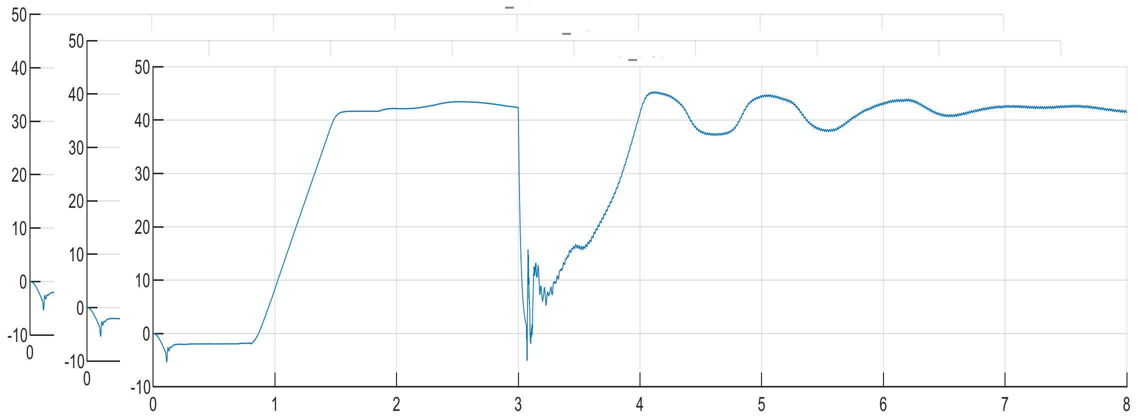
High risk to suffer SSCI in USA a effective and robust solution is needed

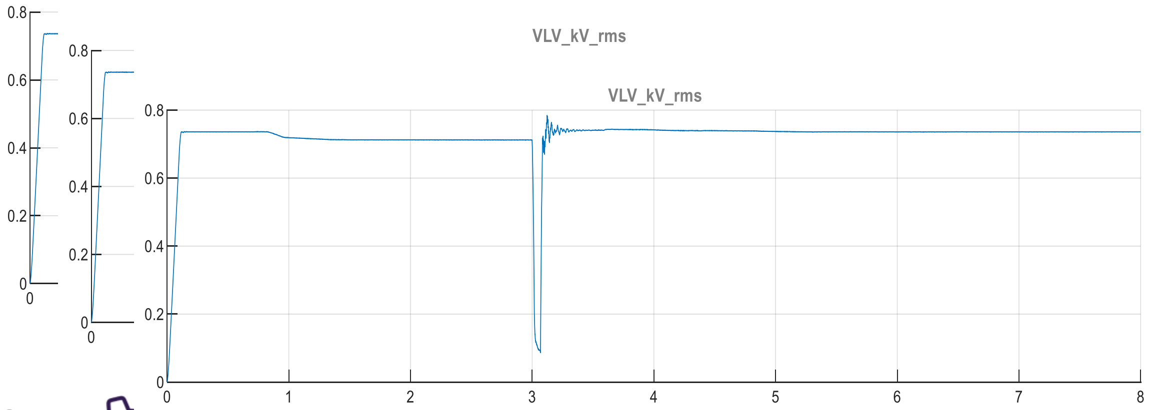
Different grid conditions considered implying oscillations that varies from 40Hz to 50Hz (60Hz system)



Real case USA
Wind farm in operation (solution included)

Exhaustive validation process N-1, N-2,N-4,N-6
A total of 72 cases were evaluated.





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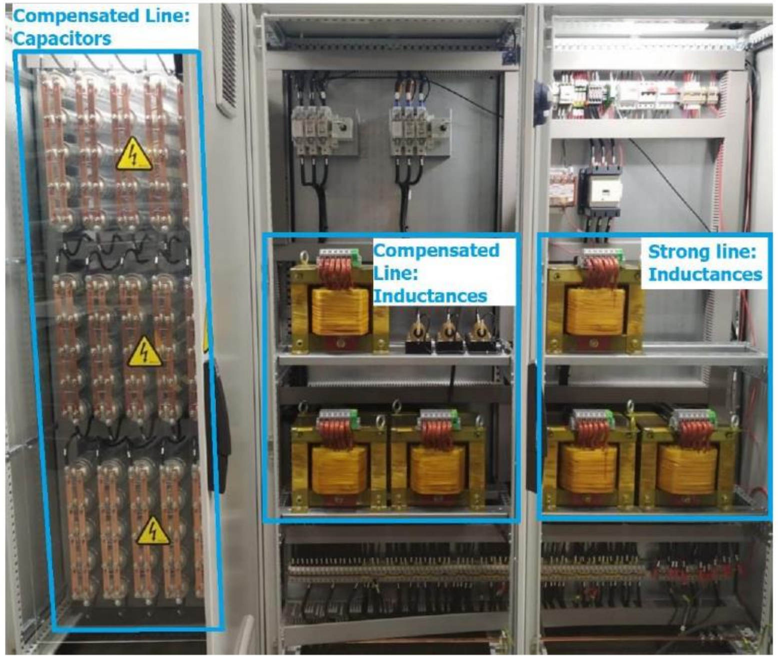
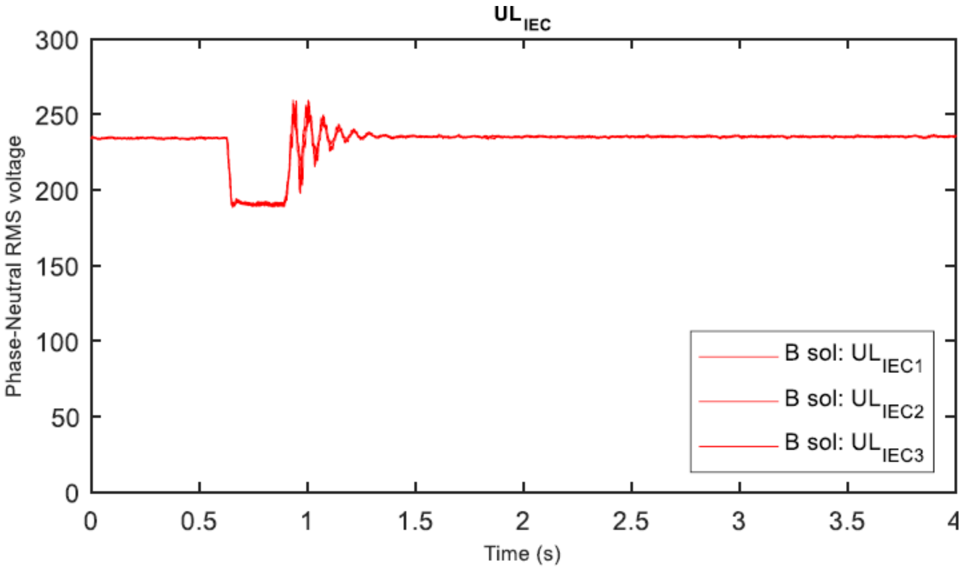
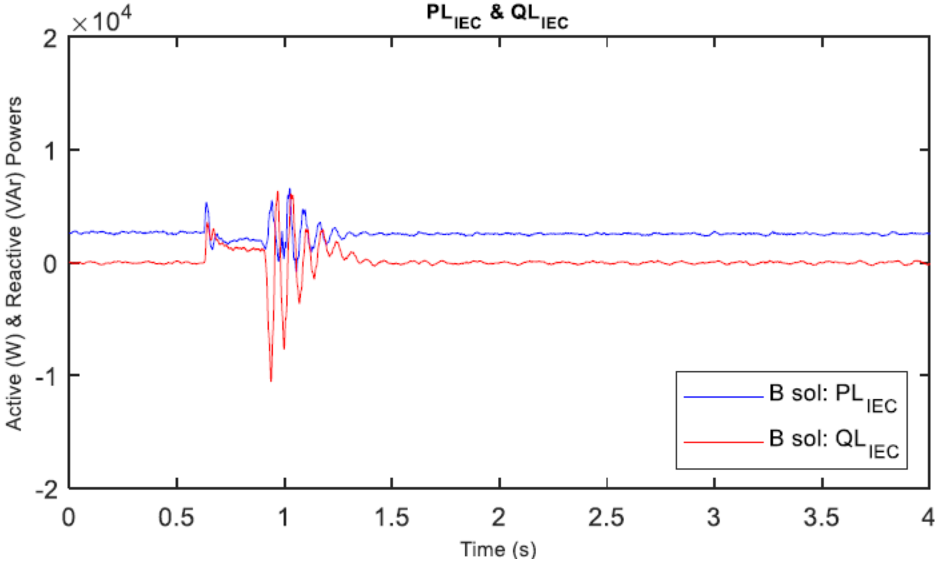
SOLUTION DESIGN VALIDATION







accurate tests in which voltage dips were also taken into account were conducted

Solution already implemented in SGRE WTG

Activated in wind farms in USA and Canada.

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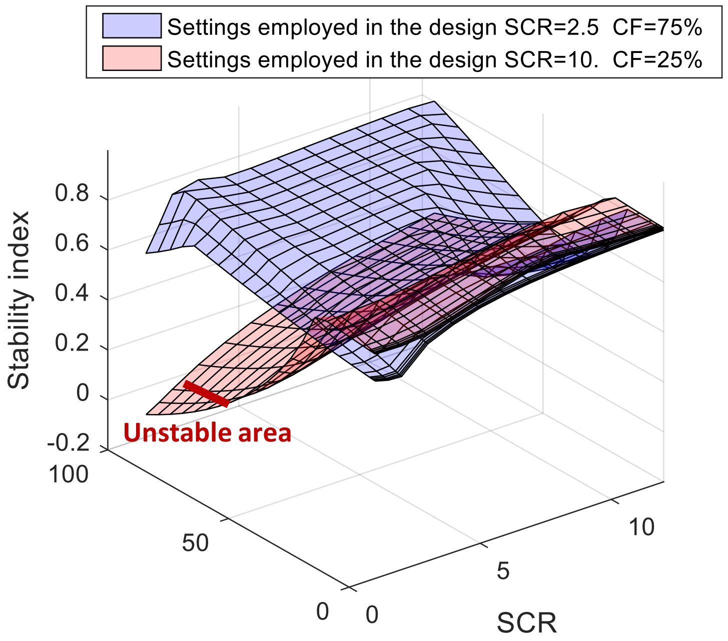
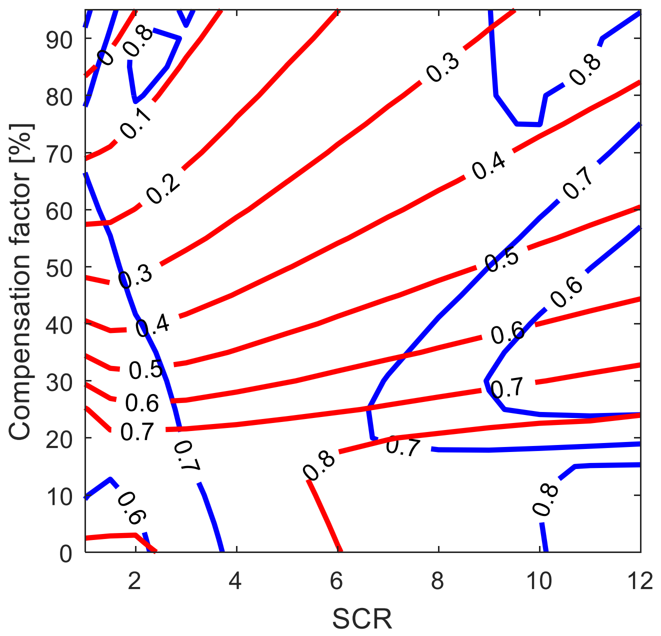
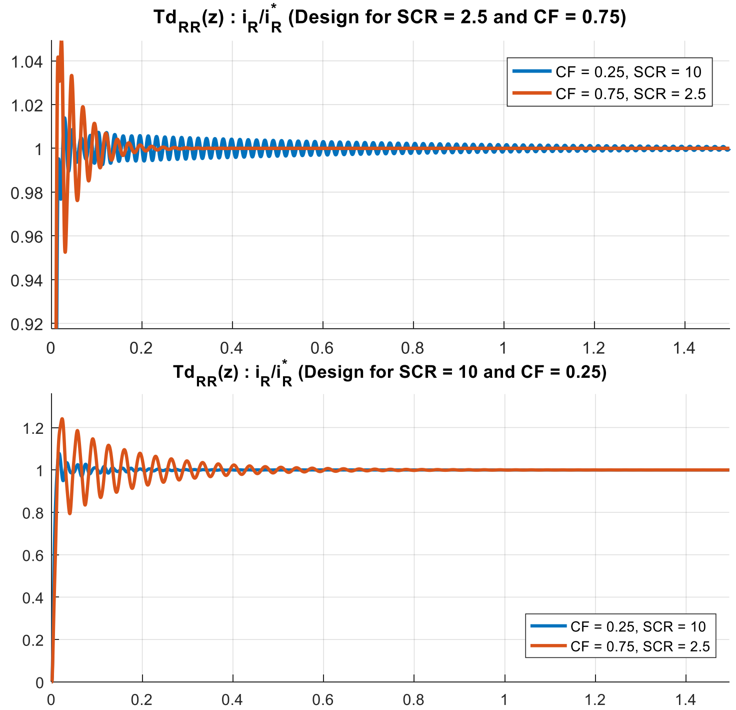
Sub-synchronous interaction

Settings are optimally design for a specific grid conditions. Nonetheless, solution is effective for a wide grid conditions







Robustness analysis based on lineal model has been done. Stability has been also evaluated in case of significant transients such as voltage dips guaranteeing the effectiveness and robustness of the solution

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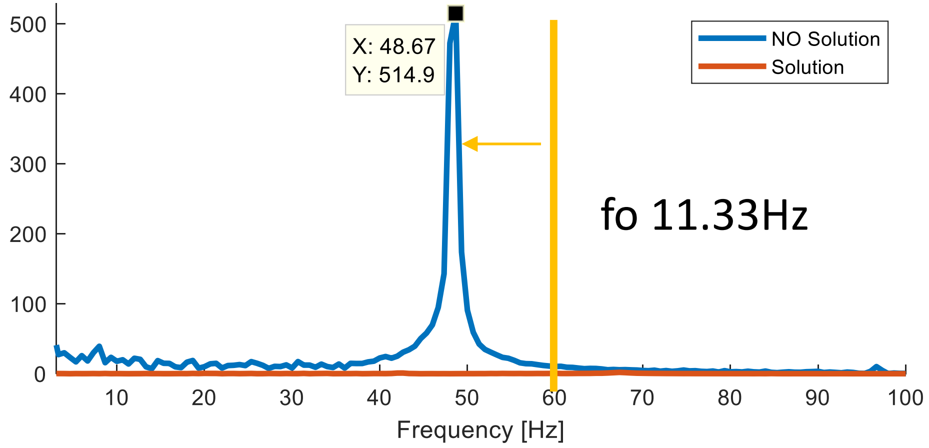
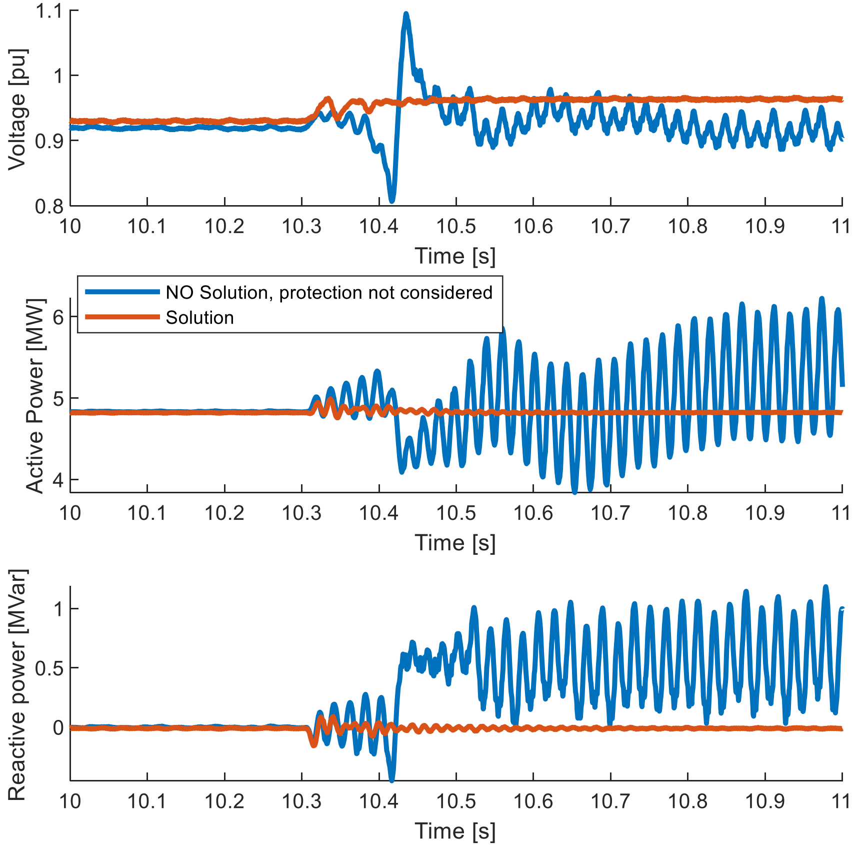
Sub-synchronous interaction

Solution robustness has been evaluated. Effectiveness was proven in a completely different wind farm located in Canada

Wind farm located in CANADA





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Inter-area oscillation

Interplant mode oscillations	Local plant mode oscillations	Inter-area mode oscillations	Torsional mode oscillations
2 – 3Hz	**1 – 2Hz**	**<1Hz** normally **0.3Hz**	**10 – 46Hz**
Machines on the same power generation site oscillate against each other	One plant oscillates against the rest of the system	These oscillations are related with poorly tuned controllers	These modes are associated with a turbine generator shaft system. Sub-synchronous resonance is a particular case of this oscillation

Method	Advantages	Disadvantages
Facts	Inter-area oscillations can be damped. No DFIG settings are modified	Extra cost
Supplementary controller	Inter-area oscillations can be damped	Possible interactions with current control strategies

Synchronous generators

PSS

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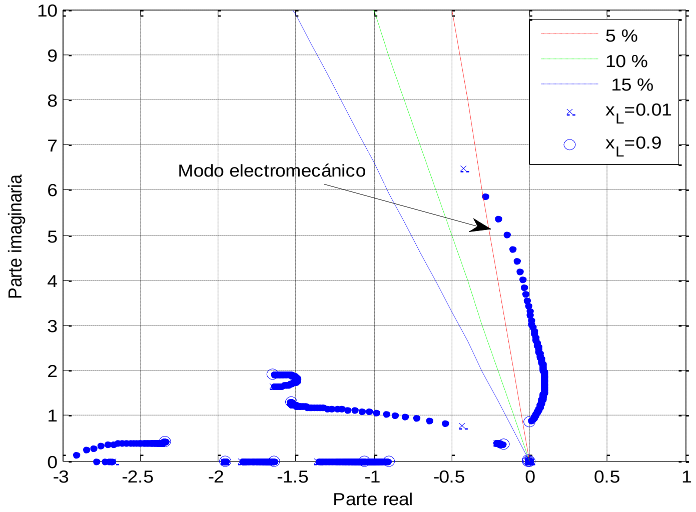
Inter-area oscillation

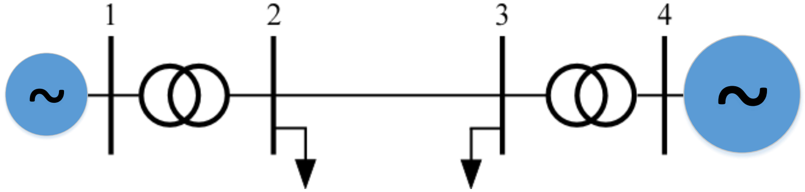
REE Spanish TSO – request MODAL ANALYSIS

Technical norm in accordance UE 2016/631

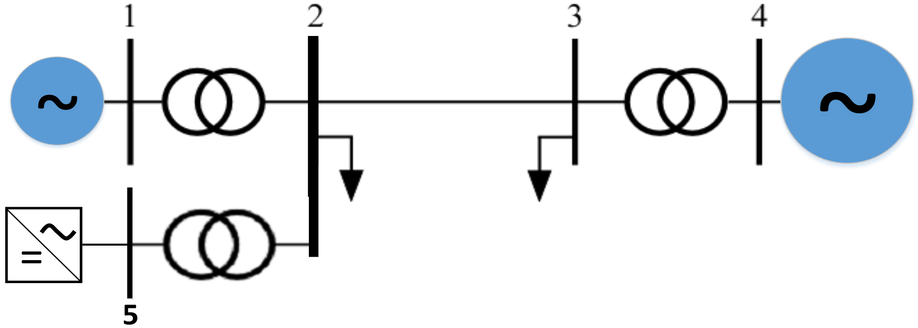
In the event of synchronous generation, a study based on modal analysis should be delivered, showing the effectiveness of PSS. In the event of electronic based technologies it should be demonstrated that these elements do not erode power system stability



Two areas system – based on Kundur



Wind farm erode power system stability?



The inclusion of the a POD for wind farms is not mandatory. At this moment just a modal analysis should be provided showing that power system stability is not being compromised.

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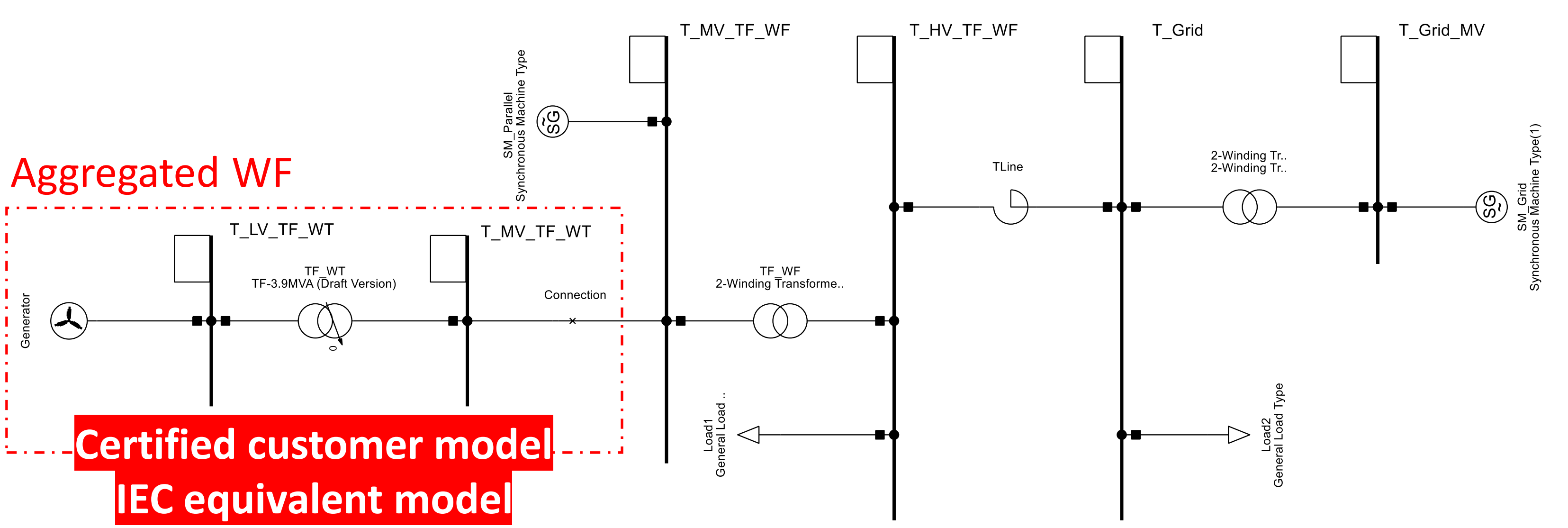
Inter-area oscillation

Single Line Diagram of Two Areas Sysytem in DIgSILENT PF with WF



WF Model

- Wind power is introduced from the MV bus of Area 1.
- Aggregation is achieved with the number parallel units feature of static generator and transformer models.

- Total generation in Area 1 is kept constant, i.e. Synch. Gen 1 + WPP = 1350 MW
- 20%, 50% and 80% wind power penetration cases are studied.

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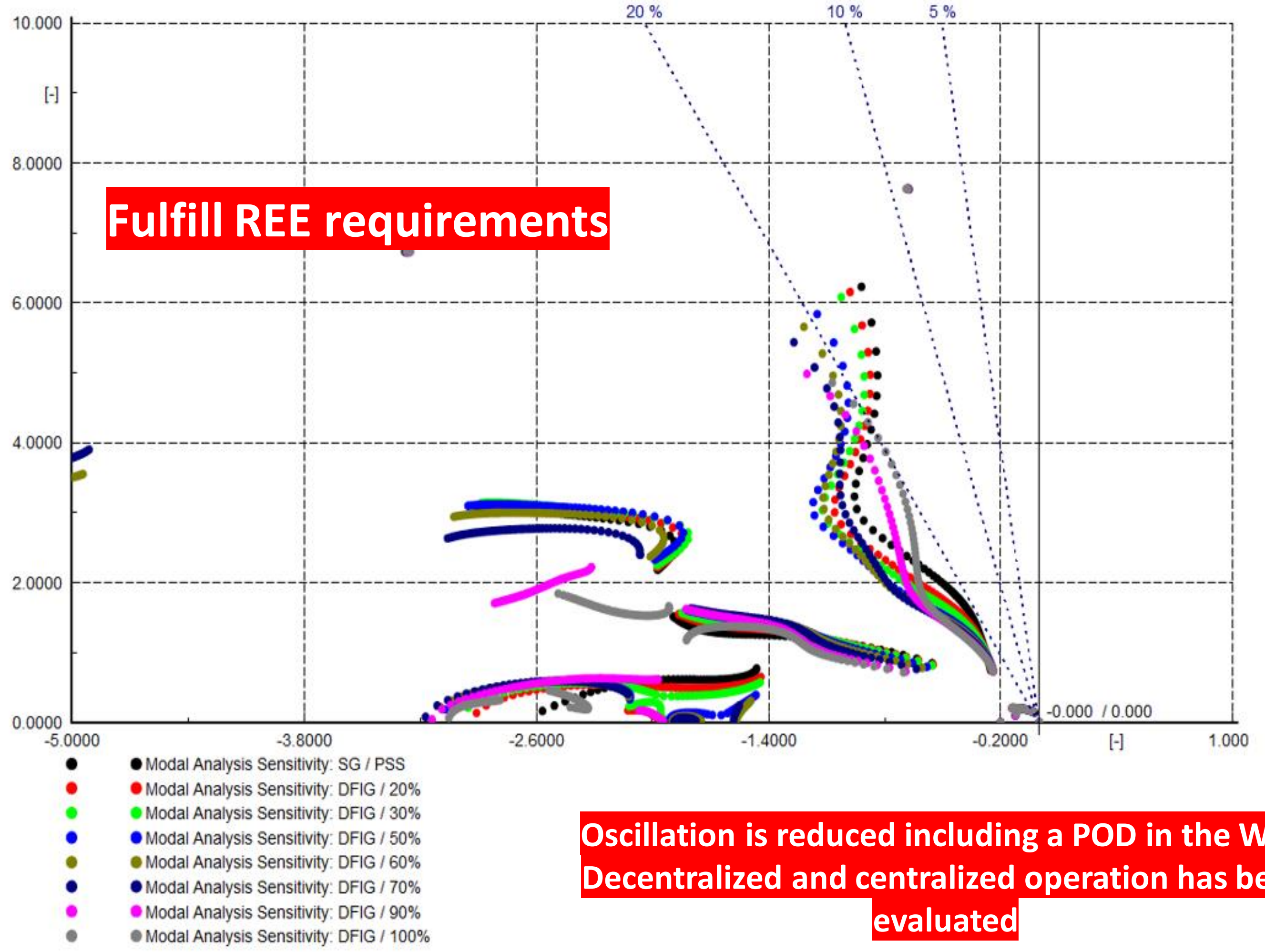
Synchrouns generator -PSS

Modal Analysis at Different WF Levels – WTG IEC Eq. Model



Fulfill REE requirements

Oscillation is reduced including a POD in the WTG Decentralized and centralized operation has been evaluated

current REE requirements are fulfilled

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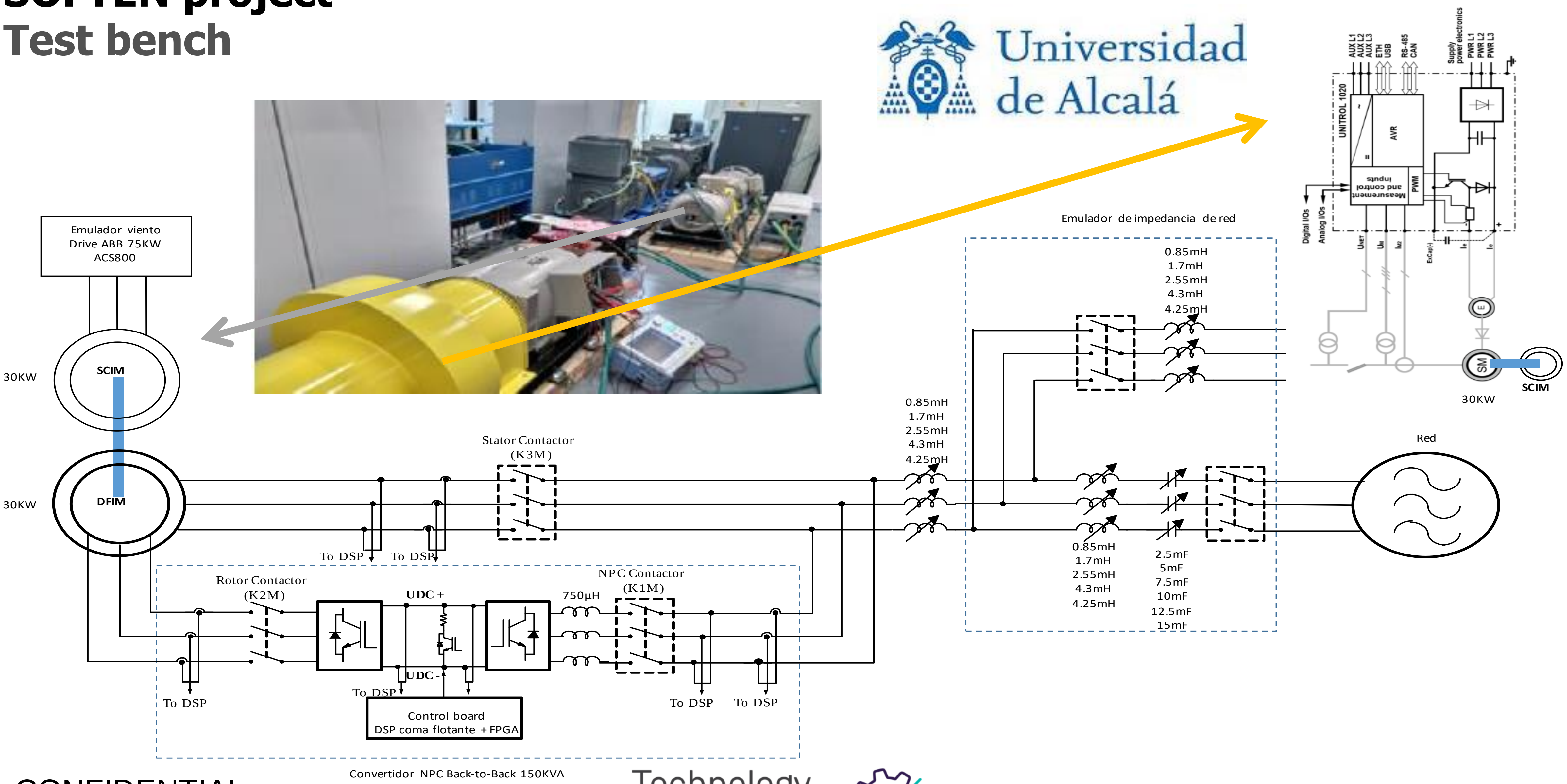
Test bench



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Inter-area oscillation

Large number of test were conducted for guaranteeing the implementability of the solution proposed

PSS (P loop) – Oscillation is damped in frequency negligible impact on voltage. Interaction with current controllers
PSS (Q loop) – Oscillation is damped in frequency no in voltage. Interaction with drive train
PSS (Q loop) + (P loop)