Small signal modelling and analysis of an offshore HVDC transmission link

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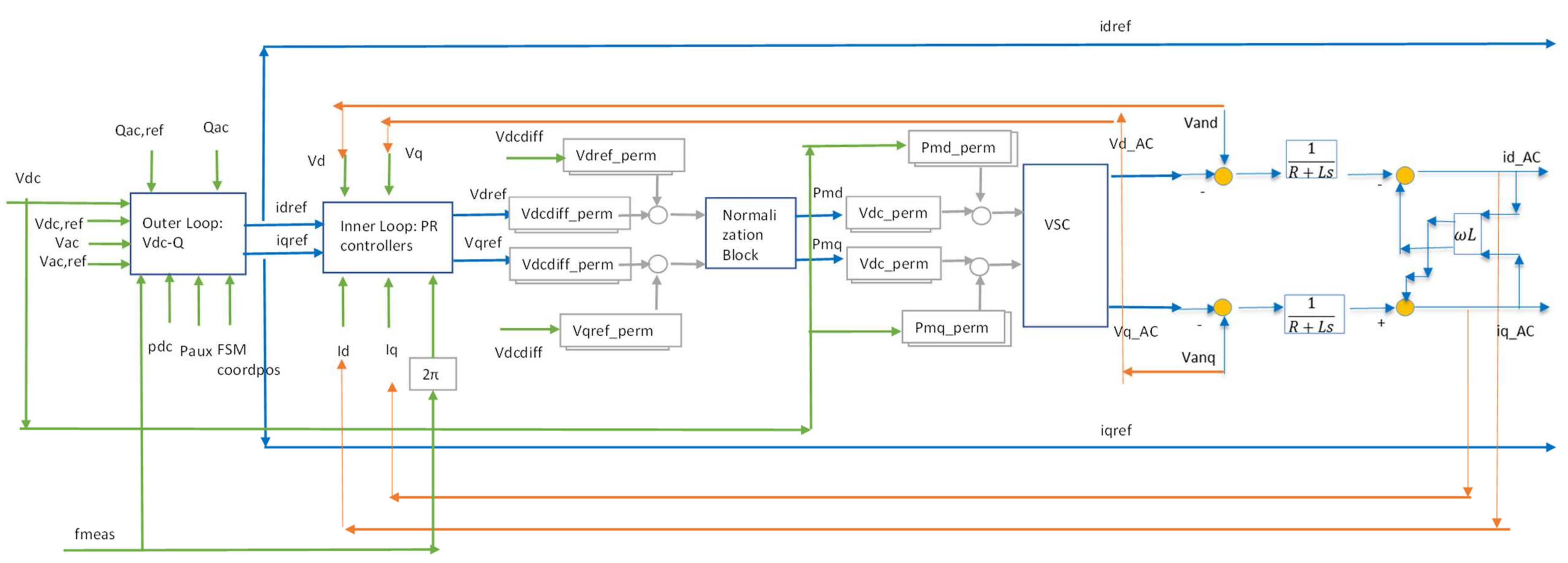
When an offshore wind farm is connected to the AC grid by means of a VSC terminal that conveys the energy through an HVDC transmission link, it is of high importance to guarantee a safety and stable system performance, i.e. the assurance of stability margins and robustness of the whole system against perturbations such as frequency excursions. Very few authors have focused on the design of inner control loop, though being a key block in the VSC terminal to achieve stability and other response characteristics. While most authors choose the simplest inner control loop scheme based on proportional integral (PI) controllers, others decide for a proportional resonant (PR) schemes to cope with voltage unbalances while performing other functions such as harmonic filtering. Therefore, the PR scheme gives better performance than other control loop schemes. However, they present issues such as their sensitivity to frequency variations and further analysis must be carried out to improve their robustness. Thus, this paper studies an offshore HVDC transmission link with PR current controllers using small signal analysis technique. A small-signal model of all control blocks that compound the VSC terminal, operating as a Vdc-Q node, is constructed in Octave and validated against the complete model of an offshore HVDC transmission link implemented in time domain in DIgSILENT PF. To this aim, based on the closed-loop scheme, the impact of several key control parameters on local stability is assessed.

Small signal model

Block diagram

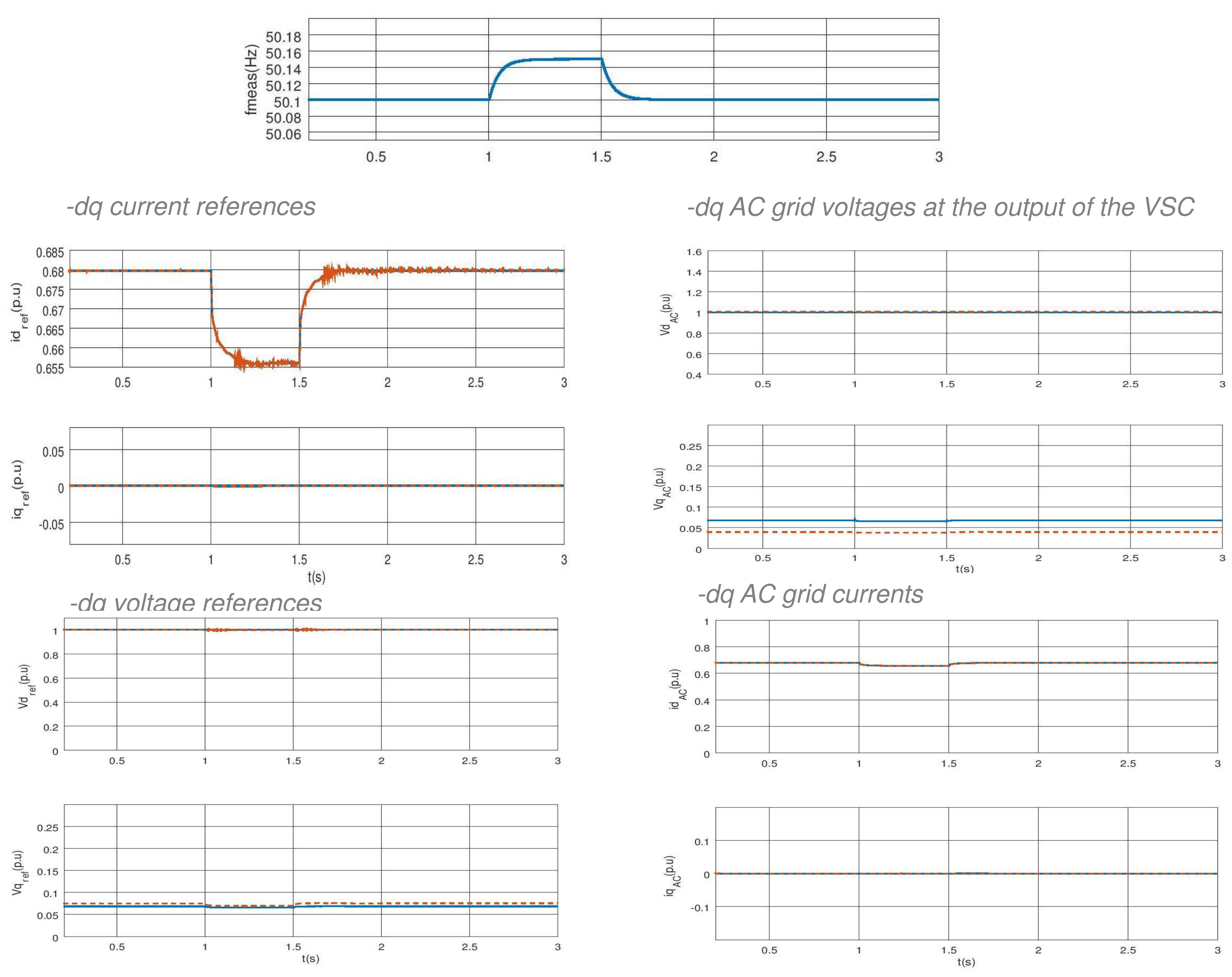


The Vdc-Q node is composed by several subsystems:

- *__Outer Control Loop:__ in charge of generating the dq current references that are calculated by means of PI controllers and taking into account Vdc,Qac,Vac and f setpoints and measurements.*
- *__Inner Control Loop:__ calculates voltage references in dq currents (originally in αβ frame but converted into dq frame to perform linear analysis) for the VSC converter.*
- *__Normalization Block:__ calculates modulation indexes for the VSC converter according to the characteristics of the VSC.*
- *__VSC converter:__ outputs AC voltages at the AC grid depending on the setpoint changes of the previous control blocks*
- *__AC plant:__ consisting in the output filter inductance, and the resistance and inductance of the AC line connecting the VSC converter with the AC grid. It outputs the AC currents.*

Octave/DIgSILENT Validation

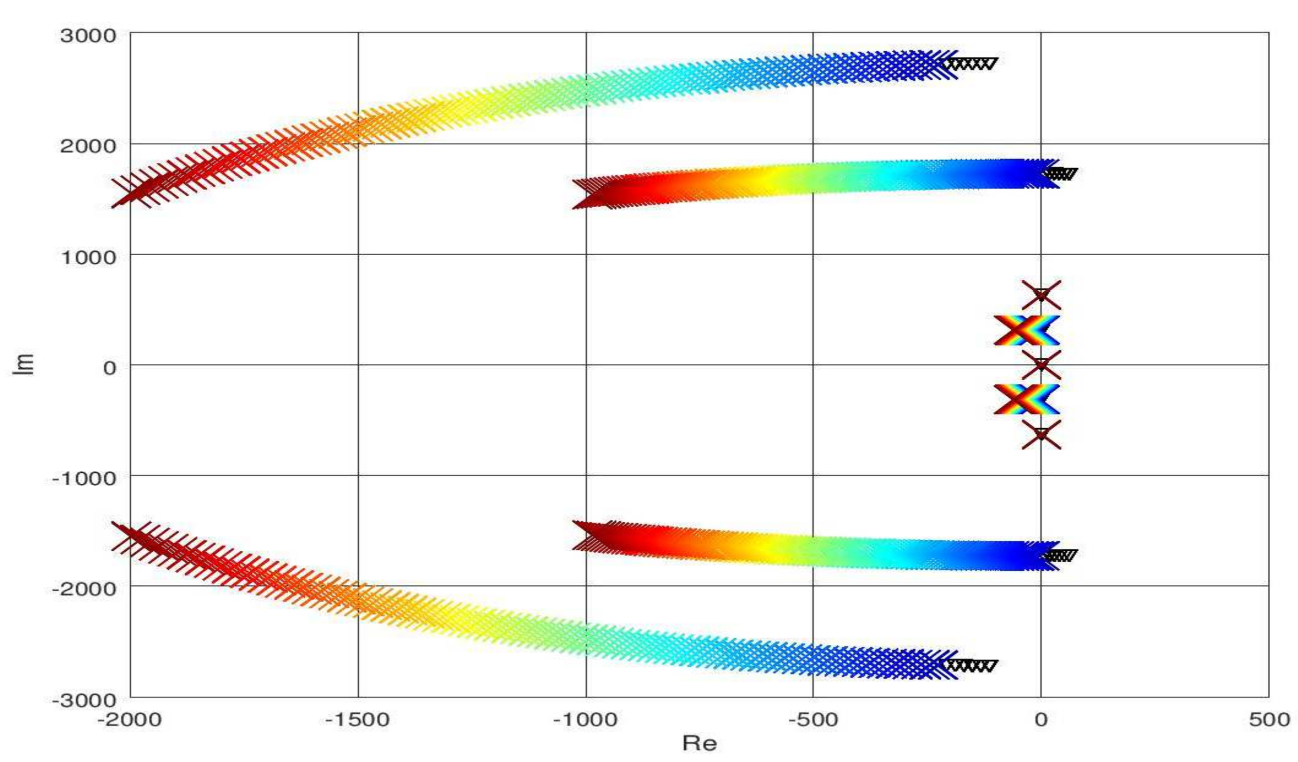
Small-signal system response to a perturbation in the measured frequency (orange-Octave, blue-DIgSILENT)



Impact of PR control parameters on stability and sensitivity to frequency deviations(Δf)

Impact of PR control parameters on stability

Variation of proportional constant kp (0,3)

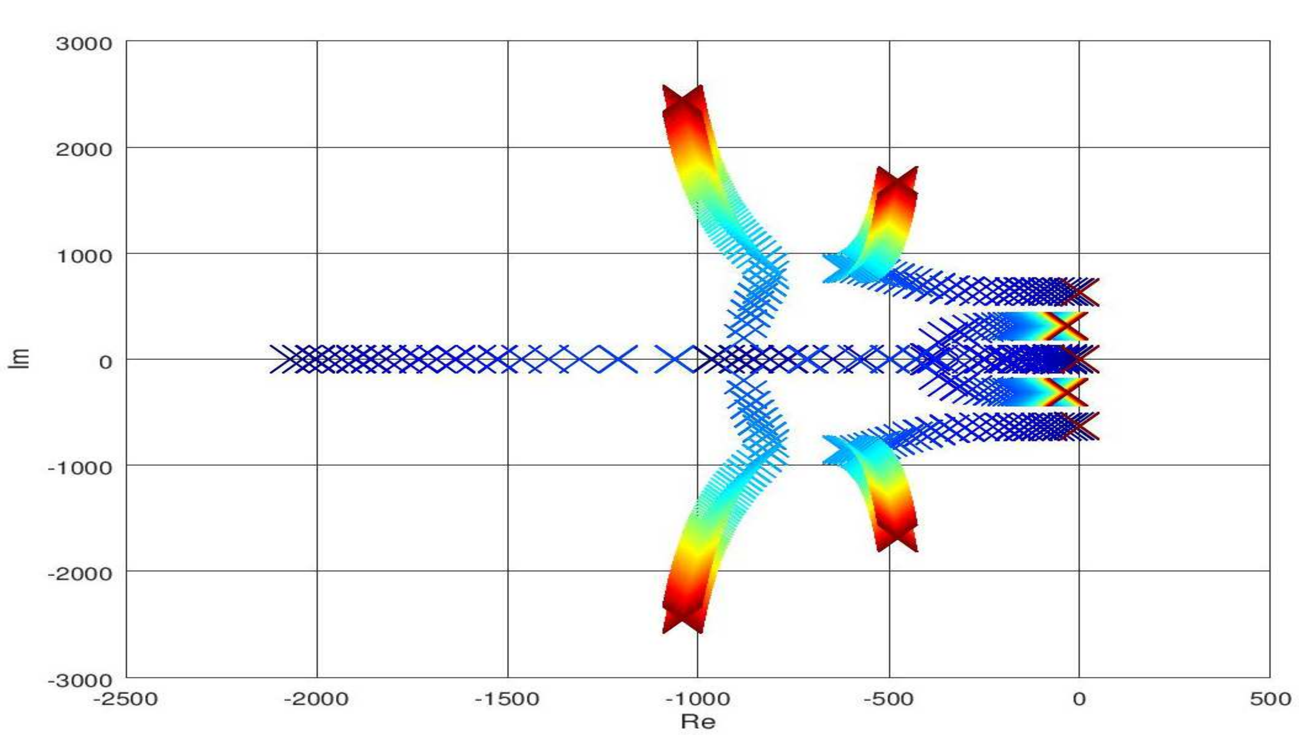


Kp has a strong influence on small signal stability:

-At kp=0 the system is completely unstable

-By increasing kp along the interval the unstable modes cross the imaginary axis and become stable while at the same time a more damped behavior is obtained through the closeness of modes to real axis.

Variation of integral constant ki (0,5000)



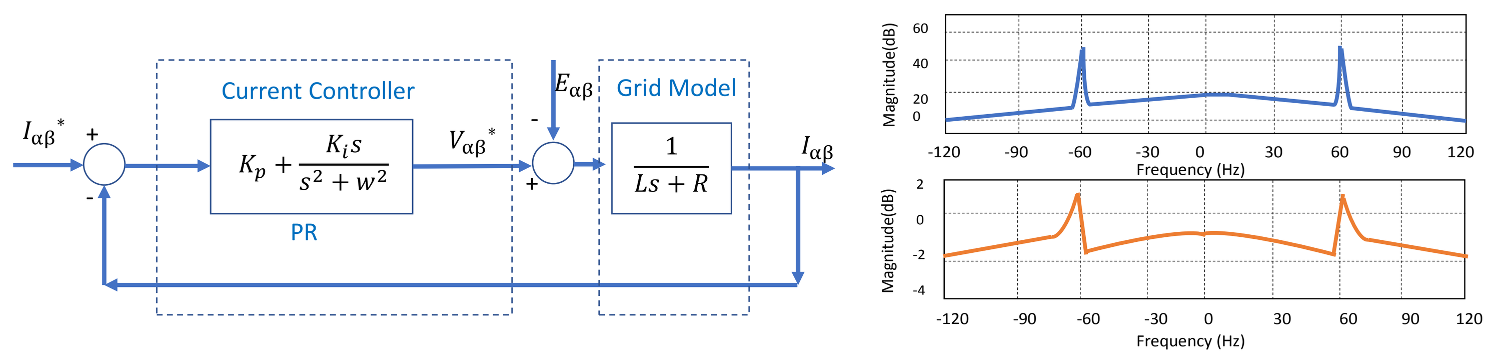
Ki has a strong influence on oscillatory behavior, since it is selected to maximize system gain at the resonant frequency.

Conclusions

The closed-loop small signal model of the VSC terminal has been presented and validated against EMT simulations in DIgSILENT of the complete HVDC transmission link. The impact of PR control parameters on stability has been analyzed. Different topologies for inner control loop have been proposed and their frequency response discussed. An adequate selection of control parameters is needed to guarantee the stability margins but, as well, the robustness under Δf of the selected PR topology must be ensured.

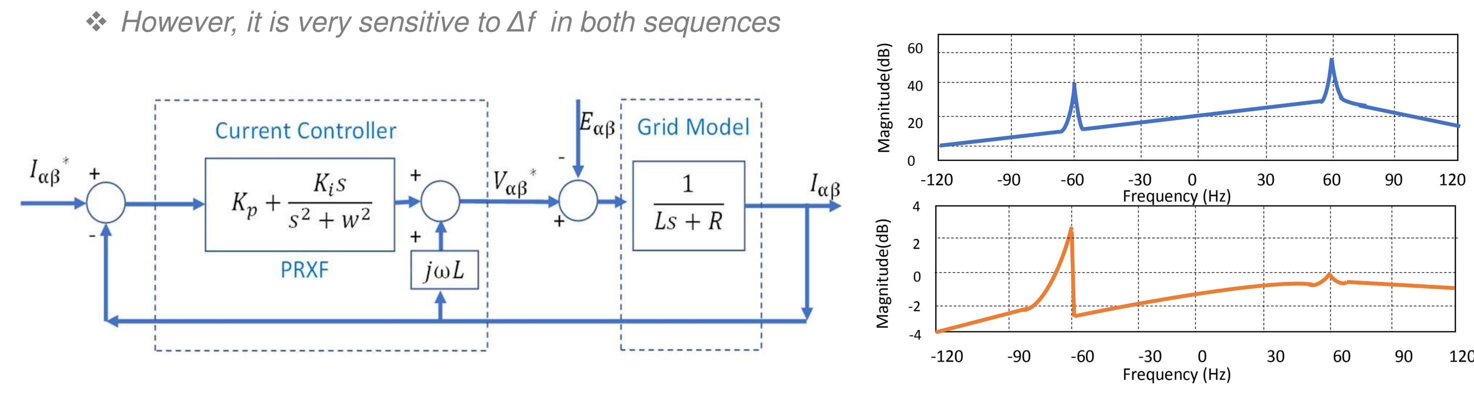
Frequency response

PR topology / Bode plot



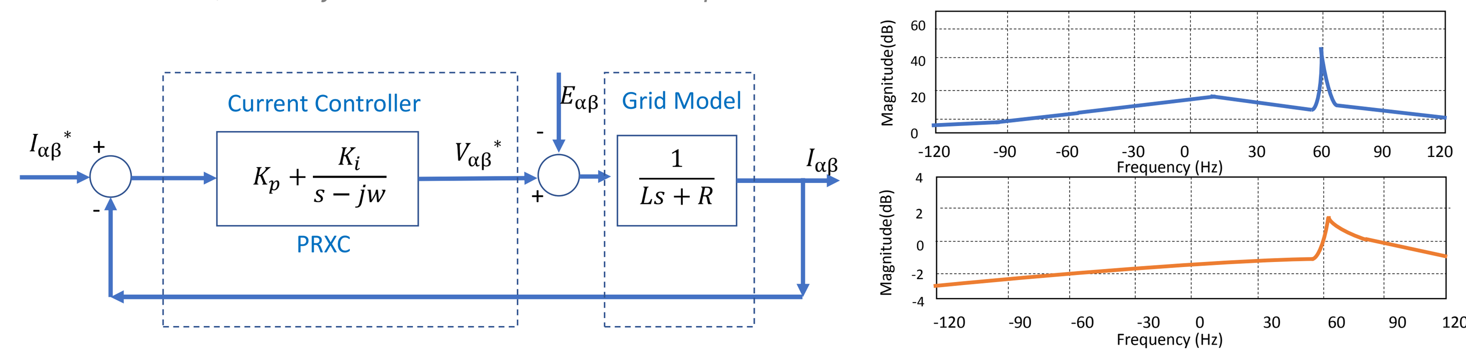
Frequency response of PR topology (blue, opened-loop and orange, closed-loop)

- *✓ It manages Δf at both direct and inverse sequences*
- *❖ However, it is very sensitive to Δf in both sequences*



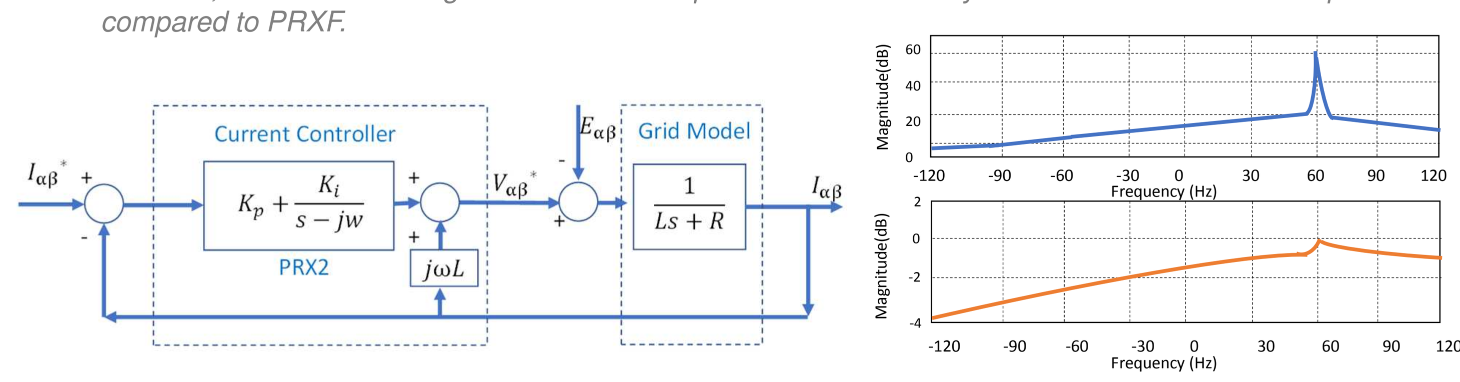
Frequency response of PRXF topology (blue, opened-loop and orange, closed-loop)

- *✓ It improves greatly the robustness against Δf in direct sequence.*
- *❖ However, it is very sensitive to Δf in inverse sequence*



Frequency response of PRXC topology (blue, opened-loop and orange, closed-loop)

- *✓ It improves the robustness against Δf in direct sequence compared to PR.*
- *❖ However, it does not manage Δf in inverse sequence and is still very sensitive to Δf in direct sequence compared to PRXF.*



Frequency response of PRX2 topology (blue, opened-loop and orange, closed-loop)

- *✓ It improves greatly the robustness against Δf in direct sequence compared to PR, PRXC.*
- *❖ However, it does not manage Δf in inverse sequence.*

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