Stability and Control of VSC-HVDC Connected to Weak Grids and Multi-Terminal Networks

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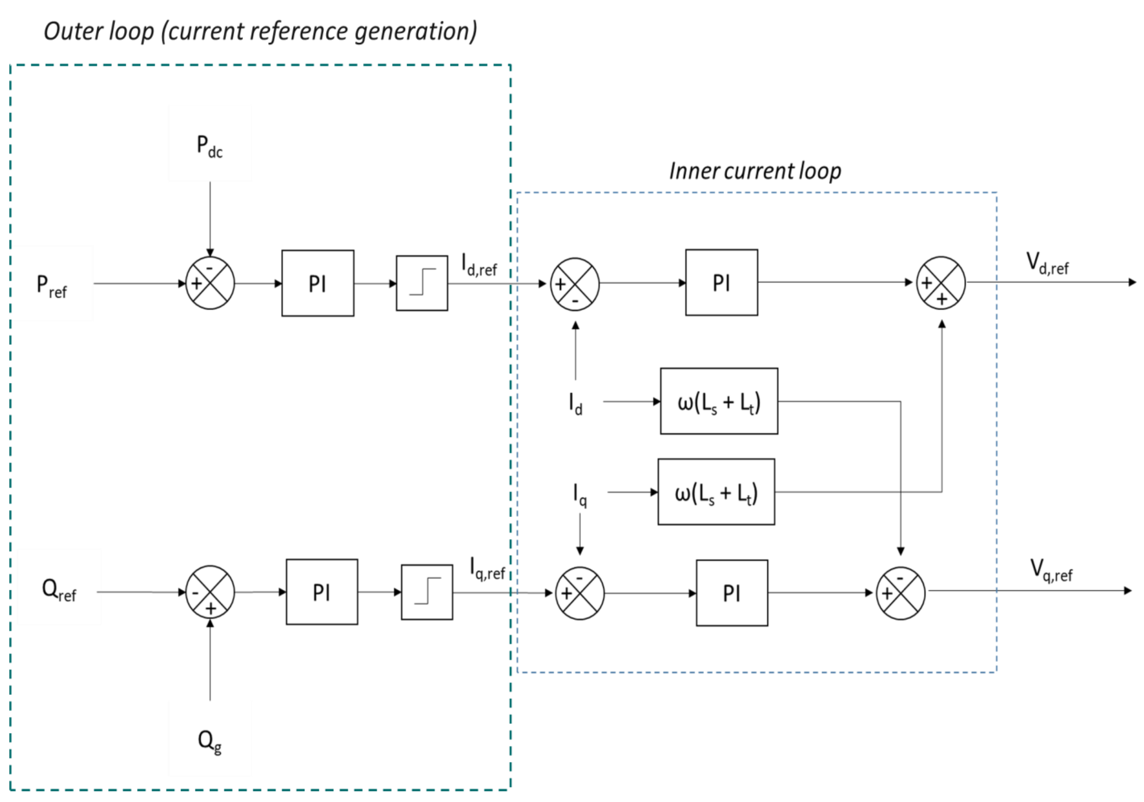
Abstract

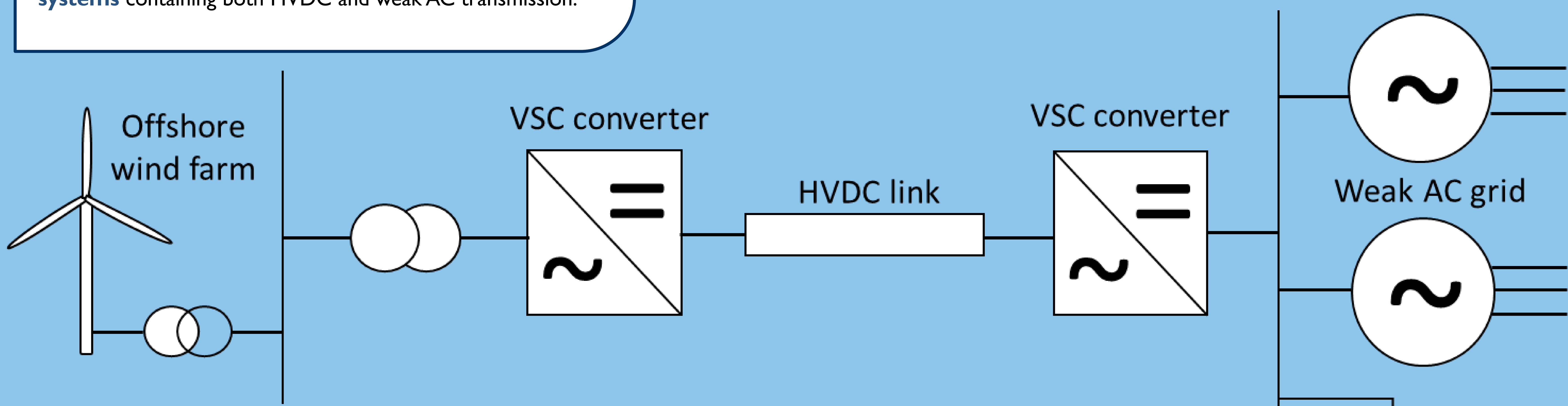
HVDC transmission is the most cost-effective way to transmit power from far-offshore wind farms and for long-distance electricity transmission across continents[1]. However, these transmission links are often required to inject power at locations where the AC grid is very 'weak' due to high penetration of renewables, low system voltage or low generation levels. A 'weak' grid is characterised by a short-circuit ratio (SCR) < 3 [2].

Traditional control methods for HVDC converters cannot operate in SCR < 2 without causing large instabilities and limiting maximum power transfer. This project therefore seeks to **assess current methodologies** and **develop new, robust control methods** for VSC-HVDC converters connected to weak AC grids. In addition, controller interactions in multi-terminal networks will be investigated in order to **propose robust control methods for multi-infeed systems** containing both HVDC and weak AC transmission.

Controller structures



Traditional control methods for VSC-HVDC employ Vector Current Control (VCC) consisting of an inner current loop and an outer loop which generates the current references based on demanded real and reactive power injection. A key advantage of VCC is the current-limiting capability provided by the inner loop – maintaining this inner structure therefore has huge advantages for fault ride through capability. Our approach is to keep this inner loop and modify the outer loop to account for cross-coupling and the non-linearity of active-reactive power curve. Some effects of early, simple modifications of this nature can be seen in Figures 1 and 2.



Controller requirements & results

1. Stabilise power injection and AC voltage support

Weak AC grids are particularly susceptible to voltage sags, both in the event of a fault and when trying to inject large amounts of power into the grid or the HVDC link. Supporting the grid voltage and maintaining stability is therefore vital to ensure safe operation of the power system. Figure 1 shows that conventional vector current control is unstable when higher power transfers are demanded. The controller shown in Figure 2 has a modified outer loop which stabilises the voltage and power transfer when the power limit is reached in an extremely weak grid.

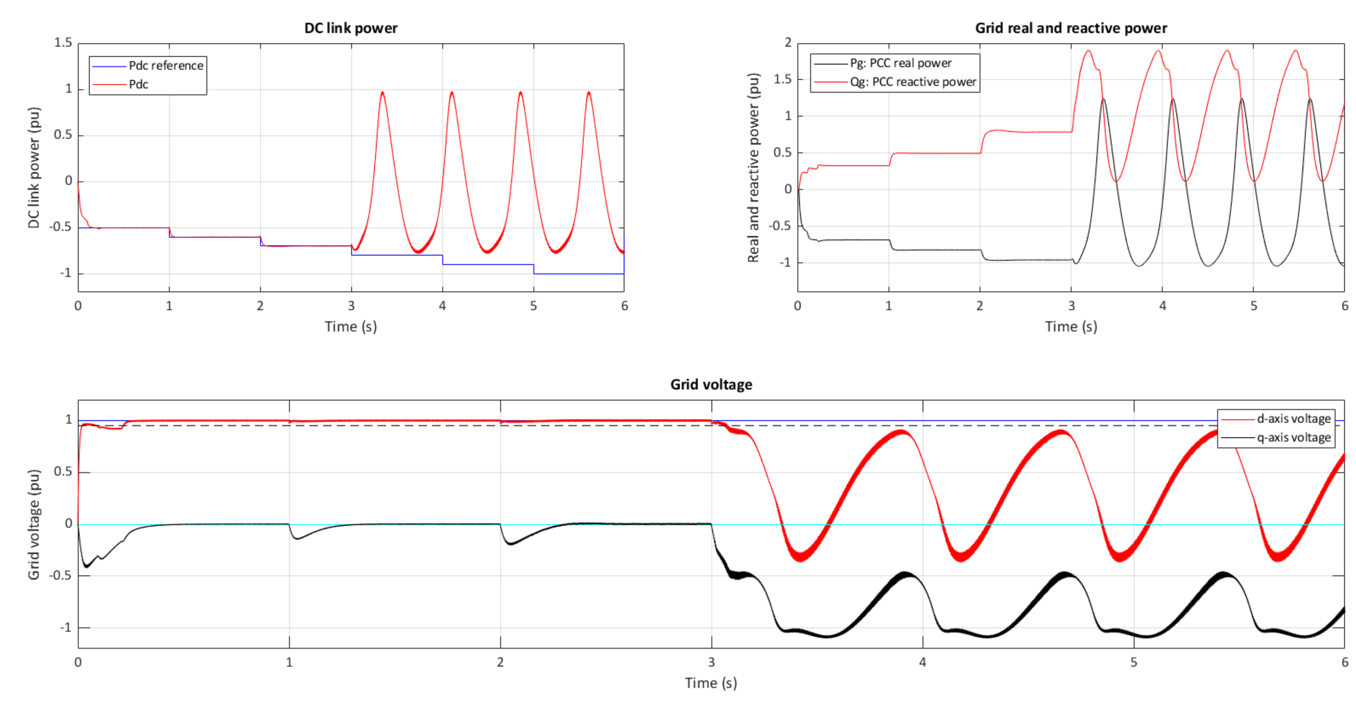


Figure 1 – power and voltage response of a VSC-HVDC rectifier using conventional VCC in a SCR = 1 grid

2. Provide bidirectional 1.0 pu power injection

Although the modified outer loop can stabilise the power and voltage, it still cannot achieve full 1.0 pu power transfer with this extremely weak grid. Other modifications to VCC in the literature have shown that power transfers of up to 0.89 pu in rectifying mode and up to 1.0 pu in inverting mode are possible[3], but often require very complex control strategies or unacceptably slow response times. This maximum power transfer capability is the most significant goal for future controllers under development

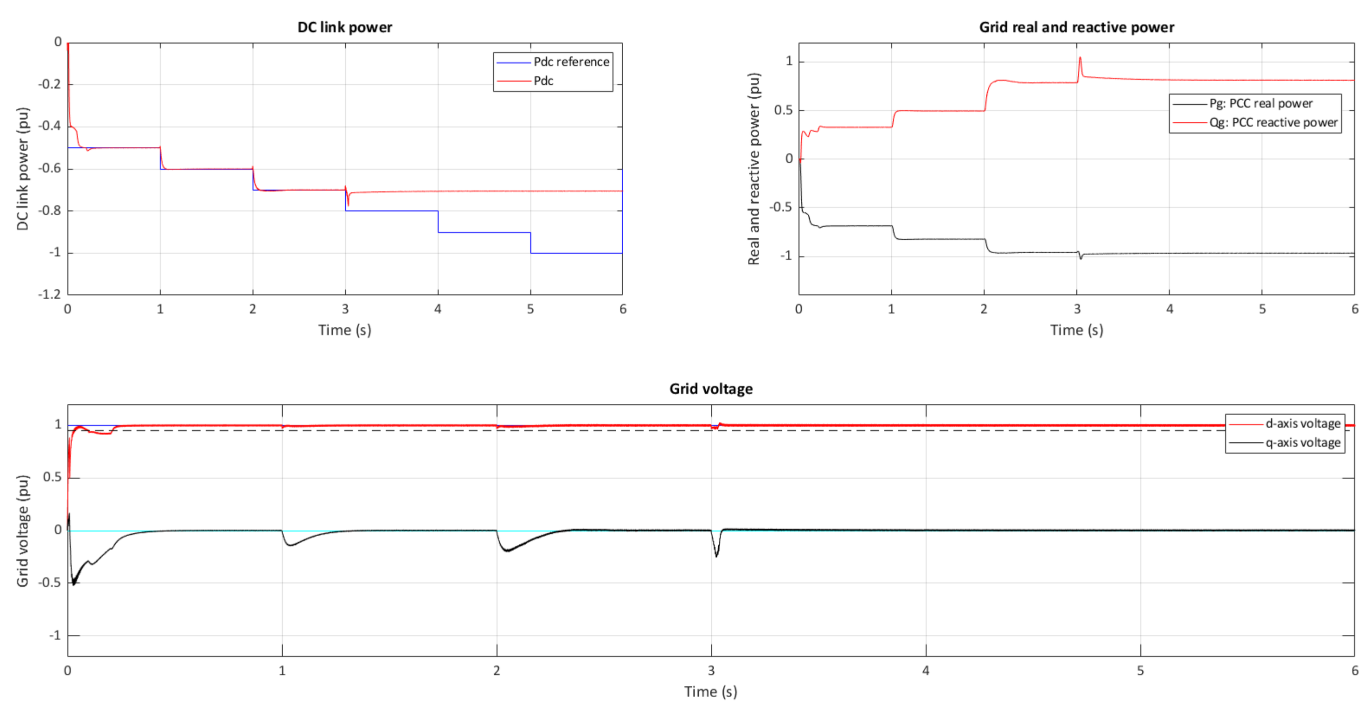


Figure 2 – power and voltage response of a VSC-HVDC rectifier using modified VCC in a SCR = 1 grid

Next steps

Outer loop control modifications which are designed to compensate for power injection non-linearity in weak grids have shown promising results for stabilising the AC grid voltage and power injection. However, these methods are currently dependent on accurate estimation of the grid SCR, which is not always possible. A key next step will be to improve the robustness of these controllers to changes in the grid impedance and to attempt to extend the performance envelope for full stability. The impact of employing multiple controllers of this form in a multi-infeed system will then be investigated

[1] A. Alassi, S. Bañales, O. Ellabban, G. Adam, and C. MacIver, "HVDC Transmission: Technology Review, Market Trends and Future Outlook," Renewable and Sustainable Energy Reviews. 2019.
[2] D. Jovcic and K. Ahmed, High-Voltage Transmission High-Voltage Transmission. John Wiley & Sons, Ltd, 2015.
[3] A. Egea-Alvarez, S. Fekriasl, F. Hassan, and O. Gomis-Bellmunt, "Advanced Vector Control for Voltage Source Converters Connected to Weak Grids," IEEE Trans. Power Syst., vol. 30, no. 6, pp. 3072–3081, 2015.

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