eigenvalues and neither do the internal circulating currents $\boldsymbol{i}_{dq}^{\Sigma}$.

6 Conclusions

This paper presented a small signal model of a droop-controlled MMC with CCSC connected to a DC power source and an equivalent capacitance. The resulting model was validated against EMT simulations. The presented detailed small signal model of the MMC with SSRF may be extended to other control methods where the internal stored energy (and the DC current) are explicitly controlled. The small signal analysis suggests that the calculations of the modulation indexes with the measured DC voltage enhances the stability of the system. Moreover, the studied system has shown that the active power flow direction has an effect on the stability margin. This phenomenon will have a large impact on multiterminal DC grids.

By means of modal analysis and participation factors, it was shown that the observed instabilities are directly related with the uncontrolled DC (output) current of the MMC. This indicates that closed loop control of the DC current can be beneficial for the small-signal stability of an MMC-based HVDC terminal.

Appendix

A. Park Transformation

$$\boldsymbol{P}_{n\omega} = \frac{2}{3}\begin{bmatrix} cos(n\omega t) & cos(n\omega t - \frac{2\pi}{3}) & cos(n\omega t - \frac{4\pi}{3}) \\ sin(n\omega t) & sin(n\omega t - \frac{2\pi}{3}) & sin(n\omega t - \frac{4\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (27)$$

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