in this paper is satisfactory.

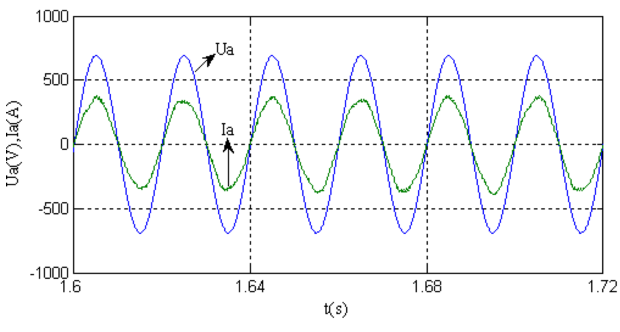
Converter itself can absorb or emit some reactive power, so reactive compensation devices are not needed, which can reduce the weight of equipment and the size of offshore platform. The reactive power step changes from 0pu to 0.6pu at t=1s and the simulation results are shown in Fig. 11: (1) The impact on DC voltage induced by step change of reactive power is small shown in Fig. 11(a). (2) Voltage and current waveforms for phase U of wind farm side stagger some phase after t=1s shown in Fig. 11(b). Some reactive power for supporting AC system can be provided by the converter. (3) Active and reactive power are shown in Fig. 11(c). (4) The voltage of converter AC side (9-level PWM waveforms of three phases) is shown in Fig. 11(d) and the modulation index M is shown in Fig. 11(e). The reactive power increases and M is decreases, so number of triangular carriers covered by the reference signal and output voltage level are decreased. However, this has little effect on quality of multi-level waveforms. (5) Capacitor voltages of the eight SMs in phase U shown in Fig. 11(f). The total output power increases induced by the step increasing of reactive, so the fluctuation of capacitor voltages increases slightly during reactive power step changing, but doesn't affect system operation.

Transient process is common in power system, for example three-phase short circuit, short circuit to ground and so on. It is essential for VSC-HVDC system to have the ability of anti-interference, especially used for offshore wind farm. The fault of three-phase short circuit to ground starts at t=1s and continues for 0.12s at grid side. The response curves are shown in Fig. 12: (1) DC voltage can track the given value at about 0.6s after recovery shown in Fig. 12(a), where Vdc1 is the response of DPC controller and Vdc2 is of double closed-loop vector control strategy. The overshoot of Vdc1 is less than Vdc2. It is proved that dynamic performance of DPC is better than vector control, again. (2) Capacitor voltages of phase U at grid side are shown in Fig. 12(b). The voltages increase less than 30% and numerical difference of SM voltage between upper and lower arms is about 5kV (7.1%Vdc) during the transient. (3) Active and reactive power of grid-side converter (fault side) is shown in Fig. 12(c) and track the given value at about 0.7s after recovery. There are overshoot and oscillations occurrence during the transient and dual vector or other control strategies can be used for suppressing the overshoot [17]-[18], but it exceeds the field of this paper.

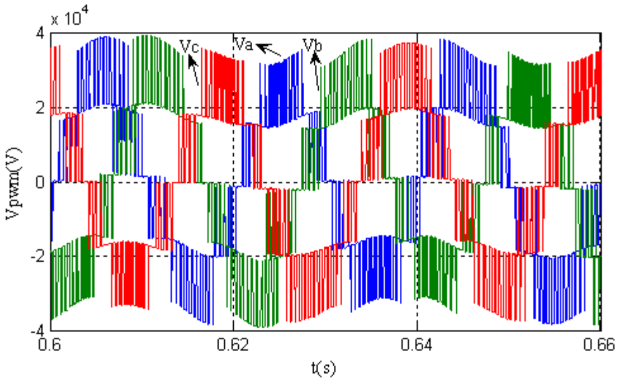
6 Conclusion

Based on MMC topology, simulation research of VSC-HVDC for offshore wind farm is carried out. Technology of multi-carrier PD-SPWM is used for generating trigger pulses of converter SMs. For different modulation method of MMC (n+1 and 2n+1 level MMC), different control strategies (capacitance-voltage sorting and adding balance component to reference signal) for voltage balancing are adopted, respectively. At the same time the additional DC capacitors are used for DC link to improve the performance of DC voltage and reduce its fluctuations. Simulation results show that 2n+1 level MMC with additional DC capacitors possessing more excellent dynamic and static performances.

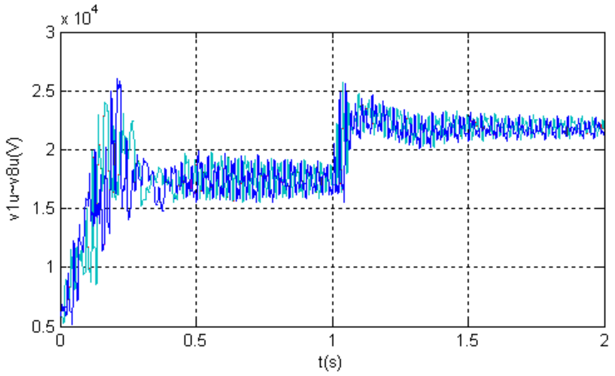
To improve the system dynamic performance, the strategy of VF-DPC is used for MMC-based VSC-HVDC. Active and reactive power can be controlled independently and current waveform is smooth, closing to sine wave, without passive filters. The phase-locked loop (PLL) is replaced by virtual flux-oriented to achieve synchronization with grid voltage, eliminating the AC voltage sensor of grid and with the advantages of cost savings, improving the performance of anti-interference. Power and virtual flux estimation algorithms for the MMC are designed and by comparing with actual power shows the precision of power estimation algorithm is high. Finally, the performances of system response under various conditions are simulated and compared with traditional strategy of double closed-loop vector control. The results show that the MMC-based VSC-HVDC system designed in this paper possesses more excellent performance



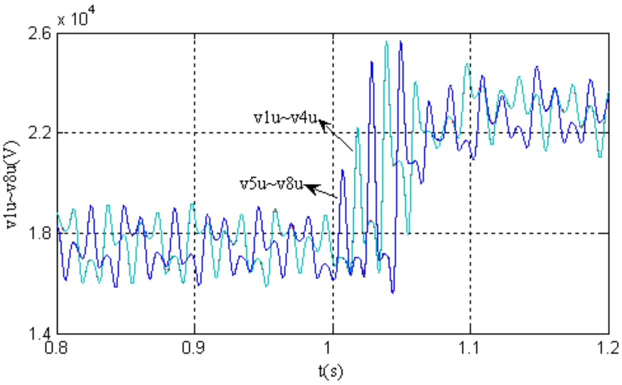
(a) AC system voltage, current response of phase U for grid side



(b) 5-level PWM waveform of converter in phase U

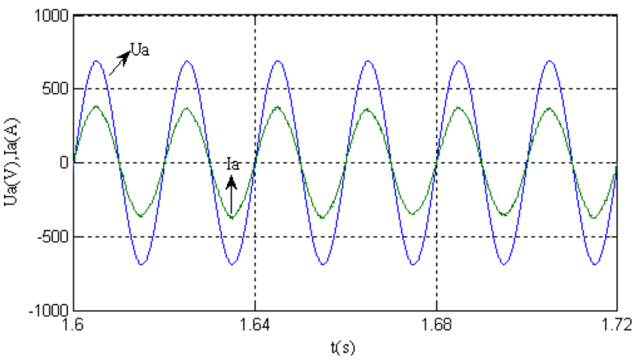


(c) Capacitor voltages of SMs in phase U

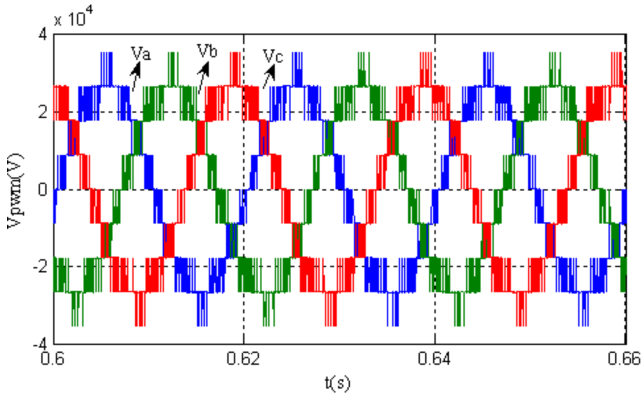


(d) Magnified curve of capacitor voltages during step response

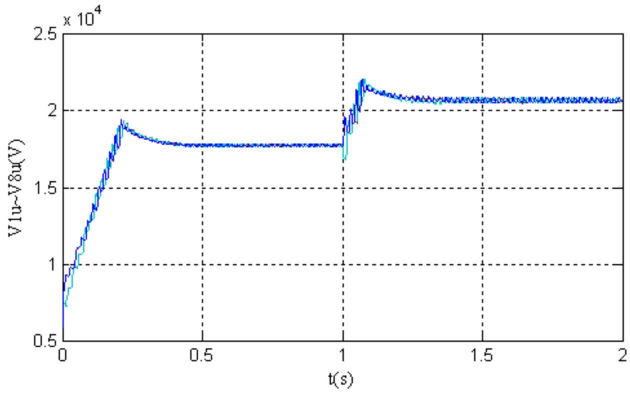
Fig. 8- DC voltage step responses of n+1 level MMC



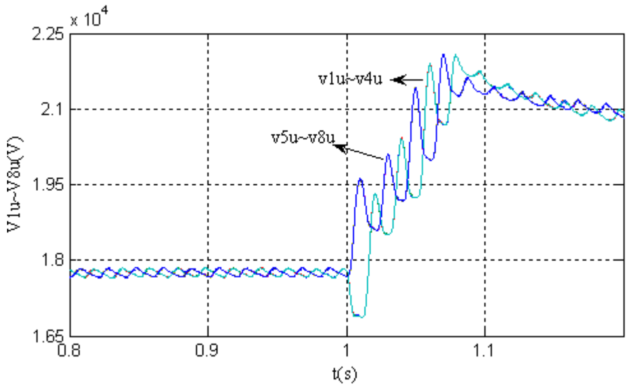
(a) AC system voltage, current response of phase U for grid side



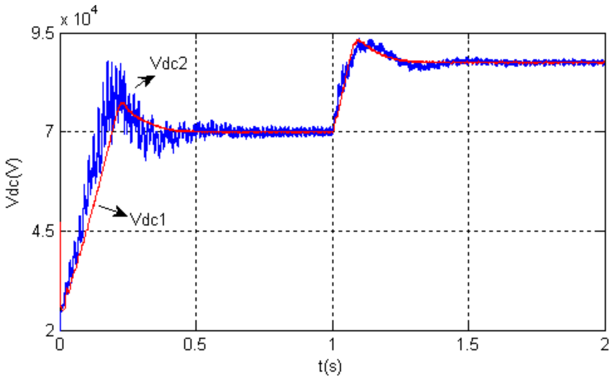
(b) 9-level PWM waveform of converter in phase U



(c) Capacitor voltages of SMs in phase U

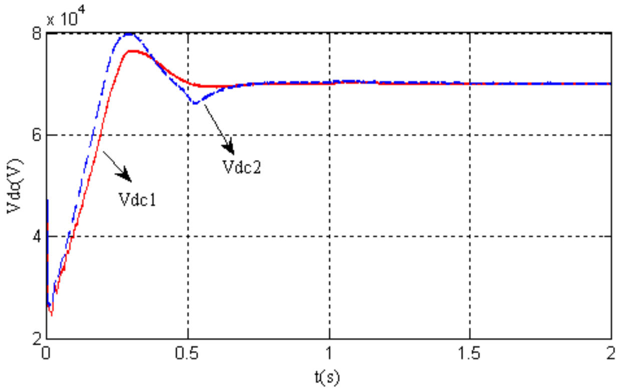


(d) Magnified curve of capacitor voltages during step response

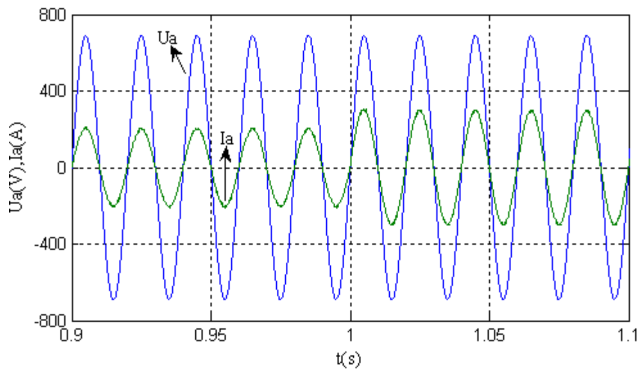


(e) DC voltage of n+1 and 2n+1 MMC.

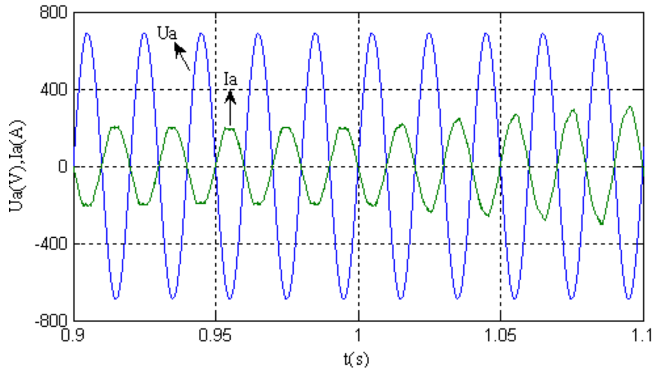
Fig. 9- DC voltage step responses of 2n+1 level MMC



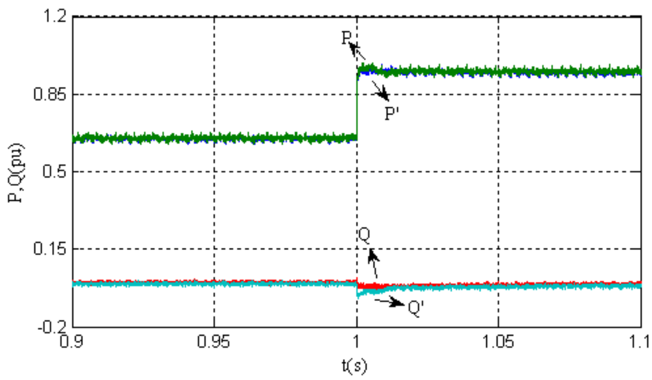
(a) DC voltage response of n+1 and 2n+1 MMC-based VSC-HVDC



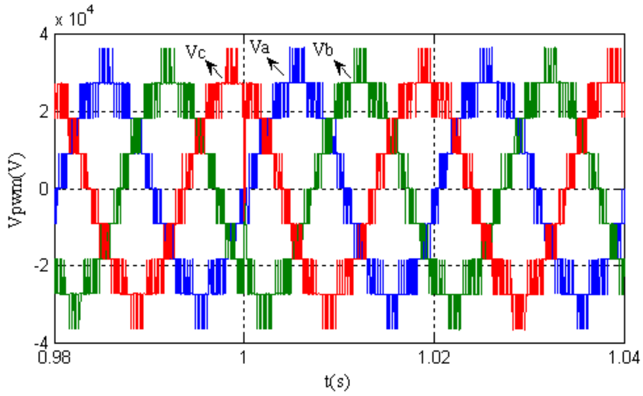
(b) AC voltage and current responses of phase U for wind farm side converter



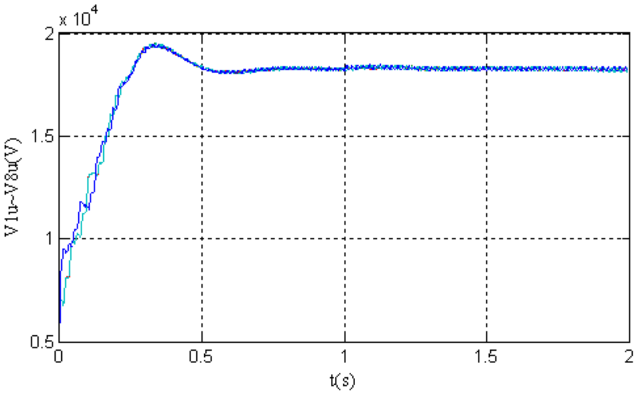
(c) AC voltage and current responses of phase U for grid side converter



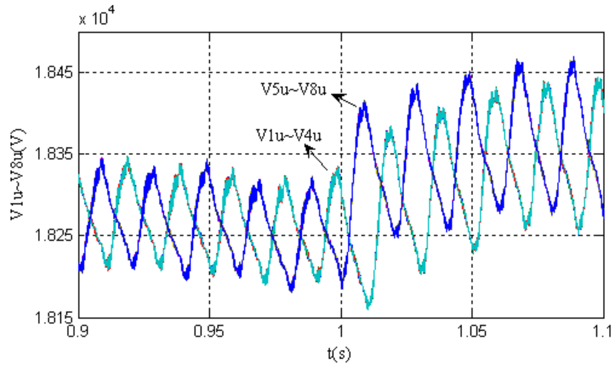
(d) Active and reactive power obtained by estimation and measurement



(e) PWM waveform of converter in wind farm side

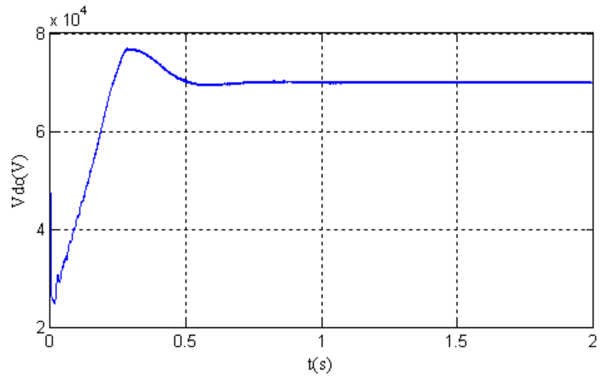


(f) Capacitor voltages of SMs in phase U

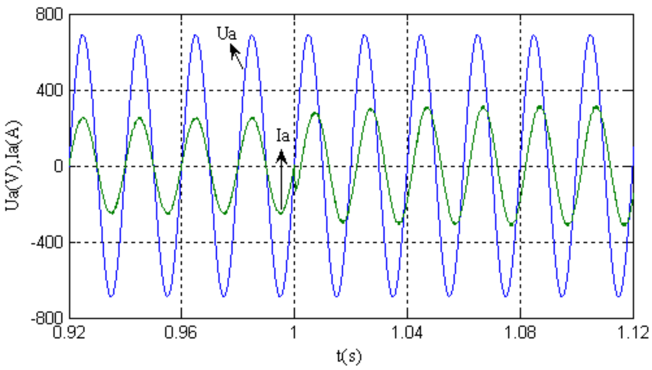


(g) Magnified curve of capacitor voltages during step response

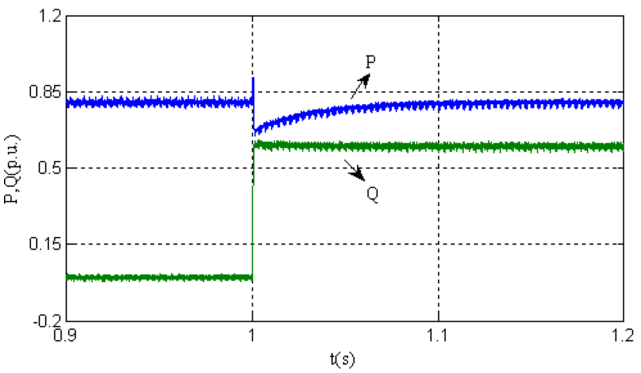
Fig. 10- Responses of MMC-based VSC-HVDC when active power step change from wind farm



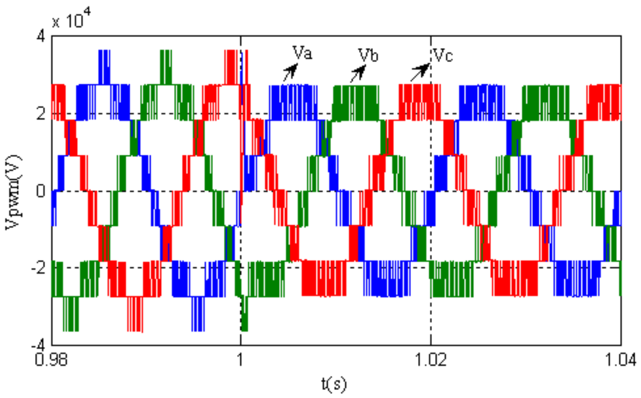
(a) DC voltage response



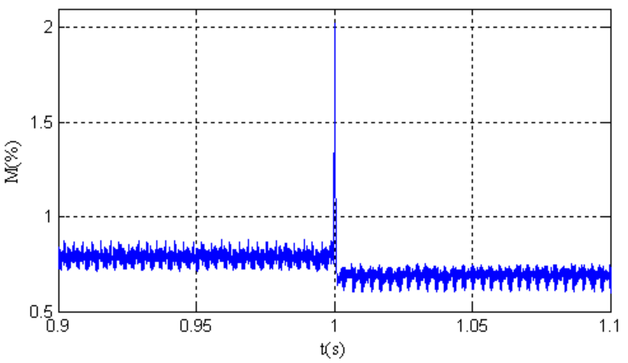
(b) AC voltage and current responses of phase U for wind farm side converter



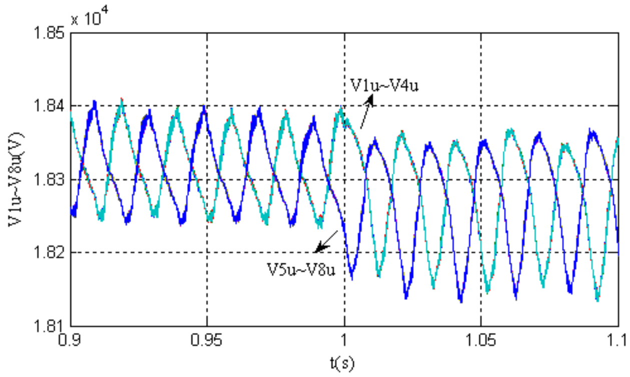
(c) Response curves of active and reactive power



(d) PWM waveform of converter in wind farm side during step change of reactive power

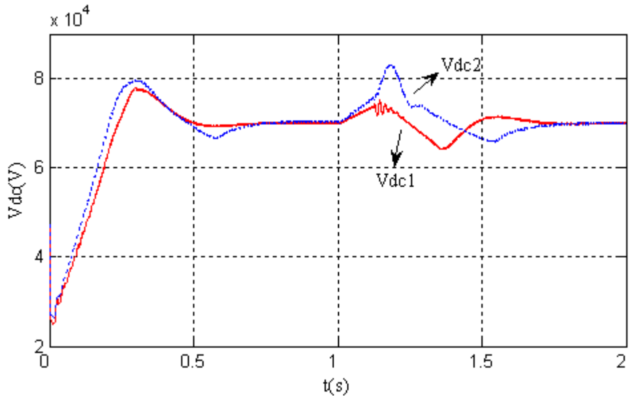


(e) Modulation index of DP-SPWM

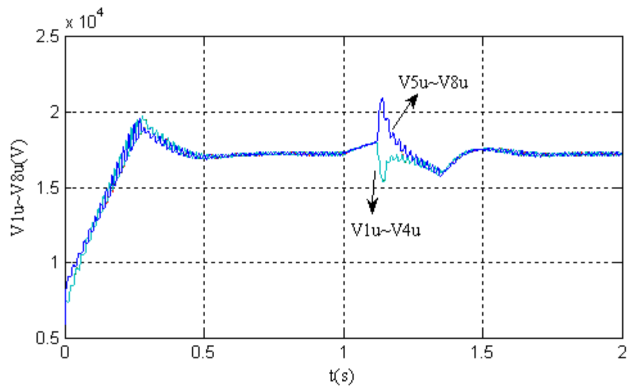


(f) Capacitor voltages of SMs in phase U during step response

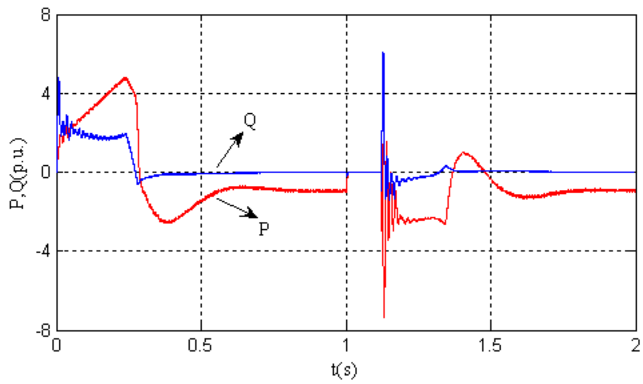
Fig. 11- Responses of wind farm side converter when reactive power step change



(a) DC voltage response of VSC-HVDC



(b) SMs capacitor voltages of phase U during step response in grid side (fault side) converter.



(c) Active and reactive power of grid-side converter

Fig. 12- Responses of MMC-based VSC-HVDC during transient grid fault.

Acknowledgements

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