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An Extended OPF Incorporating Multi-Terminal VSC-HVDC and Its Application on Transmission Loss Evaluation

This paper summarizes the main results from [1] which propose an extension of the traditional ac Optimal Power Flow (OPF) model to incorporate the Voltage Source Converter based Multi-terminal High Voltage Direct Current system (VSC-MTDC). The detailed VSC-MTDC system model is included in the extended OPF. A case study using the proposed M-OPF model and the Nordic 32-bus system evaluates the contribution of the embedded VSC-MTDC system on the overall system loss reduction. The study results show that the overall system loss of an ac transmission grid is not necessarily reduced by embedding a VSC-MTDC system into it. The reduction of the system loss by embedded VSC-MTDC system depends on their configurations and locations, and the VSC station loss ratio as well.

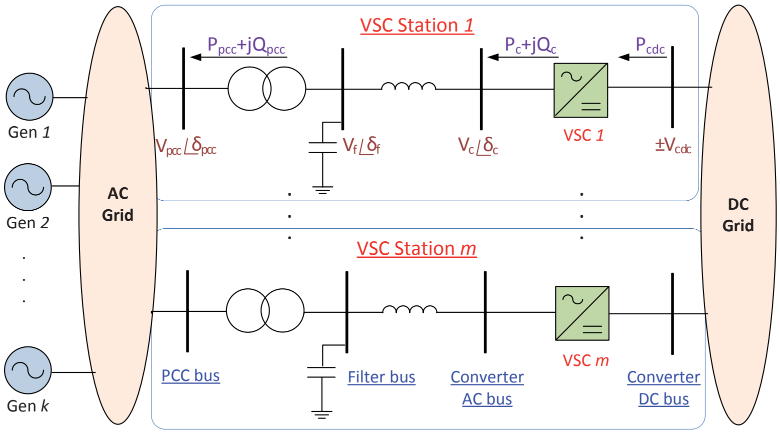

Figure 1: A representation of a mixed AC/DC power system

Extended OPF model incorporating VSC-MTDC (M-OPF)

The Voltage Source Converter based Multi-terminal High Voltage Direct Current transmission system (VSC-MTDC) has been considered as an attractive alternative in reinforcement project of the aging electric power grid, thanks to its unique advantages, such as the highly flexible power flow controllability and the possibility of using extruded XLPE cables [2]. To fully understand and evaluate the possible contribution of VSC-MTDC in the steady-state operation (e.g., reduction of system losses), the conventional ac grid Optimal Power Flow model (OPF) should be extended to incorporate the VSC-MTDC system. This extended OPF model will play an important role not only for the optimal operation of the power system with VSC-MTDC systems, but also in the evaluation of the potential benefit of the mixed AC/DC system in the planning process for the reinforcement project considering VSC-MTDC as candidates.

A general representation of a mixed ac/dc system based on VSC-MTDC can be illustrated in Figure 1, which consists of two major parts: the meshed ac grid and dc grid. VSCs work as power “exchangers” converting active power between ac and dc grids. In the M-OPF model, the power injections from VSCs to ac and dc grids (Pc, Qc, and Pcdc) are set as the decision (optimization) variables, which are constrained by the maximum dc bus voltage limits and maximum valve current limits, etc. Thus, the power flow equations of the ac and dc grid are coupled by the exchanged active power through VSCs, and solved simultaneously. The objective function of the M-OPF model is the minimization of transmission power losses in this study, and it is subject to the constraints from ac network, dc network, and VSCs as describe above. The power losses include three

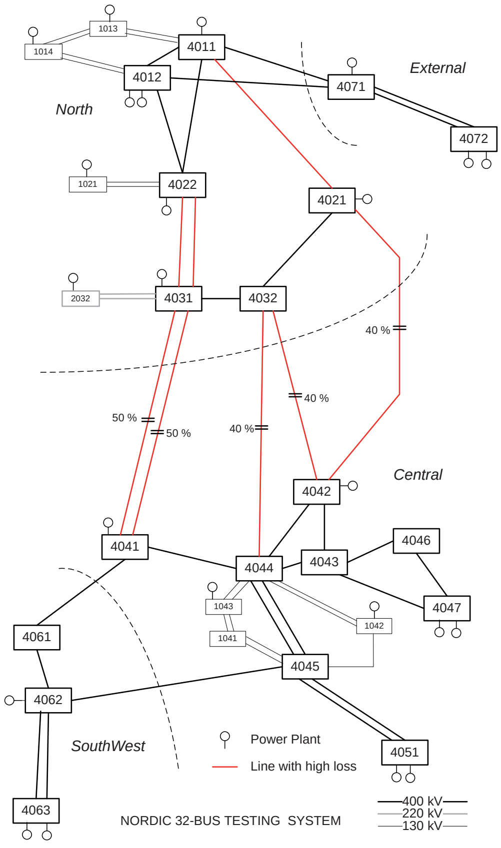

Figure 2: Ntework of Nordic 32-bus system.

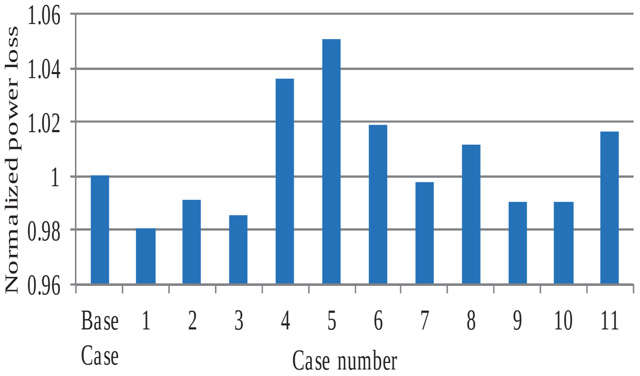

Figure 3: Normalized power losses at the nominal load condition.

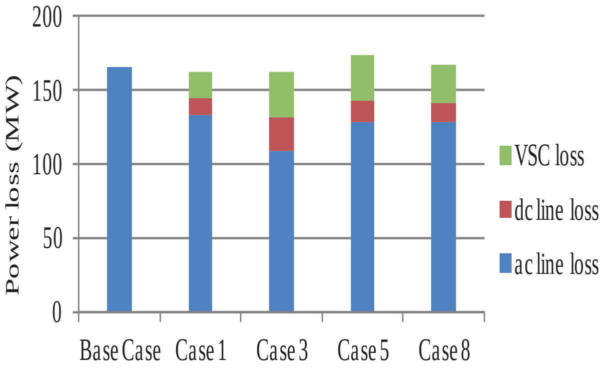

Figure 4: Comparison of power losses of selected cases.

parts, the transmission losses from ac and dc network, and the VSC station losses represented as a quadric function of the VSC valve current.

Case Study and Results

A case study using the proposed M-OPF has been executed to evaluate the effect of an embedded VSC-MTDC system on the power losses of a transmission grid. The Nordic 32-bus test system [3] is used in the study as a Base Case as shown in Figure 2, and is further modified to include VSC-MTDC candidates. A total of 11 modified cases with different VSC-MTDC systems listed in Table 1 are considered. The effects of the VSC-MTDC system on the system losses are evaluated by comparing the results from the Base Case and those of other modified cases. The VSC loss ratio is set to 1% of the VSC rating in the nominal condition in the study.

The power losses of all cases at the nominal load level are shown in Figure 3, which are normalized over the power loss of the Base Case. As can be seen, 6 among all 11 modified cases have the lower system losses than that of the Base Case, and other cases show opposite results, which mean that not all VSC-MTDC systems help the ac grid to reduce the overall system losses even if the high loss ac transmission lines are replaced by equivalent dc links. The contribution of the VSC-MTDC systems in the reduction of the overall system losses depends on their configurations and locations. Figure 4 shows the power loss components of five cases. It can be seen that the total losses through ac lines and dc cables are reduced when the VSC-MTDC systems are used. However, VSC stations introduce the extra losses which make the overall system losses of some cases higher than that of the Base Case.

Table 1: 12 Network Cases

Case Number	VSC Location (Connected ac bus)
Base Case	*Nordic 32-bus system*
Case 1	*4032 – 4044b*
Case 2	*4021 – 4032 – 4044*
Case 3	*4011 – 4021 – 4032 – 4044*
Case 4	*4022 – 4031 – 4041*
Case 5	*4012 – 4022 – 4031 – 4041*
Case 6	*4022 – 4031 – 4032 – 4044*
Case 7	*4021 – 4032 – 4042 – 4021*
Case 8	*4032 – 4042 – 4044 – 4032*
Case 9	*4021 – 4042*
Case 10	*4011 – 4021 – 4042*
Case 11	*4011 – 4021 – 4042 – 4044*

To test how the system loss will be affected by the VSC power loss ratio, a sensitivity analysis was carried out in the nominal load condition. The VSC loss ratio was set from 1.8 % to 0.6% of the VSC rating. The analysis results of four cases are shown in Figure 5. As can be seen, the system losses of all four modified cases decrease with the decrease of the VSC station loss ratio. When the loss ratio is 1.8 %, the system losses of all four cases are higher than that of the Base Case, which indicates that the embedded VSC-MTDC system shows negative effects on the power losses. As already discussed above, when the VSC loss ratio is 1 %, the system losses might be reduced by the VSC-MTDC systems in some cases depending on their configurations and locations. If the power loss ratio of the VSC station could be further decreased to 0.6 %, the system power losses of all four cases are found to be lower than that of the Base Case. Especially the VSC-MTDC system in Case 4 can help the ac grid to reduce about 10 % of system losses.

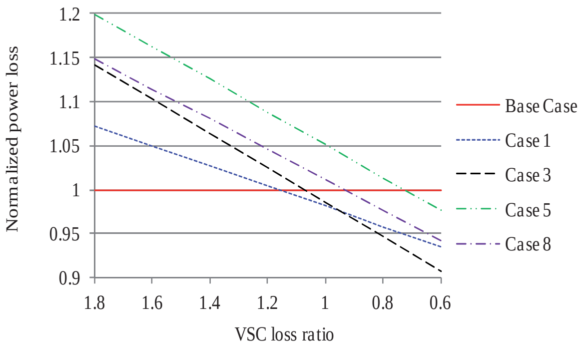

Figure 5: Normalized power losses of some typical cases in different VSC loss ratio.

Concluding remarks

- The reduction of the system loss by embedded VSC-MTDC system is not guaranteed, which depends on their configuration and location, and the VSC station loss ratio as well.
- VSC-MTDC systems cannot reduce the system losses when the VSC loss ratio is about 1.8 % of the VSC rating, while the system losses might be reduced in the nominal load level if the VSC loss ratio is lower than about 1 %.

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