Multi-objective optimization operation with corrective control actions for meshed AC/DC grids including multi-terminal VSC-HVDC

M.K. Kim

Department of Energy System Engineering, Chung-Ang University, 84, Heukseok-ro, Dongjak-gu, Seoul 06974, Republic of Korea

1. Introduction

With the advent of smart grids, transmission power systems are facing a significant paradigm shift. It is become evident that the need for investment in the power transmission infrastructure is growing, not only to replace aging grid assets but also to extend the grid capabilities and increase their bulk power transfer capacity [1]. In this situation, high-voltage direct current (HVDC) systems are expected to play a key role in reinforcing the transmission system, as they allow for power transfer over longer distances with lower losses and improved power system controllability. Voltage-source-converter-based HVDC (VSC-HVDC) systems have been planned around the world to connect DC networks to AC power systems. Compared to conventional HVDC systems based on line-commutated converters (LCCs), VSC-HVDCs constitute a more economical and efficient power transmission technology and can rapidly regulate active power [2]. At the same time, they can control the reactive power at each terminal, independent of the DC power transmission. Besides, with relative ease, VSC-HVDCs can be extended to multi-terminal HVDC connections (MTDC) for long-distance power transmission. Therefore, these systems offer additional controllability and constitute a feasible solution for the operation of meshed AC/DC grids. Various techniques have been proposed for VSC-MTDC networks, including steady-state modeling for load flow calculations [3–4], dynamic modeling for power system simulation [5], control strategies [6], allocation [7], protection [8], integrating wind farms [9], and stability analysis [10].

The optimal power flow (OPF) method determines the optimal control variables of a power system with respect to a predefined objective function and the defined constraints [11]. Traditionally, OPF control considers the static physical limits and operating limits as the only constraints. However, to protect the system against credible contingencies, it is necessary to also examine security constraints in the OPF corresponding to degraded system conditions. Consideration of these conditions leads to security-constrained OPF (SC-OPF) problems [12]. The immediate goal of SC-OPF is to achieve a solution for the economic operation of power transmission systems while taking into consideration both the normal operating limits and the violations that can occur during contingencies. However, security constraints are highly nonlinear and are difficult to include in large-scale optimization problems. Therefore, most
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gencies. Meanwhile, corrective control actions in SC-OPF can be a contingency. Preventive control actions are therefore conserva-
tion problem with the set of trade-off optimal solutions.

OPF approaches apply simplified security constraints, because of the complexity of considering accurate security constraints.

In general, SC-OPF control actions can be classified into two types: preventive control actions (PSC-OPF) and corrective control actions (CSC-OPF). Conventional SC-OPF problems can be regarded as preventive control solutions (i.e., PSC-OPF) because they impose additional constraints to allow for a feasible operational state, while respecting the security criteria. However, they do not take into account the ability to change control settings in the event of a contingency. Preventive control actions are therefore conservative and may be expensive owing to an over-tightened feasible region, or even infeasible in the case of potentially critical contingencies. Meanwhile, corrective control actions in SC-OPF can be considered to represent post-contingency control actions to eliminate system violations [13], leading to CSC-OPF. This approach can therefore relax the feasible region largely by calling upon corrective actions in the post-contingency state. The CSC-OPF control actions include post-contingency generation rescheduling and load/generation shedding. Some global optimization methods have also been considered to solve the SC-OPF problem [14–17]. Although these methods have obtained some achievements in solving the power generation scheduling problem, all of them treated only the single-objective of minimizing the operation cost of power system. Therefore, in this paper, the focus will be on CSCOPF, which, unlike PSC-OPF, considers the possibility of generation rescheduling control in post-contingency states. The task of security enhancement is also formulated as a multi-objective optimization problem with the set of trade-off optimal solutions.

With the recently increasing interest in fast control devices for AC systems, OPF control of AC/DC systems has become an impor-
tant problem. Many research studies have addressed the issue of the optimal operation of meshed AC/DC grids. An OPF model including the VSC-HVDC system was proposed in [18], but with the VSC-HVDC model limited to a two-terminal configuration. In [19], an OPF-based control strategy was presented to minimize the transmission loss in an MTDC network for large offshore wind farms. An OPF-based voltage control scheme was employed to compare the results with and without the \( N - 1 \) security criterion [20]. However, these methods optimize the operation with a DC network only; AC systems are not considered. A second-order cone programming formulation was employed in [21] to solve the extended OPF problem for an AC/DC system using a VSC-MTDC. In [22], an OPF problem of minimizing the total transmission loss of a meshed AC/DC grid was discussed. All the nonlinear equations associated with the active and reactive losses in the AC and DC lines as functions of the line-flow variables were solved with the interior point
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