General Sensitivity Formulas for Maximum Loading Conditions in Power Systems

Summary: The maximum loading condition of a power system is of particular interest for technical and economical reasons. As a consequence, a variety of techniques have been proposed in order to compute the loading margin of a system. The loading margin can be defined as the additional load that the system can provide without exceeding a technical limit and ensuring that an instability problem does not appear. Typically, technical limits are bus voltage limits and line thermal limits. The fact of exceeding these limits does not drive the power system to an immediate emergency situation but should be avoided. However, the problems related to instability phenomena, in particular the voltage instability, can lead the system to the collapse. The computation of the maximum loading condition is only a part of the information that can be useful to avoid instability. One can be interested in determining how the parameters of the system affect the loading margin. This is useful both to determine the most critical parameters and to design an effective corrective action to avoid the collapse. This information can be obtained by a sensitivity analysis at the maximum loading condition.

In the literature, the problem of sensitivities calculation for the maximum loading condition has been tackled through two procedures. The first one is based on the numerical calculation of the sensitivities. This procedure leads to high computational costs. In the second one, the Continuation Power Flow is used to obtain the loading margin of the system and sensitivities calculations are based on the linearization of the system equations at the critical point. This procedure allows obtaining sensitivity expressions but each expression depends on the system situation at the maximum loading condition.

This presentation provides and explains generalized sensitivity expressions based on the solution of a Voltage Stability Constrained
Optimal Power Flow (VSC-OPF). These expressions use the dual variables (Lagrangian multipliers) at the optimal solution and the properties of the KKT optimality conditions. These expressions allow calculating sensitivities of a generic variable with respect to a generic parameter. The presentation shows that if the maximum loading condition problem is formulated as a VSC-OPF, a closed expression for the loading margin sensitivities can be obtained from its solution. In addition, it can be demonstrated that the sensitivity formulas that have been proposed in the literature are particular cases of the general sensitivity formulas proposed in this presentation.