論文の内容の要旨

論文題目　Development of an Efficient Calculation Method Based on Evolutionary Programming for Optimal Power Flow Considering Transient and Voltage Stabilities
(過度安定度と電圧安定度を考慮した進化的プログラミングに基づいた効果的な最適潮流計算手法の開発）

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(本文)

Recently, the advent of electric power system deregulation and economic growth has brought about the competitive environment and dramatic changes in many countries. Electric supply industry, therefore, has to operate and supply enough electricity to customers in economical and secure manners as well as satisfying technical and social constraints. Optimal power flow (OPF) is a promising tool to fulfill this mission. Generally, conventional OPF aims to determine the control variables such as active power outputs etc. to minimize or maximize a selected objective function while meeting the system constraints simultaneously. Various classical optimization techniques for the conventional OPF problem have been proposed. However, these methods are effective only with convex, smooth, and differentiable objective functions, sensitive to an initial point, and sometimes torturing from insecure convergence properties. The techniques based on derivatives and gradients can lead to a local optimum which is undesirable. When the classical optimization techniques are applied to solve the conventional OPF problem, objective functions and constraints have to be confined into a simplified pattern. Therefore, this dissertation proposes the application of the Evolutionary Programming (EP)-based methods, which provide a great freedom in objective functions and constraints for the OPF problem.

To prevent the transient instability and voltage collapse phenomena, the transient stability and voltage stability issues, which play an important role on blackouts in many countries around the world, are considered in the conventional OPF. In this dissertation, the transient stability issue is treated as the additional constraints of the conventional OPF. The additional constraints are the swing equation, which describes the transient behavior of a synchronous generator, and transient stability limit, which is used to evaluate the stability status of the system. This problem is called Transient Stability Constrained OPF (TSCOPF). Time domain simulation based on the trapezoidal rule is adopted to cope with this swing equation. When the number of the considered contingency is more than 1, the problem is called Multi-Contingency TSCOPF (MC-TSCOPF). Next, the voltage stability issue is considered by adding the value of indicator L into the objective function of the conventional OPF. The indicator L, which is widely used in many applications due to its simplicity of calculation and accuracy, is selected to estimate the voltage stability margin of the system. The larger the indicator L is, the closer the system is to the voltage collapse point. The indicator L at the weakest bus is used as the voltage stability indicator of the whole system. Therefore, the objective function now changes to minimize both indicator L of the weakest bus and the fuel cost simultaneously. The scaling factor is used to weight the importance of voltage stability issue and fuel cost term. The modified objective function brings about the trade-off problem between the financial issue and system security issue. Lastly, OPF with transient and voltage stability

considerations is formulated by considering the transient stability issue as the additional constraints and voltage stability issue as one of the objective functions to be minimized.

In this dissertation, two novel EP-based methods are developed to enhance the performance of the conventional EP. The first new method is Improved EP (IEP), which introduces the crossover techniques normally found in Genetic Algorithm (GA) to enhance the offspring generation process. In IEP search template, both mutation and crossover are applied to generate the offspring individuals based on the crossover acceptance rate. The mutation puts emphasis on perturbing the control variables of parent individuals whereas the crossover techniques focus on the information exchange between two parent individuals. The second version of the EP-based methods is Adaptive EP (AEP). The AEP reduces the parameters required to pre-define when the EP method is selected to solve the OPF problem. The reduced parameter is the population size, which normally plays a crucial role on the quality of solution and execution time. The population size starts with one single individual at the beginning and then it will change adaptively according to the adaptation rule adopted from an idea that the population having many improved individuals can reduce its size whereas the population having few improved individuals should increase its size.

In TSCOPF problem, time domain simulation used to assess transient stability leads to very long computational time when the EP-based methods are applied. To alleviate the above problem, this dissertation proposes the combination of time domain simulation and artificial neural network to evaluate the system transient stability. The neural network, which is less time-consuming, is first used to classify the individual into three regions, namely *stable*, *unstable*, and *critical* regions using pre-set thresholds and then time domain simulation will be performed with only individual classified in the *critical* region. The reduction of computational time of TSCOPF can be expected from this proposed strategy.

The effectiveness of the proposed EP-based methods is tested on WSCC 9-bus and IEEE 30-bus systems with three types of cost functions representing the approximated cost model and detailed cost model of the thermal unit. The results show that, for almost all OPF problems, IEP and AEP can obtain the better solutions with the shorter computational time than the conventional EP. When the neural network is incorporated into the EP-based methods, the computational time of TSCOPF and MC-TSCOPF is dramatically reduced while the quality of solution is almost the same as the methods without the neural network. The results of different OPF problems show that the solution from the conventional OPF problem provides the cheapest operating point among all OPF problems. However, it cannot guarantee the transient stability after some possible contingencies and cannot provide a satisfactory voltage stability margin. The solution from TSCOPF can guarantee transient stability after the considered contingency with the significant increases in fuel cost and computational time. The solution from OPF considering voltage stability provides the larger voltage stability margin than that from the conventional OPF. The increase in stability margin is gained by setting the voltage magnitudes of generator buses at a high value. The computational time of this problem is not as long as that of TSCOPF. The reason is that the calculation time of indicator L is much shorter than time domain simulation. Lastly, the solution from OPF considering both transient and voltage stabilities can provide transiently-stable operating point with a satisfactory voltage stability margin. As expected, the fuel cost and computational time of this problem are the most significant among all OPF problems.