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Optimal preventive control actions using multi-objective fuzzy linear programming technique

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Abstract

This paper presents a proposed procedure depends on the multi-objective fuzzy linear programming (MFLP) technique to obtain the optimal preventive control actions, for power generation and transmission line flows, to overcome any emergency conditions. The proposed procedure is very significant to eliminate violation constraints and to give an optimal preventive action for multi-operating conditions. The proposed multi-objective functions are: minimizing the generation cost function, maximizing the generation reserve at certain generator, maximizing the generation reserve for all generation system and maximizing the preventive action for one or more critical transmission line. Numerical examples are presented in order to show that the proposed MFLP technique achieves a feasible economical cost in addition to the maximal preventive control actions for power systems.

Keywords: Economical power dispatch; Security dispatch; Fuzzy LP; Preventive action

1. Introduction

In normal operation of power systems, the constrained optimal dispatch imposed by active and reactive power generation and/or transmission line capacities must be satisfied. It has been recognized for many years that the economic dispatch may be unsafe, that is, it may not be capable to keep the system in a normal state after a major disturbance (sudden increasing in load and/or generation outages). This led to the concept of system preventive control action, and to the view that the objective of system operation is to keep the system in a normal state during the relatively long periods between disturbances. This insures that, the system will not depart from the normal state on the occurrence of a major disturbance.

The approach of security regions was first proposed by Hnylicza et al. [1]. Fischl et al. [2–4] developed methods to identify security regions and utilize these regions in contingency selection transmission planning. The idea of security regions was extended by Banaker and Galiana [5], where a method to construct the so-called "security corridors" is suggested for security assessments. Using the duality concept of mathematics programming, Dersin and Levis [6] characterized explicitly the feasibility sets of load demands. Wu and Kumagei [7] derived hyperbox subsets of the steady-state security regions based on nonlinear load flow equations. Liu [8] presented a method to compute maximal steady-state security regions based on dc load flow model. But the numerical testing indicates that the algorithms used to expand the initial region produces only nearly maximal security regions.

The fuzzy set theory is a natural and appropriate tool to represent inexact relations [9]. It has been applied for optimal power flow and scheduling with crisp constraints [10]. Based on the fuzzy set theory, an optimal power flow problem can be modified to include fuzzy constraints and fuzzy objective functions. A fuzzy set method was applied to the optimal

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power flow problem [11]. Another application of fuzzy logic to the unit commitment problem was demonstrated in Ref. [12]. A MFLP method was presented in Ref. [13] to obtain the optimal reactive power transmission loss and maximize voltage stability margin. In this paper, the MFLP is applied to effectively model for maximizing the preventive control actions.

2. Solution methodology

From an operational point of view, minimizing cost does not mean that a rigid minimum solution is achieved. It is more appropriate to state the objectives of the optimal power dispatch as: to reduce the cost as much as possible without moving too many control settings, while satisfying the soft constraints as much as possible and enforcing the hard constraints exactly. Here, the concepts of "as much as possible" and "not too many" are fuzzy in nature. Firstly, the optimal load dispatch is solved using fuzzy linear programming (FLP) technique to determine the initial output of the generators satisfying the active system constraints while the generation costs are minimized. Secondly, the maximal of active preventive control action is achieved by applying the MFLP technique to increase the power generation reserve and to decrease the power flows in the critical transmission lines.

2.1. Fuzzy economical dispatch

The fuzzy economical dispatch is formulated as a constrained optimization problem:

$$\min F_1 = \sum_{i=1}^{NG} f_i(\widetilde{PG}_i) \quad (1)$$

Subject to:

$$\sum_{i=1}^{NG} \widetilde{PG}_i = \widetilde{PD} \quad (2)$$

$$PG_i^{min} \le \widetilde{PG}_i \le PG_i^{max} \quad (3)$$

$$PF_k^{min} \le \widetilde{PF}_k \le PF_k^{max} \quad (4)$$

where $\widetilde{PG}_i$ is the fuzzy real power generation of the generation unit i; $\widetilde{PD}$ is the fuzzy load demand and power losses; $f_i(\widetilde{PG}_i)$ is the cost function of the generation unit i; NG is the number of generation buses; PG_i^{min} and PG_i^{max} are the minimum and maximum limits of power generation, respectively; $\widetilde{PF}_k$, is the fuzzy real power transmission line flow in line k; PF_k^{min} and PF_k^{max} maximum limits of line flow k, respectively.

However, the power generations are considered as control variables. While, the power flows and generation costs are considered as dependent variables for certain load demand.

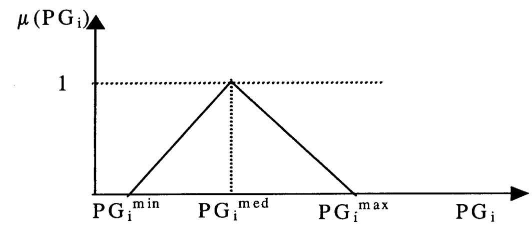

Fig. 1. Triangle fuzzy membership function for power generation unit i.

2.2. Fuzzy modelling

2.2.1. Fuzzy modelling of constraints

The triangle fuzzy modelling for the real power generation at bus i is shown in Fig. 1. It is seen that, a membership function equal to 1 is assigned to PG_i^{med}. Each generation is represented by two linear constraints for the upper and lower limits. The membership function for the lower generation limit at bus i is described as:

$$\mu 1(PG_i) = \begin{cases} 0 & PG_i \le PG_i^{min} \\ \left(\frac{PG_i - PG_i^{min}}{PG_i^{med} - PG_i^{min}}\right) & PG_i^{min} \le PG_i \le PG_i^{med} \\ 1 & PG_i \ge PG_i^{med} \end{cases} \quad (5)$$

and the upper generation limit membership function is:

$$\mu 2(PG_i) = \begin{cases} 1 & PG_i \le PG_i^{med} \\ \left(\frac{PG_i^{max} - PG_i}{PG_i^{max} - PG_i^{med}}\right) & PG_i^{med} \le PG_i \le PG_i^{max} \\ 0 & PG_i \ge PG_i^{max} \end{cases} \quad (6)$$

where, PG_i^{min} and PG_i^{max} are the minimum and maximum limits of power generation for unit i, respectively. While, PG_i^{med} is a point between the minimum and maximum limits of the power generation at unit i and equal to the initial value of this unit.

A triangle fuzzy modelling for the transmission line flow at critical line $k(PF_k)$ is shown in Fig. 2. It is seen that a membership function equal to 1 is assigned to PF_k^{med}. Each line flow is represented by two linear constraints for the upper and lower limits. The membership function for the lower line

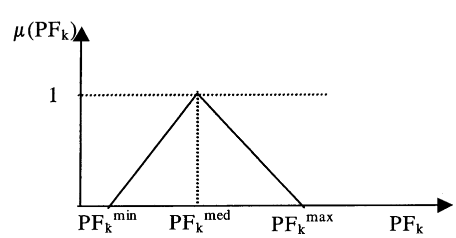

Fig. 2. Triangle fuzzy membership function for power flow.