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NERC compliant load frequency control design using fuzzy rules

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Abstract

This paper presents a load frequency control design for interconnected electric power systems using a set of fuzzy logic rules. The design objectives are (i) to comply with the North American Electric Reliability Council's (NERC) control performance standards, CPS1 and CPS2, (ii) to reduce wear and tear of generating unit's equipments, and (iii) to design a feasible control structure. A test system with multiple generation and distribution companies that takes into account regulation and load following services is used to demonstrate the effectiveness of the proposed methodologies.

Index terms: Load frequency control; Load following service; Regulation service; Automatic generation control; Fuzzy logic; NERC's control performance standards

1. Introduction

Restructuring of the electricity industry has forced vertically integrated utilities that own generation, transmission, and distribution systems to split into independent and more specialized companies, including generation (Gencos), transmission (Transcos) and distribution (Discos) companies [1,2]. New participants have emerged to compete in the generation business and to provide ancillary services such as regulation and load following. To benefit fully from this environment market participants have to minimize their operating and maintenance costs associated with generating unit's maneuvering.

Specifically, regulation service, one of ancillary services provided by Gencos, is required to track fluctuations in Disco's power demand to provide continuous service to the customers, and also to comply with the performance standards imposed by the North American Electric Reliability Council (NERC) for equitable operation of an interconnected system. This service is provided by the load frequency control mechanism (LFC), which is an automatic control of the generator's setpoints. The LFC is to regulate a signal called area control error (ACE). ACE accounts for errors in the interconnection frequency (Δf) as well as errors in the interchange power with neighboring areas over tie lines, i.e. the tie-line power error (ΔP_{tie}). Conventional LFC uses a feedback signal that is based on the integral (I) of ACE or is based on ACE and its integral (proportional–integral or PI) type controller. These feedback signals are used to maneuver the turbine governor setpoints of the generators so that the generated power follows the load fluctuations. However, continuously tracking load fluctuations definitely causes wear and tear on governor's equipments, shortens their lifetime, and might require replacing them, which can be very costly.

This paper presents a novel load frequency controller manipulated by a fuzzy logic system whose rules are designed to reduce wear and tear of the equipments, and to assure that its control performance is in compliance with NERC's control performance standards, CPS1 and CPS2.

The LFC control structure is selected to be consistent with general practices and would be feasible for implementation. This control structure is a decentralized, integral-type controller whose parameter is automatically tuned using fuzzy rules. The control parameter is reduced to diminish high-frequency movement of the speed governor's equipments

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when the control area has high compliance with NERC's standards. When the compliance is low, the control parameter is raised up to the normal value. The proposed methodology is assessed through a three-area power system that has five Gencos and three Discos. To make the test system more realistic, both regulation and load following services are taken into account.

The paper is organized as follows. NERC's control performance standards CPS1 and CPS2 are presented in Section 2. Section 3 describes the fuzzy logic design approach. A test system to illustrate the proposed techniques is given in Section 4 and Section 5 has the nonlinear simulation results that compare the proposed methods to conventional designs.

2. NERC's control performance standards

Electric power systems consist of a number of interconnected control areas that are responsible for supplying power to their native load, maintaining interchange power with their neighbors to its scheduled value. Due to constant changes in power demand, control areas have to maintain this energy balance. The energy balance for a control area (i) is assessed using its area control error, which is given:

$$\mathrm{ACE}_i = \Delta P_{\mathrm{tie}} - 10 B_i \Delta F \tag{1}$$

where ΔF is the interconnection frequency error and ΔP_{tie} is the tie-line power error. B_i represents a control area's frequency bias expressed in MW/0.1 Hz.

For equitable operation of the interconnected system, control areas have to comply with the North American Electric Reliability Council control performance standards CPS1 and CPS2, which were adopted in February 1997. Each control area is required to monitor its control performance and report its compliance with CPS1 and CPS2 to NERC at the end of each month [3]. CPS1, CPS2 and the relationship between them are described next.

2.1. CPS1

CPS1 assesses the impact of ACE on frequency over a 12-month window or horizon and it is defined as follows: over a sliding 12-month period, the average of the "clock-minute averages" of a control area's ACE divided by "10 times its area frequency bias" times the corresponding "clock-minute averages of the interconnection frequency error" shall be less than the square of a given constant, ε_1, representing a target frequency bound. This is expressed by:

$$\mathrm{AVG}_{12\text{-month}}\left[\left(\frac{\mathrm{ACE}_i}{-10 B_i}\right)_1 \Delta F_1\right] \le \varepsilon_1^2 \tag{2}$$

where ΔF_1 is the interconnection frequency error, B_i the frequency bias of the ith control area, ε_1 the targeted frequency bound for CPS1 and $(\cdot)_1$ is the clock-1-min average.

To calculate CPS1, a compliance factor (CF) and a 1-min average compliance factor (CF_1) are introduced:

$$\mathrm{CF} = \mathrm{AVG}_{12\text{-month}}[\mathrm{CF}_1] \tag{3}$$

$$\mathrm{CF}_1 = \left[\left(\frac{\mathrm{ACE}}{-10B}\right)_1 \left(\frac{\Delta F}{\varepsilon_1^2}\right)_1\right] \tag{4}$$

CPS1 is then obtained from the following equation:

$$\mathrm{CPS1} = (2 - \mathrm{CF}) \times 100\% \tag{5}$$

To comply with NERC, CPS1 should not be less than 100%.

2.2. CPS2

The second performance standard, CPS2, limits the magnitude of short-term ACE values. It requires the 10-min averages of a control area's ACE be less than a constant (L_{10}) given in the equation below.

$$\mathrm{AVG}_{10\text{-min}}(\mathrm{ACE}_i) \le L_{10} \tag{6}$$

$$L_{10} = 1.65 \varepsilon_{10} \sqrt{(-10 B_i)(-10 B_\mathrm{s})} \tag{7}$$

Note that B_s is the summation of the frequency bias settings of all control areas in the considered interconnection, and ε_{10} is the targeted frequency bound for CPS2.

To comply with this standard, each control area must have its compliance no less than 90%. A compliance percentage is calculated from the following equation:

$$\mathrm{CPS2} = \left[1 - \frac{\mathrm{violations_{month}}}{\text{total periods} - \text{unavailable periods}}\right] \times 100 \tag{8}$$

where $\mathrm{violations_{month}}$ are a count of the number of periods that the clock-10-min averages of ACE are greater than L_{10} in 1 month.

2.3. Relationship between CPS1 and CPS2

Gross and Lee [4] have shown that when CPS1 is met, CPS2 is automatically satisfied if:

(1) ACE random variables of each control area are independent; and
(2) the averages of these random variables are zero.

These conditions are assumed to hold in this paper and the fuzzy rules are designed to comply with CPS1 only. This reduces the complexity of fuzzy rule design, and helps the actions of fuzzy rule based load frequency control to be even less complicated.

3. Fuzzy logic design

In this section, fuzzy logic rules are designed to manipulate the conventional integral-type load frequency control