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Application of fuzzy logic for load frequency control of hydroelectrical power plants

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Abstract

The quality of generated electricity in power systems is dependent on the system output, which has to be of constant frequency and must maintain the scheduled power and voltage. Therefore, load frequency control, LFC, is very important for power systems. However, the LFC problem in hydroelectrical power systems has received little attention by researchers so far. In this study, a conventional proportional integral (PI) controller and a fuzzy gain scheduled proportional integral (FGPI) controller have been compared for applying to a single area and a two area hydroelectric power plant, considering that Turkey has several hydro power sources. The comparison study indicated that the proposed FGPI controller has better performance than the conventional PI controller. The study results were compared by simulation.

Keywords: Power systems; Load frequency control; Hydroelectric power plants; Conventional PI controller; Fuzzy gain scheduled PI controller

1. Introduction

Nowadays, electricity generation is very important because of its increasing necessity and enhanced environmental awareness such as reducing pollutant emissions. Since electricity is not stored but consumers expect to get it, its generation must depend on consumption. Electrical power systems are continuously growing in size and complexity with increasing interconnections. Also, their dynamic behaviour depends on disturbances and on changes in the operating point. Since they consist of many generating units and many loads and also their total power demands vary continuously throughout a day, controlling them is very difficult [1]. In interconnected large power systems, variations in frequency can lead to serious large scale stability problems. Load characteristics, unexpected changes in power demand and faults also affect the stability [2]. Additionally, because of suddenly changing consumer demands or some troubleshooting in generating units or network, the system frequency may show some oscillations or corruptions. However, these oscillations have to be limited to certain values. Otherwise, due to these excessive oscillations, some loads have to be extracted from the network, and therefore, producers suffer from the damage. However, continuously tracking load fluctuations definitely causes wear and tear on governor equipments, shortens their lifetime and might require replacing them, which can be very costly [3]. Today, people try to use economical, clean and renewable energy because of global warming. Therefore, output errors of the plant have to be determined and reduced to quite minimum values in short times by using a load frequency controller [4]. For these reasons, advanced control techniques usage must be inevitable in such systems.

Load frequency control (LFC) is one of the major requirements in providing reliable and quality operation in multi-area power systems [2]. Therefore, designing load frequency controllers has received great attention of researchers in recent years, and many control strategies have been developed [5].

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LFC is to regulate a signal called area control error (ACE), which 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 (ΔPtie). Conventional LFC uses a feedback signal that is based on the integral (I) of the ACE or is based on the ACE and its integral (proportional integral, or PI) type controller. These feedback signals are used to maneuver the turbine governor set points of the generators so that the generated power follows the load fluctuations [3].

The ACE for the ith area is defined as

$$\mathrm{ACE} = \Delta P_{\mathrm{tie}} + B_i \Delta f \tag{1}$$

where $\Delta P_{\mathrm{tie}} = P_{\mathrm{tie,actual}} - P_{\mathrm{tie,scheduled}}$ and B_i is the frequency bias factor. This control philosophy is widely used in all power systems, generally for simulation models [6]. The origin of the models was proposed by Refs. [7–9]. In the same manner, the state space and discrete power models have been used [9–11]. In the literature, the proportional integral (PI) controller was used for the proposed control strategy, which is still widely used nowadays in industry. A linear model is written by linearizing the differential equations describing the dynamic performance of the power system around an operating point [12–16].

Additionally, several new controllers such as intelligent controllers and adaptive controllers have been applied for LFC. The neural network is an important technology, which provides good results in LFC in power systems [17–20]. In addition, some researchers have used fuzzy logic controllers for this purpose [21–25]. However, in all these studies, controllers had been applied to a thermal electrical power system, not to a hydroelectrical power system. For the latter system, very few studies have been realized in the literature [6,26].

Considering these situations and Turkey's plentiful hydropower sources, in this study, a two area hydroelectrical power plant was used to apply load frequency control of the power plant. For this reason, a comparison was performed between a conventional PI controller and a FGPI controller. Also, 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.

2. Background of hydroelectric power plants in turkey

As a clean and renewable energy, hydropower electrical energy is obtained by converting the potential energy of the water to kinetic energy. Hydroelectricity, or hydroelectric power, is a form of hydropower (i.e. the use of energy released by water falling, flowing downhill, moving tidally, or moving in some other way) to produce electricity. Specifically, the kinetic energy of the moving water is converted to electrical energy by a water turbine driving a generator.

Hydroelectrical energy is the most important renewable energy resource in Turkey. Hydroelectric power stations provide about 40% of the electricity production in the country presently and has a history of about 100 years. The first electricity production in the country started in Tarsus in 1902 with a hydroelectric power station of 60 kW power. In 1923, the total installed capacity of 38 electrical power stations was 33 MW, and their energy production potential was approximately 45 million kWh per year. Of this total, only 0.1 MW was produced by hydroelectric power stations. The population of Turkey in the same year was about 14 million, and electricity consumption per capita was 3.3 kWh per year. In 1953, while the total installed power reached 500 MW, the hydroelectric power accounted for only 6% of this amount, i.e., 30 MW. Between 1953 and 1963, the capacity of hydroelectrical power reached 478 MW, and with the newly established power stations, the hydroelectrical power capacity showed an increase of about 16 times in 10 years. In 1963, the share of the hydroelectric power in the total installed power reached 35% with 1381 MW. In the following years, the amount of electrical consumption per capita has continuously increased and reached 1417 kWh per capita per year in 1999 [27]. By the end of 2010, the total installed electrical power of Turkey is estimated to be 35,587 MW. Of this amount, 22,974 MW will be generated from thermal power systems and 12,578 MW will be gengerated from hydroelectrical power systems. As for total electric energy generation of the country, it will be 140,580 GWh, which will be obtained from 75% thermal and 25% hydroelectrical power systems [28]. The technical hydroelectric energy potential in Turkey is estimated as 216 billion kWh. The economical hydroelectric potential is the total hydroelectric energy from a river basin that can be technically developed and is economically justifiable. In other words, the economical hydroelectric energy potential shows the hydraulic resources with economic feasibility. The economical hydroelectric energy potential of Turkey is about 125 billion kWh. The share of Turkey in the world gross hydroelectric energy potential is about 1% and its economical potential makes 15% of the European economical hydroelectric energy potential [27]. Important river basins that have a hydraulic production potential above 5 TWh are the Euphrates (38.1 TWh), Tigris (16.8 TWh), East Black Sea (11.4 TWh), Coruh (10.5 TWh), Seyhan (7.3 TWh), Kizilirmak (6.8 TWh), Yesilirmak (5.6 TWh), East Mediterranean Sea (5.3 TWh) and Antalya (5.2 TWh) [29]. Given the information mentioned above, it is understood that hydroelectrical power systems control is very important for Turkey.

3. The proposed hydroelectrical power system models

3.1. General overwiev of a power systems

Naturally, electrical power systems have complex and multi-variable structures. Also, they consist of many different control blocks. Most of them are non-linear and/or non-minimum phase systems [21]. Power systems are