Electric Power Systems Research 141 (2016) 529–537

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Fuzzy hierarchal approach-based optimal frequency control in the Great Britain power system☆

Zeyad Assi Obaid[a,b,*], L.M. Cipcigan[a], Mazin T. Muhssin[a]

[a] Institute of Energy, School of Engineering, Cardiff University, UK
[b] College of Engineering, Diyala University, Iraq

ARTICLE INFO

Article history:
Received 25 October 2015
Received in revised form 23 February 2016
Accepted 25 August 2016

Keywords:
GB power system
Hierarchal control
Secondary frequency control
Fuzzy PID controller
PSO optimisation

ABSTRACT

A design of fuzzy-based hierarchal approach is proposedto improve the frequency control in the power system. The simplified Great Britain (GB) frequency control model, was used as a single bus machine. A new simple tuning method is proposed with the aid of the conventional PID controller gains.The same gains are used to feed the fuzzy controller in the same loop without re-tuning the fuzzy gains. This method allows the fuzzy structure to supplement the conventional control rather than replacing it. Particle Swarm Optimization (PSO) is proposed to find the optimal value of the controller gains.Five modeling scenarios for the fuzzy control and two cases of uncertain parameters were considered to validate the model.Structures of fuzzy controller offered high stability and robustness in the simulation results. Therefore, the proposed hierarchal structuresare used in the real-time applications of the load frequency control in the power systems.

1. Introduction

The UK government targets for 2020 is that about 20% of the power generated will be from Renewable Energy Sources (RESs) such as Wind Turbine Generators (WTGs). Also, these RESs alongside with the classical generators have a potential to provide frequency control as ancillary services [1,12]. The primary benefit of the frequency control is to balance the active power generated on the load demand required. Hence, the system frequency deviation remains within the acceptable limits which is ±0.2 Hz [2]. The frequency response of the GB power system has been widely investigated in the literature with different elements added to the system in the primary frequency loop such as Electric Vehicles (EVs), WTGs, and Storage Systems (SS) [1–7]. RESs have power fluctuations due to the change of the wind speed and hence have an adverse impact on the stability of the frequency deviation. Therefore, the need for frequency control is increased [8]. Furthermore, RESs decrease the overall system inertia. The low system inertia has consequences to the system's capabilities to maintain the frequency deviation within acceptable limits. A reduction in the system inertia will increase the Rate of Change of Frequency (RoCoF) when the system is subjected to sudden disturbances such as loss or increase in the demand or generation. In such situations, it is highly recommended to minimize the settling time during the disturbance period [9].

Power system parameters such as turbine governor time constant (Tg), speed regulator (R), damping coefficient (D), and system inertia coefficient (H) are constantly changing, and this may degrade seriously the close-loop system performance [10]. The frequency control has different loops; primary, secondary, and tertiary loop as well as the emergency loop in particular circumstances. In the GB, the primary response is known as the dynamic power generation that reaches the maximum in 10 s, while the secondary response reaches full operation in 30 s. The frequency reserve services are divided into dynamic and non-dynamic; the former responds automatically to any change in the frequency while the latter is triggered by load frequency relays [11]. The control system which is responsible for controlling the frequency must provide a fast and stable response [9,11]. A rapid response to a high RoCoF is strongly recommended; however a very quick response has a risk of system oscillations [9,15]. In the conventional control method, there is a real risk that these local controllers may provide a wrong decision as a result of variations at the local level. Hence, this may

☆ This work is a part of PhD research of the corresponding author Z.A. Obaid who is sponsored by the Higher Committee for Educational Development (HCED) in Iraq. Z.A. Obaid is a PhD student at Institute of Energy, School of Engineering, Cardiff University, UK. Also he is a lecturer at College of Engineering, Diyala University, Iraq. L.C., and M.T.M. are with the Institute of Energy, School of Engineering, Cardiff University, UK.

* Corresponding author at: Institute of Energy, School of Engineering, Cardiff University, UK.
E-mail address: zeyad.a.obaid@gmail.com (Z.A. Obaid).

http://dx.doi.org/10.1016/j.epsr.2016.08.032
0378-7796/

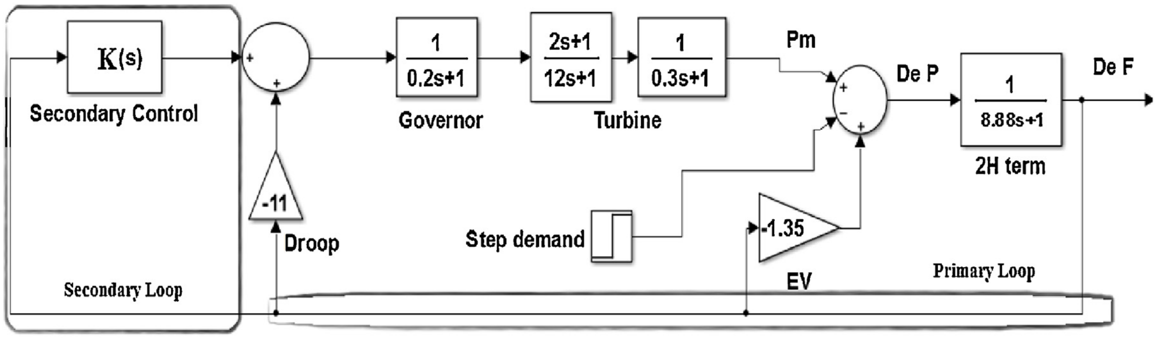

Fig. 1. Simplified model of GB power system with primary and secondary frequency loops.

lead to minor undesirable oscillations or active power overshoots with detrimental impact on the overall system frequency [9].

A flexible embedded real-time controller that offers higher flexibility versus low cost is required with the ability of event detection and response algorithm to any disturbance. The designed controller is preferable to have scalable parameters and fast controller latency to create a new adaptive protection system that is capable of standing against frequency collapse in future energy networks. This scheme is intended to supplement local control, rather than replace it. Existing load shedding and governor-frequency control processes continue to be in place, but new forms of frequency control will reduce the extent to which the conventional response would be called on. This stage will allow the control scheme to be fine-tuned based on real measurements [15].

The work presented in Ref. [16] provided some initial results of the effectiveness of using the fuzzy logic as a secondary frequency control. The results showed the response for studying different cases with EVs and Storage System (SS). The design was applied using the simplified structure of fuzzy controller with gains obtained by using the simple trial-and-error method. Therefore, these promising results motivated the authors to develop further control structures with an optimization method that can be used to supplement the conventional frequency control rather than replacing it. This control method used a robust algorithm against any parameters uncertainty.

However, to the best of the author's knowledge no attempt has been made to investigate the effect of designing the secondary frequency control that can be used to supplement the local control rather than replacing it. Also, the robustness analysis and the impact of the parameter uncertainties on the value of the frequency deviation were not investigated in the GB power system.

Therefore, the main aim of this research was to design a Fuzzy-based hierarchal frequency control with optimal performance and robustness. To achieve this aim the following steps were considered:

1. The design of a Fuzzy-based frequency control for the GB power system with a different hierarchical structure that can supplement the conventional control rather than replacing it.
2. The development of a new and simple optimization method for the system which offers a fast response performance versus high stability.
3. The investigation of the effects of parameters' uncertainty of the system with various control structures and design.

2. Generalized model of GB power system

This model (see Fig. 1) was designed by taking the characteristics of the system damping provided by the frequency dependent load and generators. The governor speed regulator was represented by the droop value Req = 11 [17]. This value was obtained by adding all droop values of each generator in the system [1,17]. The system inertia in this model was considered for the 2020 year to reflect the high penetration of the Wind Generation in the National Grid "Gone Green" scenario [1,17].

2.1. Electric Vehicles parameters

Electric Vehicles (EV) were modeled as an aggregated value represented by a feedback gain in the primary loop with the projected demand for the year 2020 [1,12]. The uncontrolled scenario was used for modeling the EVs demand. In this scenario, and during the disturbance time, it was assumed that only 3.5% of the EVs owners will charge their vehicles with an aggregated load equal to 2.16 GW. The value of this load was counted to be ≅1.35 p.u (EV load × f/Network base). The base load value was considered according to the National Grid 2020 "Gone Green" scenario and equal to 79.2 GW [1,17]. The gain has a negative value to show the disconnection of the EVs load [1]. It is working using a similar principle as the droop gain. When the disturbance occurs, the df/dt become negative, and when it multiplied by a negative gain will increase the total system power and vice versa (see Fig. 2 for the effect of the EVs gain).

2.2. Load disturbance value

An event of 27th May 2008 was used as the load disturbance, where two generators were lost with a power equal about 1320 MW of the total generation power of the GB system [1,12]. In this study, it was assumed that such disturbance occurs on an average weekday for the same event day in 24:00 hrs and the estimated losses were 0.03955 p.u.

2.3. Acceptable limits of frequency response

National Grid plc which is the GB's Transmission System Operator (TSO), sets the operating frequency at 50 ± 0.2 Hz. However, it is acceptable that the frequency may fall or rise into ±0.5 Hz but with a very specific time limit [1,11].

3. Fuzzy logic controller design methods

Classical control algorithms have some limitation in power system such as parameter uncertainties, changing the operation point which is used in deriving the model, and the collapse of these parameters. Intelligent methods such as Fuzzy Logic, Neural Network, and the Genetic algorithm have been widely used in research due to high robustness and stability, offering better control performance than classical methods [13]. Fuzzy logic is widely used in the real-time industrial applications and embedded systems. A