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A novel adaptive deadbeat- based control for load frequency control of low inertia system in interconnected zones north and south of Scotland ☆

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ABSTRACT

An adaptive deadbeat (ADB) controller was developed to investigate its capability in providing a fast frequency response to an electrical power system. This controller was developed to meet the requirements of the National Grid System Operability Framework (SOF), which requires frequency to be accelerated in line with a fast rate of change of frequency (RoCoF) when a high rate of nonsynchronous machines are presented. The controller's parameters were optimized using particle swarm optimization (PSO) to ensure a robust operation and to maintain the proper operation of the power system. The design of the ADB controller was then integrated with the multiarea model of the north and south zones of Scotland. This model was developed in order to conform to the future energy requirements scenario stated by National Grid whereby regional control can be provided in both the north and south of Scotland. In comparison with the standard PI and Fuzzy-PI controllers used in the four highlighted case studies, it was shown that the ADB controller was able to significantly reduce the RoCoF and deviation of frequency when a sudden loss of generation occurred in a low inertia zone. The ADB also showed high robustness against a wide range of operating conditions.

1. Introduction

System frequency is a variable that refers to a second-by-second balance between system demand and generation. In the power system of Great Britain (GB), the standard operating frequency is 50 Hz with the upper/lower statutory limit being ±1% Hz of nominal system frequency, i.e. ±0.5 Hz [1]. Wind generators are such a rapidly evolving technology that the latest generation of some turbine vendors has already demonstrated the capability for inertia and governor response. However, present wind generators are mostly mechanically decoupled from the grid, have rotating shafts that differ from those of the conventional generator, and do not provide system inertia [2,3]. In Scotland, it is anticipated that the capacity of onshore and offshore wind generators will surpass 50% of the total generation capacity by 2030 [4]. Therefore, increasing renewable energy in Scotland will reduce the regional and overall system inertia of the UK and make it variable and non-uniform across the grid. Because of low inertia, the absolute value of the rate of change of frequency (RoCoF) could be increased significantly and in the worst case could even degrade system stability. Thus, fast frequency response technology is required to avoid the possible drawbacks of low inertia. Additional frequency responses under existing arrangements are expected to increase CO_2 levels and cost the UK £250 million per annum by 2020 [5].

In its 2015 'Electricity Ten Year Statement' for future energy scenarios, National Grid (NG) considered the GB power system as a number of zones and boundaries. The purpose of these boundaries was to introduce control frameworks that quickly and effectively deploy nonconventional frequency reserves at each zone before propagating to the system [5,6].

On the other hand, NG has also been trying to find new innovative control system technologies to operate at a regional level, and to provide a rapid response and reduce the CO_2 emissions at a reasonable cost. One of these technologies is to harness the power consumption of some domestic and industrial loads to provide fast frequency response [7–9].

Another technology is to design an intelligent controller to provide fast ramp rate action. This is accomplished by means of a

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supplementary feedback loop control system designed to compensate for a high volume and speed of frequency drop/rise [5].

Many researchers have presented different types of controllers at the supplementary level of Load Frequency Control (LFC) power systems. For instance, in [10], a Fuzzy Logic Control (FLC) based PD plus an integral controller was used as an automated generation control (AGC) in the single isolated area power system. The work in [11,12] developed a combination based on the new technique of FLC and particle swarm optimization (PSO) for an online tuning of the PI controller in a single area power system. FLC and adaptive FLC using the PSO algorithm were used to deal with the frequency response issue in multiarea power systems with high penetration of renewables [13–16]. The H-infinity controller was designed in [17,18] to provide robust feedback load frequency control. The principal idea of these studies was to find an optimal value of the parameters of the PI/PID controller to speed up the power provision, slow down the RoCoF and reduce the frequency deviation.

The deadbeat control approach comes under the pole placement family where system control is based on the shifting of roots. In [19,20], frequency decline-based pole placement and adaptive pole placement approaches in a multi-area power system were introduced in the presence of high penetration wind generation. The main concept of these studies was to shift the roots from an unstable region and position them in a more stable margin. The deadbeat controller, however, added improving roots that eliminated the effect of the undesired roots. Thus, a deadbeat controller is a suitable controller that shows a precise behavior and satisfies the requirement for a very fast transient response [21,22].

There are still challenges to halt the fast frequency decline, particularly with the increasing volume of wind generation. Although an adaptive deadbeat (ADB) controller can compensate with fast rate of change of frequency (RoCoF) and reduce frequency deviation, thus far and to the author's best knowledge, no research has been yet carried out on this issue. Therefore, the main contributions of this paper are as follows:

1. Introduction of a new approach for load frequency control systems: the paper highlights how the novel ADB controller can reduce the RoCoF in the earliest sub-seconds following the incident.
2. Development of a system model, carefully derived from physical data, for interconnected zones north and south of Scotland: this model was developed to conform to the future Gone Green energy scenario for the Scottish power system, where regional frequency control is likely to be a major issue [6].
3. Evaluate the operation of the ADB controller by comparing its results with other two important controllers such as the standard PI controller and intelligent Fuzzy- PI controller.

2. Scottish power system

Scotland is currently experiencing massive development in renewable generation capacity, which reduces system inertia and causes the absolute value of RoCoF to increase. In practice, frequency deflection starts at the source of the disturbance and then propagates through the system (Fig. 1) [5]. To clarify the way the model is designed, several assumptions were considered:

- The north and south Scotland zones are made up of boundaries (B_0–B_5) and B_6 respectively as shown in Fig. 2(a) and (b) [6]. Mapping the boundary to Scotland zones makes the position of the generation data in each zone easier. However, the installed generation data in each boundary are given by National Grid [6].

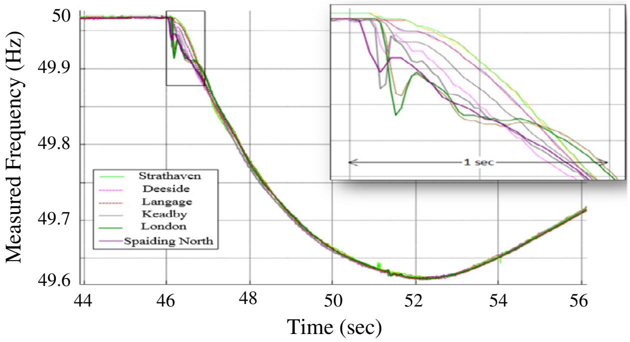
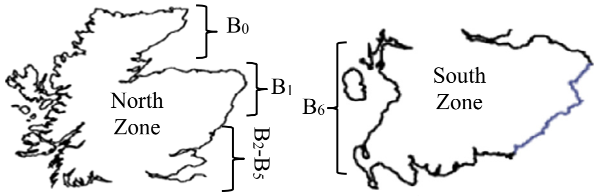


Fig. 1. Synchronized system-wide measurement of frequency disturbance [5].



(a) (b)

Fig. 2. Boundaries (a) North zone (b) South zone of Scotland [6].

- For simplicity, all generators located in these boundaries that are of a similar type are replaced with one generator considering their total power generation.
- It is assumed that thermal plants and onshore/offshore wind generators produce 80% and 40% of their total capacity respectively [2].
- A Load Frequency Control (LFC) model is used to study the power system frequency. Thus, transmission lines are not described in the model.
- System inertia is reduced, as some synchronous thermal plants are being replaced by asynchronous wind generators [5]. Tables 1 and 2 describe the Gone Green scenarios given by NG for 2014/2015, 2019/2020 and 2029/2030.
- To ensure the controller's robustness and performance, the ADB controller was designed based on the lowest (worst) system inertia scenario, i.e., the 2029/2030 scenario.

2.1. North Scotland zone

Table 1 shows the operating generation capacity of this zone for the 2014/2015, 2019/2020 and 2029/2030 Gone Green scenarios. System inertia H_{eq} was normalized to the total generation capacity. The generation and demand data are available in [6]. This zone is expected to have experienced massive growth of renewables by 2030, especially after the offshore wind farms at the Moray Firth and the Firth of Forth enter into service. The Moray Firth wind farm will add 780 MW whereas the wind farm at the Firth of Forth will give 1075 MW by 2019/2020.

By 2030, the energy capacity of wind turbines in this zone will have reached 44% of the total operating generation capacity. This will cause the system inertia in proportion to the total power capacity of this zone to decrease from 3.067 s pu in 2015 to 1.764 s pu in 2030. With a sudden loss of generation of 150 MW, the simulation results in Fig. 3(a) shows that regional absolute value of RoCoF increases in proportion to the reduction in system inertia over years 2015 to 2030 without using a supplement controller. The system inertia of this zone was calculated according to (1) and was recorded in Table 1.