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Adaptive underfrequency load shedding using particle swarm optimization algorithm

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Abstract

Underfrequency load shedding plays an important role in prevention of the power system blackout. The common load shedding methods are based on measuring the frequency first derivative; therefore, an error in measurement process can highly affect their performance. Also, for proper performance of these load shedding schemes, the exact value of some parameters of power system is needed. Any error in estimation of these parameters reduces the reliability of these load shedding schemes. In this paper, an underfrequency load shedding method based on the forecast minimum frequency of system is proposed. In this method, the samples of the power system frequency are taken after disturbance; then, particle swarm optimization algorithm is used to forecast the minimum frequency based on these samples. To verify the effectiveness of the proposed load shedding scheme, its performance has been compared with a newly suggested method.

Keywords: Blackout; Minimum frequency; Power deficit; Underfrequency load shedding

1. Introduction

Maintaining the power system frequency within the permissible limits is an important control task which in normal conditions is carried out by means of load frequency control (Hajiakbari Fini, Yousefi, & Alhelou, 2016; Ketabi & Hajiakbari Fini, 2015a; Kundur, 1994). But, when a sudden power deficit occurs as a result of outage of large generating units or islanding of some parts of power system, even if the existing generating units have enough spinning reserve to supply the demand, their response is not rapid enough to stop the frequency excursion and prevent the operation of generating units protective relays. This may lead to outage of some of the generating units. Consequently, outage of a generating unit can worsen the situation and decrease the frequency to a lower level; therefore, the relays of other generating units might trip and lead to power system blackout. A solution which is widely used in power systems for overcoming this situation is the implementation of underfrequency load shedding (UFLS) schemes (Ketabi & Hajiakbari Fini, 2015b; Laghari, Mokhlis, Bakar, & Mohamad, 2013).

In literature, a number of strategies have been implemented for UFLS (Aik, 2006; Anderson & Mirheydar, 1990; Anderson & Mirheydar, 1992; Berdy, 1968; Chuvychin, Gurov, Venkata, & Brown, 1996; Concordia, Fink, & Poullikkas, 1995; Delfino, Massucco, Morini, Scalera, & Silvestro, 2001; Halevi & Kottick, 1993; Hong & Chen, 2012; Hong & Wei, 2010; Larsson, 2005; Lokay & Burtnyk, 1968; Lopes & Mitchell, 2000; Maliszewski, Dunlop, & Wilson, 1971; Pahwa, Scoglio, Das, & Schulz, 2013; Rudez & Mihalic, 2011a, 2011b, 2011c, 2015; Terzija & Koglin, 2002; Thalassinakis & Dialynas, 2004). Conventional method is the first generation of UFLS scheme which has been introduced in (Lokay & Burtnyk, 1968) and developed by some other authors (Aik, 2006; Berdy, 1968; Concordia et al., 1995; Delfino et al., 2001; Halevi & Kottick, 1993; Maliszewski et al., 1971; Thalassinakis & Dialynas, 2004). The first stage in this method is determination of the worst probable generation loss event which results in the highest initial rate of frequency decay. Then, the amount of load shedding which ensures that the frequency will not deviate below the minimum permissible value should be specified. After that, the number and size of load shedding steps are determined based on trial and error to achieve an acceptable

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operation in case of the worst probable contingency. Determining the worst probable contingency and also the size and number of load shedding steps are not easy tasks. Also, in this method a specified amount of load is shed in every stage without considering the amount of power deficit. Hence, it is probable that overshedding occurs and the frequency increases above the maximum permissible value.

A number of algorithms have been used to optimize the conventional UFLS method (Aik, 2006; Halevi & Kottick, 1993; Hong & Chen, 2012; Hong & Wei, 2010; Lopes & Mitchell, 2000). In Hong and Chen (2012) a UFLS scheme is optimized based on genetic algorithm (GA). To maximize the lowest swing frequency and minimize the amount of shed load, GA is implemented in Hong and Wei (2010). The drawbacks of conventional UFLS can be remedied by using the adaptive UFLS method proposed in Anderson and Mirheydar (1992). In this method, using swing equation, the amount of power deficit is calculated based on the frequency derivative immediately after the disturbance. Therefore, there is no need to determine the worst probable contingency and an amount of load based on the calculated power deficit is shed at the specified stages. In Rudez and Mihalic (2011a, 2011b) the effect of load parameters on adaptive UFLS scheme is investigated. The adaptive UFLS methods estimate the power deficit using swing equation. Hence, these methods are dependent on the equivalent inertia constant of the power system and any change in this parameter may highly affect its performance. Moreover, the estimated power deficit is directly related to the frequency derivative at the moment the disturbance occurs. Therefore, errors in frequency derivative will degrade the reliability of this UFLS scheme.

In Rudez and Mihalic (2011c), a new UFLS scheme based on the minimum frequency of system after disturbance is proposed. As authors claimed, in this scheme no knowledge of power system parameters is needed. In this method, the frequency second derivative is estimated based on Newton method; then, the minimum frequency is forecasted using numerical integration. After that, the amount of load to be shed is determined based on the minimum frequency. However, measuring the frequency second derivative is a challenging problem.

In this paper, a load shedding scheme is proposed in which the frequency of system after occurrence of disturbance is forecasted using the particle swarm optimization (PSO) algorithm. Then, the minimum frequency of system is obtained as described in Section 2. After that, the amount of load which is necessary to be shed to maintain the frequency of system within the permissible limits is determined. Afterwards, the determined amount of the load can be shed in several steps as described in Section 3. In Section 4, requirements for implementing the proposed UFLS method in real power systems have been pointed out. In Section 5, the proposed load shedding scheme is compared with a newly proposed UFLS method through simulation results.

2. Implementing PSO for frequency estimation

When a disturbance such as generating units outage occurs in a power system and causes a power deficit, frequency drops as shown in Figure 1. This frequency drop can be represented by following equation (Anderson & Mirheydar, 1990):

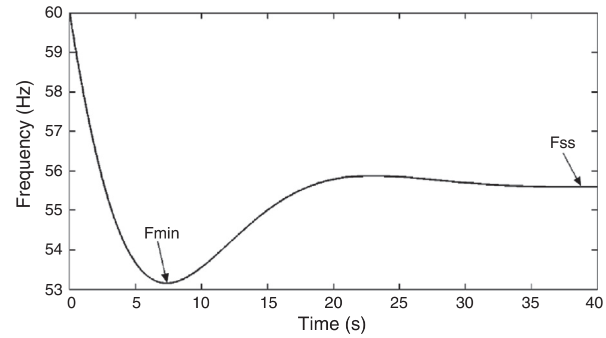

Fig. 1. Frequency drop after occurrence of power deficit in a typical power system.

$$\Delta\omega = \left(\frac{R\omega_n^2}{DR + K_m}\right)\left(\frac{(1 + T_R s)P_{step}}{s(s^2 + 2\xi\omega_n s + \omega_n^2)}\right) \quad (1)$$

where

$$\omega_n^2 = \frac{D \times R + K_m}{2H \times R \times T_R} \quad (2)$$

$$\zeta = \frac{2H \times R + (D \times R + K_m \times F_H) \times T_R}{2(D \times R + K_m)} \times \omega_n \quad (3)$$

The objective is to forecast the frequency deviation, as precisely and quickly as possible, using the minimum possible measured frequency samples. Hence, for curve fitting, a function should be chosen that represents the frequency of system precisely and has the minimum number of parameters to be estimated by PSO. By trial and error it is found that in the studied power system, the frequency deviation of system up to 3 s after the disturbance can be estimated accurately by fitting a cubic function on frequency deviation samples measured within 0.1 s after occurrence of the power deficit. So, the frequency deviation samples taken within 0.1 s after the beginning of the frequency decay is used by PSO algorithm to determine the parameters of the following cubic function:

$$\Delta f(t) = at + bt^2 + ct^3 \quad 0 \le t \le 3 \quad (4)$$

As it is shown in Figure 2, frequency deviation of the system up to 3 s after the beginning of the frequency decay is forecasted

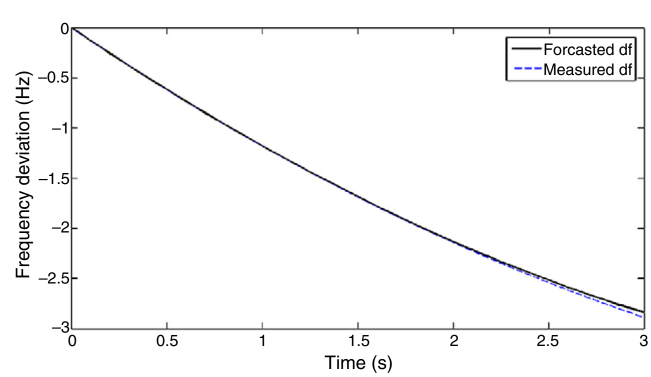

Fig. 2. Forecasted frequency deviation up to 3 s after disturbance with a cubic function.