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Optimal design of adaptive under frequency load shedding using artificial neural networks in isolated power system

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A B S T R A C T

The frequency and voltage stability is a basic principle in the power system operation. Different short circuits, load growth, generation shortage, and other faults which disturb the voltage and frequency stability are serious threats to the system security. The frequency and voltage instability causes dispersal of a power system into sub-systems, and leads to blackout as well as heavy damages of the system equipments. Optimum load shedding during contingency situations is one of the most important issues in power system security analysis. This paper presents a fast and optimal adaptive load shedding method, for isolated power system using Artificial Neural Networks (ANNs). By creating an appropriate data-base of contingencies for training the neural network, the proposed method is able to perform correct load shedding in various loading scenario. In this regard, the total power generation, the total loads in power system, the existing spinning reserved capacity value in the network and frequency reduction rate were selected as the ANN inputs. This method has been tested on the New-England power system. The simulation results show that the proposed algorithm is very fast, robust and optimal values of load shedding in different loading scenarios, related to conventional method.

1. Introduction

Recently, one of the main challenges of electric power utilities is power system blackout [1]. During a system disturbance, a power system may break up into constituent isolated sub-systems known as islands [2]. The existing control systems in the network are constrained to regulate and fix the frequency and network voltage at their nominal values. Generations increasing for frequency recovery and reactive power adjustment by the existing compensators in the network for voltage recovery are carried out through stability protection against the faults. In most cases, we encounter the problem of generation shortage and reactive power controllers in the network [3]. Consequently, the proposed solutions have been ineffective. Under frequency load shedding is a common practice for electric system utilities for preventing frequency drop in power systems after disturbance causes dangerous imbalance between load and generation [4–6].

The best load shedding scheme in power systems is one that is able to separate the least possible loads of the network in the shortest time by considering power system constraints. In this manner, the network is recovered against frequency or voltage reduction in addition to protecting the network transient stability.

The previous load shedding schemes do not have the above mentioned properties. In these methods, the load shedding process is time consuming and moreover, the unnecessary and extra loads might get separated from the network. The main motivation to study presented in this paper was application of intelligence methods for solving traditional load shedding problems. This method is performed by centralized load shedding method. In [4] an adaptive under frequency load shedding based on magnitude of disturbance estimation for protecting electric power systems from dynamic instability and frequency collapse is proposed. Two centralized adaptive under frequency load shedding algorithms for simultaneously protecting power system against frequency instability as well as voltage instability, following combinational disturbances is proposed in [7]. The most important intelligent methods that can be used for time optimization and the best load shedding, one can point to expert systems, artificial neural networks [8–12], fuzzy logic [13], genetic algorithm [14,15] and PSO algorithm [14,16]. The practical load shedding systems act in real-time [8]. Due to the fact that within a period of time, the power system has load variations, so the load shedding algorithm should present itself adaptively with new conditions. Among the above-mentioned intelligent methods, the adaptive ANN method is the most effective one that has attracted more attention, recently. The high speed property of neural networks has also provided the possibility of optimal load shedding in transient states [8]. Meanwhile, in traditional methods and even in methods such as fuzzy logic, genetic

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algorithm and PSO algorithm, they are related to voltage load shedding schemes in steady state conditions of the system.

The design of an adaptive load shedding method by neural networks is developed in [8,9]. In [8], the total generation power, total consuming load and frequency reduction rate as the input neurons of ANN, and the total amount of load shedding as the ANN output are taken into consideration. Also in [9], appropriate criterions for load shedding process design, minimizing load shedding value with regard to preserving the steady state of frequency range and prevention of lengthy reduction of frequency duration are expressed. In [10], neural network is employed for the prediction of load shedding function on the basis of frequency reduction. This reference shows that the use of ANN algorithm against traditional load shedding methods is at least a hundred times faster. In [11], the neural network is employed as a fast and precise method for the prediction of power system dynamic response during load shedding process by under frequency relay. In [12], a compound frequency load shedding method is also presented by Monte-Carlo method and neural networks. In the most previous studies, this method had been used in a fixed loading [9–11]. Also, in all the references mentioned for the ANN method, three input neurons are considered [8,10,11].

In this paper, load shedding strategy is presented in a new structure. By creating an appropriate data base of contingencies for neural network training, it is tried to do fast, optimal and robust load shedding in a considerable spectrum of different loadings scenario, which is compared with traditional load shedding method. Considering the importance of inputs for neural network training and improvement of load shedding value, in this paper, with regard to the obtained results of the previous studies, four inputs were selected. So the total network generation power, the total load in the power system, the amount of spinning reserved capacity and the frequency reduction rate are presented as the neural network inputs. Afterwards, the total required load shedding amount for preserving the power system stability is considered as the neural network output. Meanwhile, in this method, and regarding to the importance of the present reserved capacity in the network for the reduction of load shedding and preserving stability, this variable is included as the fourth main inputs of the neural network. The simulation results show that about 90% of the tested cases, the reduction in load shedding values is achieved.

Through achieving these goals, in the next section, first an adaptive load shedding scheme is presented and then the ANN structure is mentioned. Finally, the New-England power system is employed for performing experiments on the functioning of load shedding method. The simulation results depict the abilities of this algorithm in performing a fast and optimal load shedding.

2. Conventional under frequency load shedding scheme

To obtain the total amount of load shedding (*LD*), in conventional under frequency load shedding scheme, the following famous equation is employed [17]:

$$LD = \frac{\frac{L}{1+L} - d\left(1 - \frac{f}{f_0}\right)}{1 - d\left(1 - \frac{f}{f_0}\right)} \tag{1}$$

In this equation, *L* is the rate of overload per unit produced in the system resulted from distortion which is calculated as follows [18]:

$$L = (\text{total lost generation}/\text{total remaining generation})$$

Also, *f* is the least authorized frequency in the steady state operation of the system under study. With the fact that f_0 is equal to 60 Hz; the amount of *f* is also equal to 59.8 Hz, in this research. Also, the least authorized transient frequency for the system is considered to be 57 Hz only occurring in the instant of disturbance. The *d* coefficient is also the load reduction coefficient which is related to the type of disturbance and its amplitude. This relation for a sample system is shown in Fig. 1. The amount of *d* can be chosen from 0 to 6. The smaller *d* is chosen, the more the rate of load shedding will be and the frequency of the system is nearer to nominal value. Also the bigger *d* is taken, the less the rate of load shedding will be; but more drop amounts of frequency have been accepted, instead.

2.1. System frequency operation

In every power system, the total inertia presented in the network plays a very significant role in the reduction of system frequency. The more total inertia causes the less system frequency and the rate of *df*/*dt* declines. In a multi-machine system, the equal inertia is obtained from the following equation:

$$H_{system} = \frac{H_1 MVA_1 + H_2 MVA_2 + \ldots + H_n MVA_n}{MVA_1 + MVA_2 + \ldots + MVA_n} \tag{2}$$

where H_i ($i = 1,\ldots,n$) are machine inertia constants in terms of second. It should be noted that before the occurrence of any distortion in power system, the system is stable. Therefore, the creating of any deviations in the consuming power of the power system with amplitude of $P_{L\Delta}$, leads to the same amount of reduction network generation capacity. This fact is the main factor in frequency reduction in the power system. The physical interpretation of this phenomenon denotes that the power shortage causes in the generator torque (T_g) is less than the torque of load (T_l), that is,

$$\Delta T = T_g - T_l < 0 \tag{3}$$

T_g and T_l are both in terms of N m. So, the rate of frequency change is as follows [19]:

$$\frac{df}{dt} = -\frac{f_0}{2H_{sys}} . P_{L\Delta} \tag{4}$$

In this equation, f_0 is the nominal frequency of the system, H_{sys} is the total power system equivalent inertia in terms of seconds, $P_{L\Delta}$ is the distortion amplitude in terms of per-unit, and *df*/*dt* is the frequency reduction rate in terms of Hz/s.

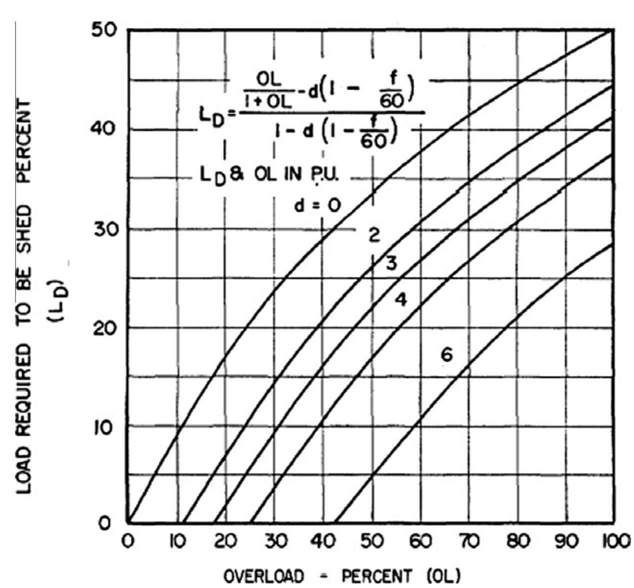

Fig. 1. Necessary load shedding at different overloads in a power system.