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Multiobjective design of load frequency control using genetic algorithms

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ABSTRACT

Recently, several modern control theory designs like H_∞ have been applied to the load–frequency control (LFC) problem optimization technique. However, the importance and difficulties in the selection of weighting functions of these approaches and the pole-zero cancellation phenomenon associated with it produces closed loop poles. In addition, the order of the H_∞-based controllers is as high as that of the plant. This gives rise to complex structure of such controllers and reduces their applicability. Also conventional LFC systems that use classical or trial-and-error approaches to tune the PI controller parameters are more difficult and time-consuming to design.

In this paper the decentralized LFC synthesis is formulated as a multiobjective optimization problem (MOP) and is solved using genetic algorithms (GAs) to design well-tuned PI controllers in multi-area power systems. The proposed control scheme has been applied to the LFC problem in a three-area power system network and the 10-machine New England test system respectively and shows desirable performance.

1. Introduction

Frequency changes in large scale power systems are a direct result of the imbalance between the electrical load and the power supplied by connected generators [1]. Therefore load–frequency control is one of the important power system control problems which there have been considerable research works for it [1–3]. Usually, the load frequency controllers used in the industry are PI type and are tuned online based on trial-and-error approaches. Also recently, several approaches based on modern control theory have been applied to the LFC design problem and there has been continuing interest in designing load–frequency controllers with better performance using various decentralized robust and optimal control methods during the last two decades [4–10].

One of the modern control techniques which has been applied to the LFC problem is H_∞ optimization technique [9,10]. However, the importance and difficulties in the selection of H_∞ weighting functions have been reported. Moreover, the pole-zero cancellation phenomenon associated with this approach produces closed loop poles whose damping is directly dependent on the open loop system (nominal system) [11]. On the other hand, the order of the H_∞-based controllers is as high as that of the plant. This gives rise to complex structure of such controllers and reduces their applicability. Then despite the potential of modern control techniques with different structures, power system utilities prefer the online tuned PI controller's. The reasons behind that might be the ease of online tuning and the lack of assurance of the stability related to some adaptive or variable structure techniques.

One of the optimization techniques that is used for tuning the PI controller parameters is genetic algorithm (GA) [12,13]. The advantage of the GA technique is that it is independent of the complexity of the performance index considered. It suffices to specify the objective function and to place finite bounds on the optimized parameters. However, in practice this approach is not capable in problems with multiple objective functions like multi-area power systems with more than one PI controller. In this paper, the LFC problem in multi-area power system is formulated as a multiobjective optimization problem and GA is employed to solve it. The proposed design approach has been applied to a three-area power system network and the well-known New England 10 generators, 39-bus system too as case studies.

The organization of the rest of the paper is as follows, In Section 2, a brief introduction to LFC and multiobjective optimization problem (MOP) is given. In Section 3, the problem formulation under MOP is discussed. Simulation results are provided in Section 4 and the paper is concluded in Section 5.

2. Backgrounds

2.1. Multiobjective optimization

Many real-world power system problems involve simultaneous optimization of multiple objectives. In certain cases, objective

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functions may be optimized separately from each other and insight gained concerning the best that can be achieved in each performance dimension. However, suitable solutions to the overall problem can seldom be found in this way. Instead, multiobjective optimization (MO) solution seeks to optimize the components of a vector-valued cost function. Unlike single objective optimization, the solution to this problem is not a single point, but a family of points known as pareto-optimal (PO) set. Each point in this surface is optimal in the sense that no improvement can be achieved in one cost vector component that does not lead to degradation in at least one of the remaining components [14].

There are following definitions related to the MO [14]:

- *Inferiority.* A vector $u = (u_1, \ldots, u_n)$ is said to be inferior to $v = (v_1, \ldots, v_n)$ if and only if v is partially less than u i.e.

$$\forall i = 1, \ldots, n \;\; v_i \leqslant u_i \;\; \wedge \exists i = 1, \ldots, n: \;\; v_i \prec u_i.$$

- *Superiority.* A vector $u = (u_1, \ldots, u_n)$ is said to be superior to $v = (v_1, \ldots, v_n)$ if and only if the v is inferior to the u.
- *Non-inferiority.* Vectors $u = (u_1, \ldots, u_n)$ and $v = (v_1, \ldots, v_n)$ are said to be non-inferior to one another if v is neither inferior nor superior to u.

Usually, the aim of MOP is to determine the trade off surface, which is a set of nondominated solution points, pareto-optimal or noninferior solutions. Actually each element in the PO set constitutes a non-inferior solution to the MOP.

2.2. Multiobjective optimization based on genetic algorithms

In an MOP, there may not exist one solution that is best with respect to all objectives. In view of the fact that none of the solutions in the nondominated set is absolutely better than any other, any one of them is an acceptable solution [15]. The choice of one solution over the other requires using an optimization technique.

Conventional optimization techniques, such as gradient and simplex based methods, and also less conventional ones, such as simulated annealing, are difficult to extend to the true multiobjective optimization case, because they were not designed with multiple solutions in mind. Evolutionary algorithms (EAs), however, have been recognized to be possibly well-suited to multiobjective optimization since early in their development. Multiple individuals can search for multiple solutions in parallel, eventually taking advantage of any similarities available in the family of possible solutions to the problem. The ability to handle complex problems, involving features such as discontinuities, multimodality, disjoint feasible spaces and noisy function evaluations, reinforces the potential effectiveness of EAs in multiobjective search and optimization, which is perhaps a problem area where evolutionary computation really distinguishes itself from its competitors [15].

One of the evolutionary computation techniques that works well with a population of points is GA. It is expected that they can find the Pareto-optimal front easily by maintaining a population of solutions, and search for many non-inferior solutions in parallel. This characteristic makes GAs very attractive for solving multiobjective optimization problems.

2.3. Load frequency control in multi-area power systems

In an isolated power system, the LFC task is limited to restore the system frequency to the specified nominal value. In order to generalize the isolated LFC model for interconnected power systems, the control area concept needs to be used as it is a coherent area consisting of a group of generators and loads, where all the generators respond to changes in load or speed changer settings, in unison [16]. Therefore, a large-scale power system consists of a number of interconnected control areas. Fig. 1 shows the block diagram of a three-control area power system, which includes 3 Gencos in each control area.

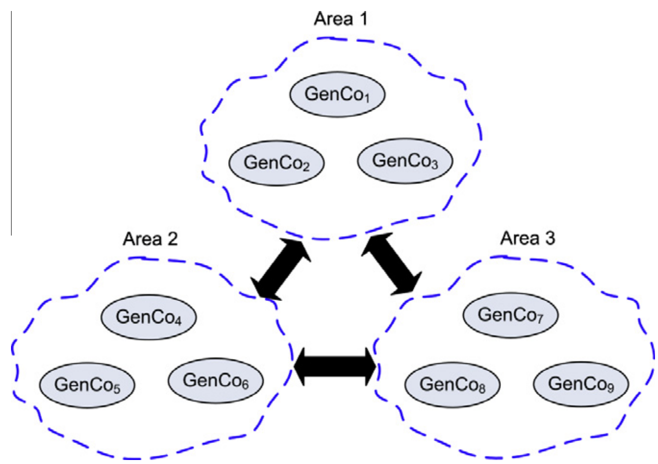

Fig. 1. A three-control area power system.

Following a load disturbance within a control area, the frequency of that area experiences a transient change, the feedback mechanism comes into play and generates appropriate rise/lower signal to make generation follow the load [16]. In the steady state, the generation is matched with the load, driving the tie-line power (ΔP_{tie}) and frequency deviations (Δf) to zero. The balance between connected control areas is achieved by detecting the frequency and tie-line power deviations to generate area control error (ACE) signal. The ACE for each control area can be expressed as a linear combination of tie-line power change and frequency deviation as follow [16],

$$\mathrm{ACE}_i = \beta_i \Delta f_i + \Delta P_{tie-i} \tag{1}$$

3. Problem formulation

3.1. Overview

A multi-area power system comprises areas that are interconnected by high-voltage transmission lines or tie-lines. The trend of frequency measured in each control area is an indicator of the trend of the mismatch power in the interconnection and not in the control area alone. The LFC system in each control area of an interconnected power system should control the interchange power with the other control areas as well as its local frequency [16]. According to above discussions, the main objectives for the LFC problem in a multi-area power system can be expressed as follow.

If the disturbance magnitude is greater than the available power reserve (supplementary control) i.e. $P_C < P_L$, the frequency deviation and tie line power changes do not converge to zero in steady state [16]. Therefore, the main goal of the LFC system in a multi-area power system is to converge each area's ACE signal to zero in steady state in the presence of load disturbance, and the multiobjective problem is reduced to optimize the PI controllers parameters, such that the ACE signals converge to zero in encountering the load disturbance too.

According to the above explanation, to have some degree of relative stability in all areas of a multi-area power system, the parameters of the PI controllers may be selected so as to minimize the objective function (2).