Load Frequency Control by using a new controller

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Abstract: In an interconnected power system, as a power load demand varies randomly, both area frequency and tie-line power interchange also vary. The objectives of load frequency control (LFC) are to minimize the transient deviations in these variables (area frequency and tie-line power interchange) and to ensure their steady state errors to be zeros. When dealing with the LFC problem of power systems, unexpected external disturbances, parameter uncertainties and the model uncertainties of the power system pose big challenges for controller design. Active disturbance rejection control (ADRC), as an increasingly popular practical control technique, has the advantages of requiring little information from the plant model and being robust against disturbances and uncertainties. In this paper an optimal load frequency controller for two area interconnected power system is presented to quench the deviations in frequency and tie line power due to different load disturbances. In classical LFC problems, PI type controllers are used to control of system. But due to some disadvantages of the PI type controllers, the researches are toward finding a better control scheme. Although many different advanced method have been carried out to LFC problem, but the industries are willing to use simple PI controllers. In this regard, PID type controller is used for LFC in this paper.
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1. Introduction

Power systems are used to convert natural energy into electric power. They transport electricity to factories and houses to satisfy all kinds of power needs. To optimize the performance of electrical equipment, it is important to ensure the quality of the electric power. It is well known that three-phase alternating current (AC) is generally used to transport the electricity. During the transportation, both the active power balance and the reactive power balance must be maintained between generating and utilizing the AC power. Those two balances correspond to two equilibrium points: frequency and voltage. When either of the two balances is broken and reset at a new level, the equilibrium points will float. A good quality of the electric power system requires both the frequency and voltage to remain at standard values during operation. For North America, the standard values for the frequency and voltage are *60 Hertz* and *120 Volts* respectively. However, the users of the electric power change the loads randomly and momentarily. It will be impossible to maintain the balances of both the active and reactive powers without control. As a result of the imbalance, the frequency and voltage levels will be varying with the change of the loads. Thus a control system is essential to cancel the effects of the random load changes and to keep the frequency and voltage at the standard values. Although the active power and reactive power have combined effects on the frequency and voltage, the control problem of the frequency and voltage can be decoupled. The frequency is highly dependent on the active power while the voltage is highly dependent on the reactive power. Thus the control issue in power systems can be decoupled into two independent problems. One is about the active power and frequency control while the other is about the reactive power and voltage control. The active power and frequency control is referred to as load frequency control (LFC).

Many control strategies for Load Frequency Control in electric power systems have been proposed by researchers over the past decades. This extensive research is due to fact that LFC constitutes an important function of power system operation where the main objective is to regulate the output power of each generator at prescribed levels while keeping the frequency fluctuations within pre-specifies limits. A unified tuning of PID load frequency controller for power systems via internal mode control has been proposed [1]. In this paper the tuning method is based on the two-degree-of-freedom (TDF) internal model control (IMC) design method and a PID approximation procedure. A new discrete-time sliding mode controller for load-frequency control in areas control of a power system has been presented [2]. In this paper full-state feedback is applied for LFC not only in control areas with thermal power plants but also in control areas with hydro power plants, in spite of their non minimum phase behaviors. To enable full-state feedback, a state estimation method based on fast sampling of measured output variables has been applied. The applications of artificial neural network, genetic algorithms and optimal control to LFC have been reported in [3-5]. An adaptive decentralized load frequency control of multi-area power systems has been presented in [6]. Also the application of robust control methods for load frequency control problem has been presented in [7-8]. In this paper PI and PID type controllers are simulated and compared. The parameters of the proposed controllers are tuned by using Tabu search (TS).

2. Plant model

Fig. 1 shows a two-control area power system which is considered as a test system. The state-space model of the system is as (1) [9].

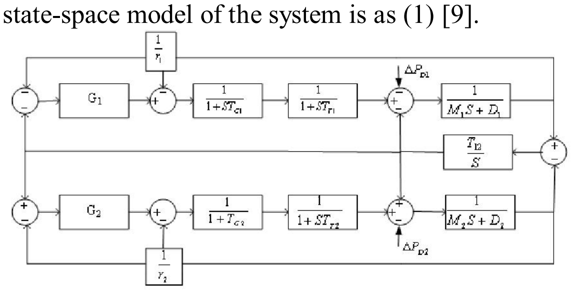

Figure 1: Two-area electric power system for LFC studies

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx \end{cases} \qquad (1)$$

Where:

$u = [\Delta P_{D1}, \Delta P_{D2}, U_1, U_2]$

$y = [y_1, y_2] = [\Delta f_1, \Delta f_2, \Delta P_{tie}]$

$x = [\Delta P_{G1} \quad \Delta P_{T1} \quad \Delta f_1 \quad \Delta P_{tie} \quad \Delta P_{G2} \quad \Delta P_{T2} \quad \Delta f_2]$

$$A = \begin{bmatrix} \frac{-1}{T_{G1}} & 0 & \frac{-1}{r_1 T_{G1}} & 0 & 0 & 0 & 0 \\ \frac{1}{T_{T1}} & \frac{-1}{T_{T1}} & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{M_1} & \frac{-D_1}{M_1} & \frac{-1}{M_1} & 0 & 0 & 0 \\ 0 & 0 & T_{12} & 0 & 0 & 0 & -T_{12} \\ 0 & 0 & 0 & 0 & \frac{-1}{T_{G2}} & 0 & \frac{-1}{r_2 T_{G2}} \\ 0 & 0 & 0 & 0 & \frac{1}{T_{T2}} & \frac{-1}{T_{T2}} & \\ 0 & 0 & 0 & \frac{1}{M_2} & 0 & \frac{1}{M_2} & \frac{-D_2}{M_2} \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & 0 & \frac{1}{M_1} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{M_2} \\ \frac{1}{T_{G1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{T_{G2}} & 0 & 0 \end{bmatrix}$$

The parameters of model, defined as follow:

Δ: Deviation from nominal value

M=2H: Constant of inertia

D: Damping constant

R: Gain of speed droop feedback loop

T_t: Turbine Time constant

T_G: Governor Time constant

G_1: First area controller

G_2: Second area controller

The typical values of system parameters for nominal operation condition are as follow:

$T_{T1} = T_{T2} = 0.03 \qquad T_{G1} = T_{G2} = 0.08$

$T_{P1} = T_{P2} = 20 \qquad R_1 = R_2 = 2.4$

$K_{P1} = K_{P2} = 120 \qquad B_1 = B_2 = 0.425$

$K_1 = K_2 = 1; a_{12} = -1 \qquad T_{12} = 0.545$

Where, the footnote 1 indicates first area parameters and footnote 2 indicates second area parameters and the parameters of two areas are considered equal.

The objectives are Design G_1 and G_2 in Load Frequency Control (LFC). As referred before, many methods have been carried out to design these controllers so far. In this paper PID type controller is considered to control of system. A Meta heuristic optimization method named TS is used to tuning the proposed controllers.

3. Design methodology

The PID controller performance is evaluated on the proposed test system given in section 2. The parameters of the PID controllers are obtained using TS. In the next subsection a brief introduction about TS is presented.

3.1. Tabu search

Tabu search (TS) was first presented in its present form by Glover. Many computational experiments have shown that TS has now become an established optimization technique which can compete with almost all known techniques and which - by its flexibility - can beat many classical procedures. Up to now, there is no formal explanation of this good behavior. Recently, theoretical aspects of TS have been investigated [10]. The success with TS implies often that a serious effort of modeling be done from the beginning. In TS, iterative procedure plays an important role: for most optimization problems no procedure is known in general to get directly an "optimal" solution.

The general step of an iterative procedure consists in constructing from a current solution x_i a next solution x_j *and* in checking whether one should stop there or perform another step.

In other hand, a neighborhood $N(x_i)$ is defined for each feasible solution x_i, and the next solution x_j is searched among the solutions in $N(x_j)$.

In this part we summarize the discrete TS algorithm in four steps. Assume that X is a total search space and x is a solution point sample and f (x) is cost function:

1- Choose $x \in X$ to start the process.

2- Create a candidate list of non-Tabu moves in neighborhood. (x_i, i=1,2,...,N)

3-Find $x_{winner} \in N(x)$ such that $f(x_{winner}) < f(x_i)$, $i \neq winner$.

4- Check the stopping criterion. If satisfied, exit the algorithm.

If not, winner $x = x_{winner}$, update Tabu List and then go to step 2.

In order to exit from algorithm, there are several criterions that are considered in our research.

1- by determining a predetermined threshold: If the value of cost function was less, algorithm would be terminated.

2- Determination of specific number of iterations.

3- If the value of the cost was remained invariable or negligible change for several iterations, algorithm would be terminated.

A didactic presentation of TS and a series of applications have been collected in [10].

3.2. controller adjustment using TS

In this section the parameters of the proposed PID controllers are tuned using TS. In optimization methods, the first step is to define a performance index for optimal search. In this study the performance index is considered as (2). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (*ITAE*).

$$ITAE = \int_0^t t|\Delta\omega_1|dt + \int_0^t t|\Delta\omega_2|dt \quad (2)$$

It is clear to understand that the controller with lower ITAE is better than the other controllers. To compute the optimum parameter values, a 10 % step change in ΔP_{D1} is assumed and the performance index is minimized using TS. It should be noted that TS algorithm is run several times and then optimal set of parameters is selected. The optimum values of the PID parameters are obtained using TS and summarized in the Table 1.

Table 1. Optimum parameters of PID controllers

	K_P	K_I	K_D
First area	13.43	45.71	1.04
Second area	6.22	70.23	1.10

In order to comparison and show effectiveness of the proposed method, PI type controller optimized by TS is incorporated for LFC. The optimum value of the PI controllers Parameters are obtained and summarized in the Table 2.

Table 2. Optimum values of K_P and K_I for PI controllers

	K_P	K_I
First area	11.7321	43.1291
Second area	5.5099	66.7739

4. Results and discussions

The results are carried out on the multi area test system with the proposed PID and PI controllers. Three operating conditions are considered for simulation as follows:

i. Nominal operating condition

ii. Heavy operating condition (20% changing parameters from their typical values)

iii. Very heavy operating condition (40% changing parameters from their typical values)

In order to demonstrate the robustness of the proposed method, The *ITAE* is calculated following step change in the demand of first area (ΔP_{D1}) at all operating conditions (Nominal, Heavy and Very heavy) and results are listed at Table 3. Following step change, the PID controller has better performance than the PI controller at all operating conditions.

Table 3. 10% Step increase in demand of first area

	The calculated ITAE	
	PID	PI
Nominal condition	0.0025	0.0055
Heavy condition	0.0041	0.0681
Very heavy condition	0.0066	0.0112

Figure 2 shows $\Delta\omega_1$ at nominal, heavy and very heavy operating conditions following 10 % step change in the demand of first area (ΔP_{D1}). Each figure contains two plots as solid line for PID controller and dashed line for PI controller. It is seen that the PID controller has better performance than the other method at all operating conditions.

5. Conclusions

This paper presented the application of a new control scheme for LFC problem. PID type controller has been successfully carried out for LFC problem. The parameters of the proposed PID controller have been tuned by using TS. The proposed PID controller had significant priority rather than PI controller. The simulation results which have been carried out on a two-area electric power system showed the viability of PID controller. The PI controller is the most commonly used controller in the industry and practical systems, therefore the paper's results can be used for the practical LFC systems.

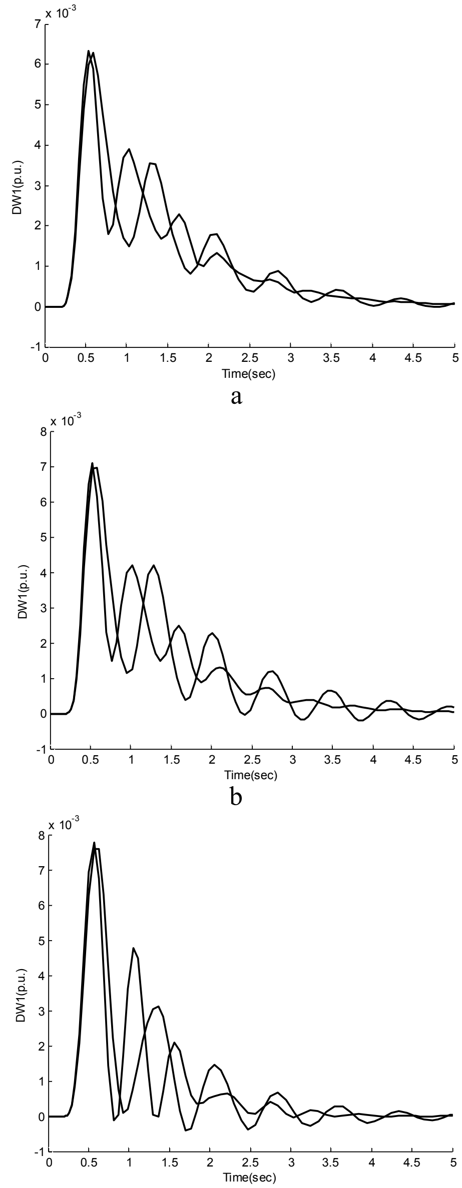

Figure 2: Dynamic response $\Delta\omega_1$ following step change in demand of first area (ΔP_{D1})
a: Nominal b: Heavy c: Very heavy
Solid (PID controller), Dashed (PI controller)

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