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PARAMETER OPTIMIZATION OF PI SLIDING MODE AGC OF MULTI-AREA POWER SYSTEMS

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Abstract. An approach to parameter optimization of PI sliding mode load control used for Automatic Generating Control (AGC) of multiarea power systems with nonlinear elements has been proposed. The method has the advantages of PI and sliding mode control. Instead of using traditional analysis algorithm to obtain the controller parameters, a single-input single-output (SISO) nonlinear optimization technology is introduced and a robust PI parameter formula is derived. MATLAB Nonlinear Control Design (NCD) toolbox is used as the PI parameter optimization tool to deal with the interconnection of the SISO AGC loops. The nonlinear objects such as generation rate constraint (GRC) and deadband of the turbine governor are treated easily with the help of NCD. The proposed optimizing method is suitable for power system engineering applications. The simulation of a two-area power systems is reported and the results are reasonable. Copyright@2002 IFAC

Keywords. Automatic Generating Control, Sliding Mode Control, PI controller, parameter optimization

1. INTRODUCTION

Automatic Generating Control (AGC) is a very important component in power system operation and control for supplying sufficient and reliable electric power with good quality. To ensure satisfactory control of area frequencies and interarea tie line transfers is one of the main requirements of interconnected power system. Errors in the quantities arise due to unpredictable load variations which cause mismatch between the generator output and load demand. One of the tasks of AGC is to minimize the transient deviations and to ensure zero steady state errors of these two variables [1]. Many control strategies have been proposed based on linear control theory. However, because of the inherent characteristics of the load changes, the operating point of a power system may move a lot during a daily cycle. Some authors have applied the variable structure control [2,3] to make the controller insensitive to the system parameter changes. However, this method requires the information of the system states which are very difficult to predict and collect completely. In a recent paper [4] the PI sliding mode load frequency control of multiarea power system is presented, but there a conventional analysis method is adopted and the PI parameter setting is based on the state space model of the power system. When considering the generator rate constraint (GRC) and deadband, the calculation of this state feedback gain PI controller parameter is complex and onerous, and not easy to be used to the engineering environment.

All those motivate a more practical approach for parameter optimization of PI sliding mode load control used in AGC of multiarea power systems. The method proposed in this paper has the advantages of both PI and sliding mode control for both linear and nonlinear systems. The single-input single-output (SISO) technology is introduced and a robust PI parameter formulae is derived. MATLAB Nonlinear Control Design (NCD) toolbox [5] is used as the PI parameter optimization tool to deal with the interconnections between the SISO AGC loops. This will enable the engineers to use the vast amount of knowledge that has been gathered with MATLAB from several decades of research into engineering practice. Sliding mode superface with integral item could make the system reach on sliding mode from initial time. After reaching on sliding mode, the system will be controlled by PI controller based on ACEN as prescribed in [6]. When considering the nonlinear elements such as generator rate constraint (GRC) and deadband of the turbine governor, the proposed optimizing method is easily realized to engineering application and it will insure the system have good performance. The simulation of a two-area power systems is reported and the results are reasonable.

Next section is the background of sliding mode PI algorithm for ACEN in multiarea power systems. The equivalence is derived that connects traditional PI control to sliding mode control in AGC system. Then the interconnection of AGC loops in multiarea power systems is decoupled to SISO loops, and a robust PI parameter optimization formula for the AGC SISO system is derived. MATLAB NCD optimization realization for the nonlinear generator rate constraint (GRC) and deadband is presented in section 4, and last section draws some conclusions.

2. The EQUIVALENCE OF PI AND SLIDING MODE CONTROL IN AGC

Area Control Error (ACE) is a basic concept in power system load frequency control [1]. Although Kothari et al have proposed a more feasible technique for coordinating system-wide corrections of time error and inadvertent interchange [2], the modified expression for Area Control Error (i.e. new ACE or ACEN) is widely applied in recent years. For using PI control of the AGC, the ACEN of area *m* could be expressed as [2]:

$$ACE_m = \Delta P_{tiem} + B_m \Delta F_m + a_m \varepsilon_m + \alpha_m I_m \qquad (1)$$

where ΔP_{tiem} is the incremental change in tie-line power, B_m the frequency bias constant, ΔF_m the incremental frequency change, a_m the time error bias setting, ε_m the time error, α_m the inadvertent interchange bias setting, and I_m the inadvertent interchange accumulation, and *m* is the area. Because the ACEN in (1) is not obvious for engineering application, it can be changed by:

setting $$a_m / \alpha_m = 60 B_m \ , \qquad (2)$$

and $$\begin{cases} \varepsilon_m = \dfrac{1}{60}\int \Delta F_m \mathrm{dt} \\ I_m = \int \Delta P_{tiem} \mathrm{dt} \end{cases} , \qquad (3)$$

then (1) can be rewritten in a unified form:

$$ACE_m = \Delta P_{tiem} + B_m \Delta F_m + \alpha_m \int (\Delta P_{tiem} + B_m \Delta F_m) \mathrm{dt} \qquad (4)$$

This ACE_m is different from the conventional ACE. It is easy to see that the new ACE in area *m* is the summation of the conventional ACE and its integration with α_m. The control of ACE_m will guarantee zero steady state time error and inadvertent interchange. It is suitable to design the controller in PI form as:

$$U_m(t) = -K_{mp} ACE_m(t) - K_{mi} \int ACE_m(t) \mathrm{dt} \qquad (5)$$

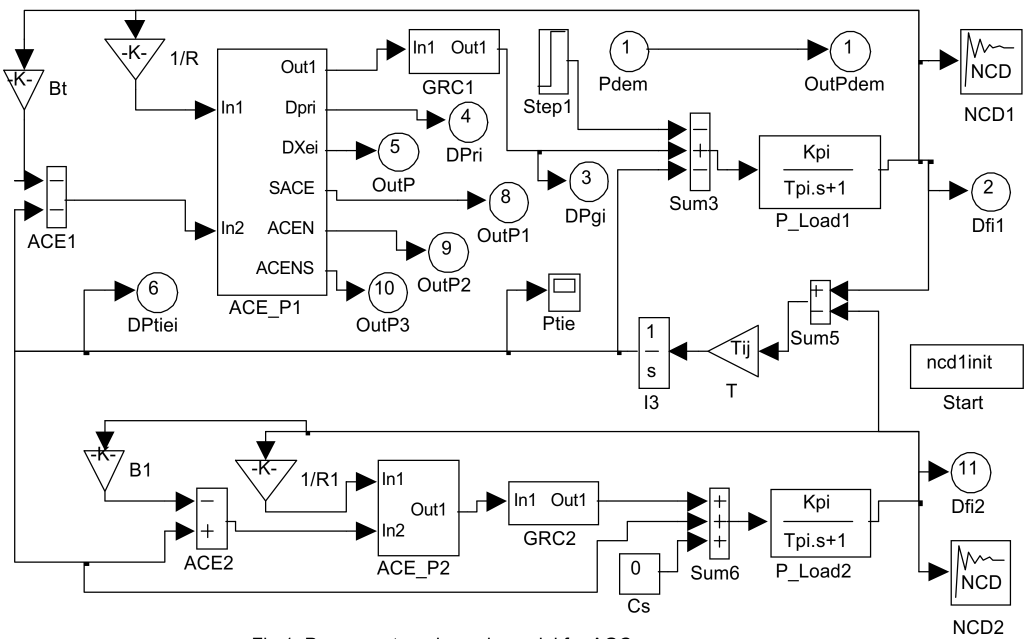

Fig 1 Power system dynamic model for AGC

This equation is familiar to process control engineers. The tuning of the parameters of K_{mp} and K_{mi} with sliding mode depends on the ACE_m (i.e. ACEN) and the model of the interconnected power systems.

Generally, the interconnected power systems can be modeled by [5] as:

$$\dot{X} = AX + Bu + F\Delta P_d \tag{6}$$

with $X(0) = 0$, and $X = [X_1, X_2, \cdots, X_n]^T$, $u = [u_1, u_2, \cdots, u_n]^T$, $\Delta P_d = [\Delta P_{d1}, \Delta P_{d2}, \cdots, \Delta P_{dn}]^T$

where X, u, ΔP_d are state vector, control vector, and load disturbance vector respectively. The parameters of the system are:

$$X_i = \left[\Delta f_i, \Delta P_{gi}, \Delta P_{ri}, X_{ei}, \Delta P_{tiei}, \int ACE_i dt, \int ACEN_i dt, ACEN_i\right]^T$$

and

$$A = \begin{bmatrix} A_{11} & A_{12} & \Lambda & A_{1n} \\ A_{21} & A_{22} & \Lambda & A_{2n} \\ & M & & \\ A_{n1} & A_{n2} & \Lambda & A_{nn} \end{bmatrix};$$

$$B = [B_1, B_2, \Lambda\ , B_n]^T;$$

$$B_i = \begin{bmatrix} 0 & 0 & \dfrac{K_{ri}}{T_{gi}} & \dfrac{1}{T_{gi}} & 0 & 0 & 0 & 0 \end{bmatrix}^T;$$

$$F = [F_1, F_2, \Lambda\ , F_n]^T;$$

$$F_i = \begin{bmatrix} -\dfrac{K_{pi}}{T_{pi}} & 0 & 0 & 0 & 0 & 0 & 0 & -\beta_i \dfrac{K_{pi}}{T_{pi}} \end{bmatrix}^T;$$

for *i=1, 2, …, n* and *n* is the number of interconnected power systems. The sliding mode control for area *i* can be designed as [5]

$$S_i = B_i^T X_i - B_i^T \int_0^t (A_{ii} - B_i K_i) X_i(\tau) d\tau \tag{7}$$

if assign $K_i = [0,0,0,0,0,0, K_{iI}, K_{iP}]$, where K_{iI} and K_{ip} is the PI controller parameter as indicated in (5), then the sliding mode control is equivalent to a traditional PI control.

3. ROBUST OPTIMIZATION OF PI CONTROLLER PARAMETER IN AGC

Generally speaking, the sliding mode control parameters K_i in (7) can be calculated from the state equation (6) according to the linear system theory. But in the engineering environment, nonlinear objects such as GRC and governor-turbine

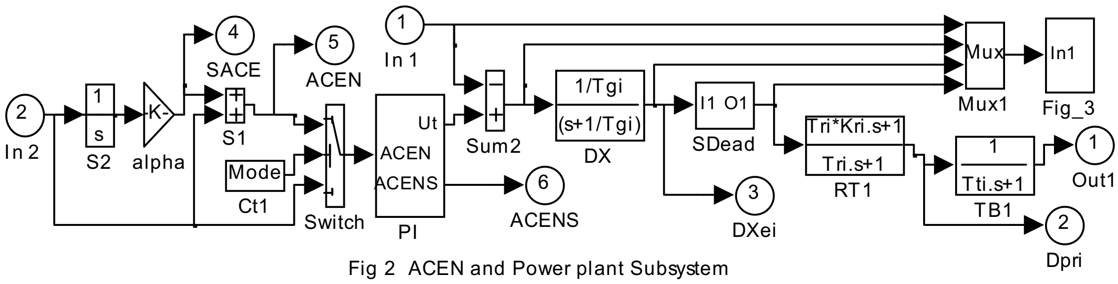

Fig 2 ACEN and Power plant Subsystem

deadband often force the theory analysis onerous or even impossible. By Comparing the equation (5) with (7), a classical technique of feedback control with modern commercial software such as MATLAB/Simulink could be adopted to solve the nonlinear problem. Fig. 1 is a MATLAB/Simulink feedback control strategy of load frequency AGC control, where ACEN in (1) and power plant model is simulated in a subsystem named ACE_P1 and ACE_P2. The difference between ACE_P1 and ACE_P2 is that more state variables are outlined in ACE_P1 for observation. ACE1 and ACE2 are constructed as in (4). GRC1 and GRC2 are nonlinear generator rate constraint. Step block presents the demand power in the real system for optimization, while Pdem for power demand is used for simulation. P_load1 and P_load2 are short for power load in area 1 and area 2. More details about ACE_P1 are shown in Fig. 2. Where alpha stands for α_m, the inadvertent interchange bias setting in (4). Mode switch (Ct1) is used for comparing the tradition ACE with new ACEN as indicated in (4). In fig.2 PI is the controller and Ut, which stands for Um(t) in (5), is the output of the controller. SDead is the deadband for boiler-turbine governor. The time constants for governor (DX), reheat turbine generator (RT1 and TB1) are all indicated in the figure. The multiarea system could be treated as some single input single output (SISO) systems which regarding the tie line power as disturbance and the governor turbine generator (GTB) with the power system load as the control object. The simplified SISO system is shown in Fig. 3. The control of multiarea AGC system is then transferred to the control of each SISO system while attenuating the interaction of each ACE loops. Note that here the reference input R(t) is always zero for the unit feedback system output ACEN. Taking ACEN as output and Ut as input in Fig.2 could make the identification of the dynamic response of the AGC system in area m independent. Thus the determination of the controller parameter is switched to tuning the PI parameter under the restriction of disturbance rejection. The optimal performance with robust control can be reached by many algorithms. In the case MATLAB Nonlinear Control Design (NCD) toolbox is used to refine the PI controller parameters as in Fig. 1, the parameter initial value is very important because the inherent nonlinear characteristic of the power systems will affect the global convergence values.

In order to obtain the PI parameter initial value, define the sensitive factor as [7]

$$M_s = \max\{\mathrm{abs}(1/(1+G_T(s)G_p(s)))\}_{s=jw}\ , \qquad (8)$$

where $G_T(s)$ and $G_p(s)$ represent the PI controller and the plant transfer function as identified from Fig.2 respectively. By using the integration error (IE) as the performance criteria, the optimal PI parameters are given as [7]

$$K_{ip} = -\alpha(\omega)/\gamma^2(\omega) \qquad (9)$$

$$K_{iI} = -\omega\beta(\omega)/\gamma^2(\omega) - \omega R/\gamma(\omega) \qquad (10)$$

The detail of the algorithm will be found in [7]. Using (9) and (10) as the DCS initial values, the main optimization steps are summarized as follows:

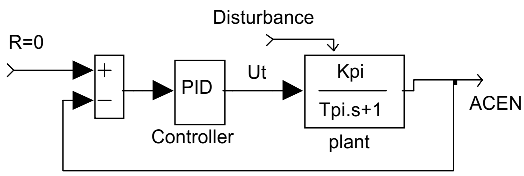

Fig 3 SISO system model for AGC

1) Initialize the NCD by double click the Start box (ncd1init) in Fig. 1. After identifying the SISO plant dynamics, the PI controller initial parameters for NCD optimization will be obtained;
2) Simulate the plant to check the output plot to make sure that the simulation is reasonable and coincident with the real process;
3) Run NCD to improve or refine the values of the optimization variables;
4) Compare the results with what the real process possesses to see whether the optimization is reasonable and acceptable, so as to decide to exit or go back to revise the initial values and do from the first step again.

4. SIMULATION AND APPLICATION

To show the approach proposed above, some simulations have been carried out for a two-area interconnected AGC power system structured as in Fig.1. The parameters for the simulation are [4]: *Tpi*=20s; *Tgi*=0.08s; *Tri*=10s; *Tti*=0.3s; *Kri*=0.5; *R*=2.4; *Kpi*=120Hz/pu; $2\pi T_{ij}$ =0.545; *Bi*=0.425.

The PI parameters used as the initial value in the simulation without nonlinear elements are Kip1 Kii1 Kip2 Kii2 and alpha for area 1 and 2 respectively. The GRC as a rate limit and the turbine-governor deadband are also considered, seeing Fig. 2. The frequency control in the neighborhood area is assumed to be perfect [9]. The demand measurement of the well behaved part of the load was assumed to be constant, and the demand from one highly varying load was superimposed on the constant part of the demand. The PI controller in the simulation can use the ACE or ACEN by switching the mode variable, as indicated in Fig. 2. No active load control capability was assumed.

MATLAB NCD initial values for PI optimum parameters are programmed in the initial file, using the algorithm (9) (10). The NCD initial values are also available from existing SCADA system in real practice. Note that if initial parameters are not suitable, the NCD could not converge to the global optimal values. A sample of NCD optimization

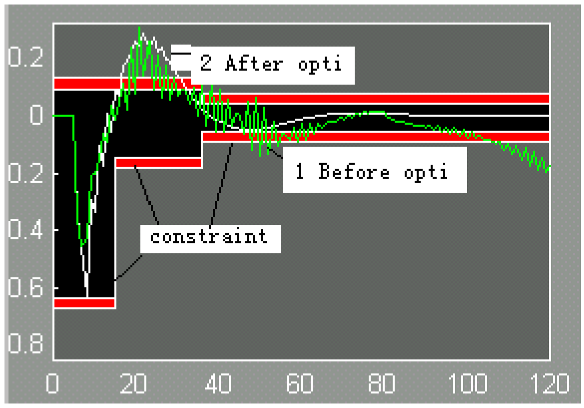

Fig. 4 Optimization using NCD

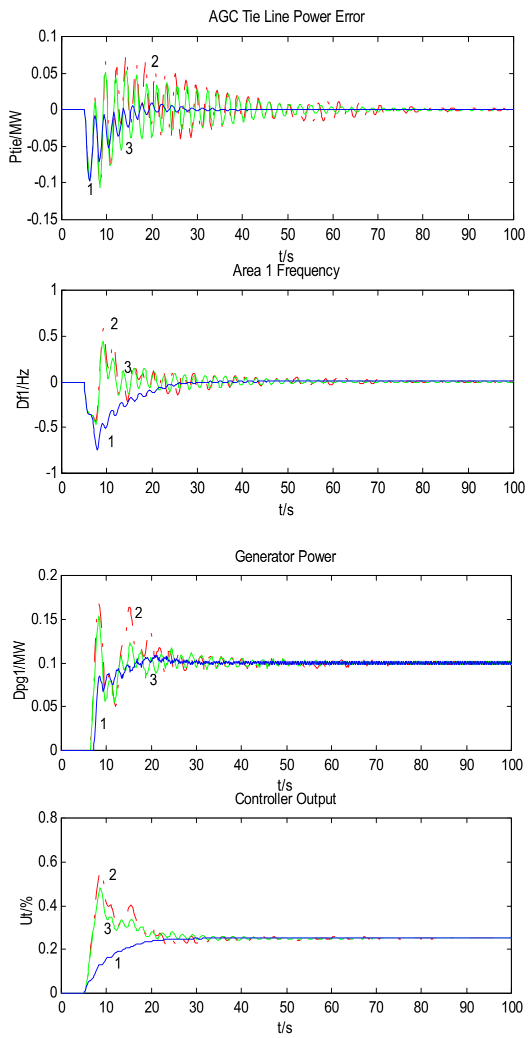

Fig. 5 Power System AGC Optimization Simulation

curve is shown in Fig. 4. The NCD Outport is set for disturbance rejection. The result plots after optimization are presented in Fig.5. There are 3 curves in the each Figure. Dashed line 1 is for parameters Kip=0.15;Kii=0.02;Kip1=0.15;Kii1=0.02; alpha=0.03, and the dash-dot line 2 for Kip=0.04583; Kii=0.0275;Kip1=0.1366;Kii1=0.0093;alpha=0.0140;

and line 3 for mode ACE (without the integration of ACE). The Figure is consisted of 4 selected variables. First is AGC Tie Line Power Error (*Dptie*); second one is frequency of area 1; third one is Generated Power in area 1, and the fourth one is the controller output Ut. The interaction between area 1 and area 2 could be coordinated by NCD PI optimization. The simulation is successful for many trails. Note that the curve 1 is slower than others, while the curve 2 and 3 are fast but with oscillations. The results have shown the availability of NCD used in the AGC nonlinear system optimization.

From the simulation as shown in Fig.5, some discussions now are obtained. First, MATLAB NCD toolbox is a feasible tool for nonlinear system optimization in engineering. The virtualized Human-Machine Interface (HMI) makes it easily be used. Secondly, as shown in Fig.5, the optimal values for a given nonlinear system will different and the responses of the system will change a lot. In order to get the better results, MATLAB options for the optimization toolbox should be set properly. If the results are not satisfied by the parameter optimization, then the control system structure should be improved accordingly.

5. CONCLUSION

The approach to parameter optimization of PI sliding mode load control used for AGC of multiarea power systems proposed in this paper has the advantages of PI and sliding mode control. The SISO technology is introduced and PI parameter equivalence is derived. MATLAB NCD toolbox has successfully been used as the PI parameter optimization tool to deal with these interconnection of the SISO loops. The generation rate constraint (GRC) and turbine deadband are easily considered in the system. The optimizing method is easy to make the system have good performance in engineering application. The simulation of a two area power system is reported and the results are reasonable.

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BIOGRAPHIES

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