MATEC Web of Conferences –A New Networked AGC Control Method Based on Time-Lag Model Predictive Control

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Abstract. This paper proposes a time-lag model predictive control (MPC) method to solve the problem of communication delay in networked automatic generation control (AGC). The method uses the optimum weighting method to predict delay and the time-lag dynamic state equation of interconnected grid as the MPC prediction model. Then the deviation of predicted output is added to the objective function of rolling optimization in MPC method. The backup suboptimal control command from MPC controller can handle the loss of data packet in networked AGC. The correctness of the proposed method is verified by dynamic simulation.

1 Introduction

The traditional AGC uses dedicated communication links, and it is unnecessary to consider the influence of communication delay upon the traditional AGC system [1]-[3]. The networked AGC based on the wide area information network is used for the secondary frequency regulation and the tie line flow schedule in the smart grid due to its openness, high information sharing level, flexible control, and so on [4], [5]. However, compared with the traditional AGC systems, where control system components are usually connected dedicated channels, the main problems of the introduction of networked AGC are time-varying communication delay and packet sequence error and loss [1].

The lost of AGC system stability and its dynamic performance degradation will be caused by the time delay. Using the distributed MPC control to realize the AGC of interconnected network, the results show the AGC with MPC strategies has better dynamic control performance in [6], whereas it hasn't consider the time delay for the networked AGC. In this paper, the nonlinear and time delay model predictive control method is put forward for the networked AGC system with the uncertain time delay. This control strategy adopts the time delay state equation of AGC system as the prediction model. The optimal weighted method is used to predict the communication delay. Besides, the optimization objective function is improved by increasing the deviation of output predicted value. The proposed method is verified using the dynamic simulation software MATLAB/Simulink.

2 AGC dynamic model with communication delay

According to the theory of AGC modeling, two-area interconnected power system AGC dynamic model considering communication delay is built, shown in Figure 1. The secondary frequency regulation is implemented by hydroelectric generator, and each area is equal to one generator set. T_{gi} is the time constant of speed controller, T_{chi} is the time constant of prime mover, R_{i} is the unit difference adjustment coefficient, B_{i} is the difference adjustment coefficient of system, M_{i} is rotary inertia, D_{i} is the damping factor of load, ΔP_{ti} is output power increment of prime mover, ΔX_{gi} is location increment of speed controller, ΔP_{ci} is MPC controlling output variable, ΔP_{L} is increment of load variable, Δf_{i} is frequency deviation, ΔP_{t12} is the tie-line exchange power, ACE_{i} is area control error, T_{12} is tie-line synchronism index and τ_{i} is the time of communication delay from speed controller to actuator. The buffer is configured to store MPC multi-step preceding predictive control command sequence in the signal receiver of power plant to compensate for the wide area network random data packet loss.

3 Time-Lag MPC controller design for networked AGC system

3.1. Delay prediction

The communication delay caused by the closed and static local area network, which has distinct impact on networked AGC performance, will randomly fluctuate at a certain slight range. The optimum weighting method, which has the advantages of high accuracy in prediction, less computation and suitability for on-line analysis, is adopted in this paper to achieve the prediction value of communication delay for the online rolling optimization of time lag MPC. It takes predictive error e_{k} as the objective function and gets the weight ω_{j} on the basis of minimum and maximum principle. The optimum weighting model can be described as:

$$\min\ e_k = 1/2\,(\tau_k' - \tau_k)^2 = 1/2\,(\sum_{j=1}^{k-1}\tau_j'\omega_j - \tau_k)^2,\ \sum_{j=1}^{k-1}\omega_j = 1 \tag{1}$$

Where τ_{k} is the delay observations at time k, τ_{j}' is the delay estimates at time j, ω_{j} is the weight coefficient of delay observations at the different time.

Then the next delay predictive value $\tau_{\mathrm{k+1}}$ can be calculated as a weighted sum of delay observations sequence by equation (2).

$$\tau_{k+1} = \sum_{j=1}^{k} \omega_j \tau_j \tag{2}$$

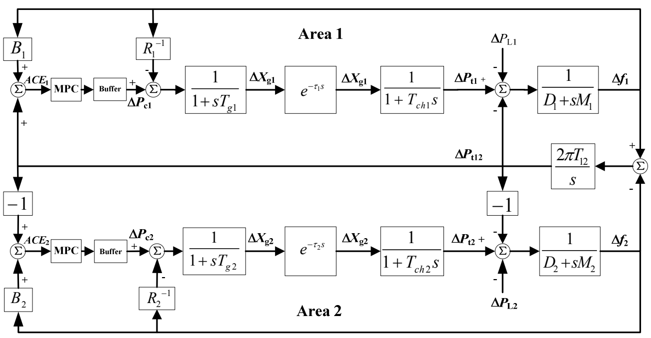

Figure 1. A two-Area interconnected power system AGC dynamic model with communication delay

3.2 Predictive model

Change the time lag state equation of networked AGC system to the controlled auto-regressive moving average (CARMA) model as follows [7]:

$$\boldsymbol{A}(z^{-1})\boldsymbol{y}(k) = z^{-d}\boldsymbol{B}(z^{-1})\boldsymbol{u}(k) + \boldsymbol{\omega}(k) \tag{3}$$

Where $\boldsymbol{y}(k)$ and $\boldsymbol{u}(k)$ stand for the output row vector composed by n (n=5) output quantities and the column vector composed by m (m=2) controlled quantities in AGC state equation at time k. $\boldsymbol{\omega}(k)$ is the white noise vector. That $d=[\tau/T]+1$ is the system time lag factor ($[\tau/T]$ is an integer less than τ/T), τ is the predicted delay of the next signal and T is the sampling time of discrete system.

3.3 Rolling optimization

The TBC control mode of AGC system will take the balance of power in the sub-region as example in the paper. The tracking target of all the output quantity is zero. In order to speed up AGC tracking and avoid generator regulation frequently, we improve the output quantity of MPC optimization function to two parts, predictive output errors and output predictive value increment, and increase the weight of predictive output increment to adjust the increment of controlled quantity predictive sequence and decrease unnecessary regulation of the generator. According to the above method, the rolling optimizing objective function can be improved as:

$$\min J = \sum_{j=1}^{N}\left\|\boldsymbol{y}(k+j|k)\right\|^2 + \sum_{j=1}^{N} k_j \left\|\boldsymbol{y}(k+j|k) - \boldsymbol{y}(k+j-1|k)\right\|^2 + \sum_{j=0}^{M-1}\lambda_j \left\|\Delta\boldsymbol{u}(k+j)\right\|^2 \tag{4}$$

Where k_j and λ_j are the weight value. The rolling optimization calculates the control increment $\Delta\boldsymbol{u}$ to meet the above objective function by embedding an optimization solution in each sampling, and then achieve the MPC optimum control law.

3.4 Feedback compensation

Considering the uncertainty of disturbance and nonlinearity of the random time-lag system, after the effect of control action at time k-1, we can get the error vector $\boldsymbol{e}(k)$ by subtracting the predicted output value $\boldsymbol{y}(k|k\text{-}1)$ from the actual output value $\boldsymbol{y}_0(k)$ as:

$$\boldsymbol{e}(k) = \boldsymbol{y}_0(k) - \boldsymbol{y}(k|k-1) \tag{5}$$

The initial predicted value at other time can be revised with the error vector $\boldsymbol{e}(k)$, as equations(6). And the revised vector $\boldsymbol{y}(k)$ will serve as the initial value of rolling optimization in the future time. The initial predicted value should be revised, when the actual output is measured at each sampling time, in order to turn MPC system into the closed-loop feedback system.

$$\boldsymbol{y}(k) = \boldsymbol{y}(k|k-1) + \boldsymbol{e}(k) \tag{6}$$

3.5 Buffer of control sequence

A buffer is installed in the signal receiver of generator actuator unit in order to save the multi-step predictive control command sent from MPC controller. The stored signal is the suboptimal control command when the data packet loses of wide area network in networked AGC. The operating principle is shown in Fig. 2.

(1) When receiving new data packet, the buffer will compare the time scale of the new and original data packet. The buffer memory will update the store contents if the time scale of new data packet is later than that of original one, other it will be shown as mis-sequence and be abandoned.

(2) The actuator follows the fixed cycle T to scan the control information in buffer. As shown in Fig. 2, the data packet of buffer will not update if it is lost or in mis-sequence, and the actuator will read the next step predictive command in original data packet as the suboptimal control command. When the network service and data packet update is normal, the actuator will choose the best predictive control command in the corresponding step length of communication delay as input through the time scale comparing. Actuator scans and reads the predicted command of control quantity repeatedly just like this.

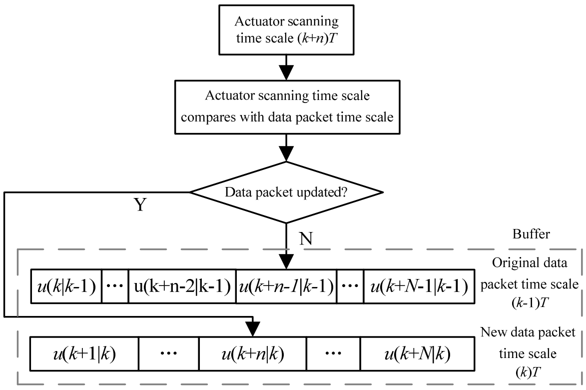

Figure 2. The principle of actuator reading the control command in buffer

4 Simulation results

A networked AGC system dynamic model of two area interconnected power system under the TBC control model is constructed as shown in Figure 1, which uses MPC functional toolbox in MATLAB/Simulink. The time-lag model predictive controller is designed according to the proposed method using the rolling optimizing objective function in equation (4). And the detail parameters of the model are listed in appendix B. Set the efficiency factor γ=0.9, the sampling period T=0.1s, the prediction horizon N=15, the control horizon M=10, k_j=5 and λ_j=1.

The correctness of the proposed method is verified by the following three cases in the paper, respectively: (1) Case 1 is comparing the step response test of networked AGC system adopting the traditional MPC and time lag MPC in the surrounding of random communication delay; (2) Case 2 is the test in the surrounding of maximum communication delay for investigating the adaptability to the communication delay; (3) Case 3 is the robustness test with the loss of data packet and the change of networked AGC system parameters. Due to space limitation, we just introduce the Case 1.

Case 1:

The random communication delay sequence in Fig.3 is adopted in case 1. Exerting the step load disturbance that ΔP_{L1}=0.03p.u. and ΔP_{L2}=0.01p.u. in area 1 and area 2 when t=0.01s. The proposed method and the traditional MPC method are used for the simulation in order to compare the dynamic response performance of networked AGC. The traditional method is the generalized MPC control method without the communication delay prediction, the time lag prediction model and the modified objective function. The response curves of each area output quantity with different control methods are shown from Fig. 4 to Fig. 7.

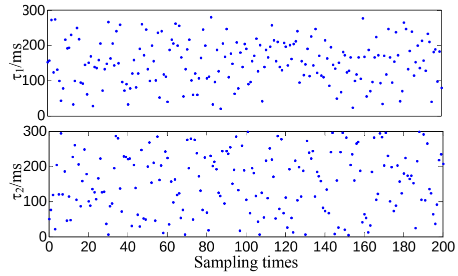

Figure 3. The random communication delay sequence in case 1

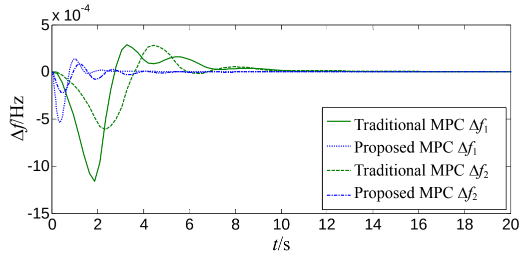

Figure 4. The frequency deviation responses in case 1

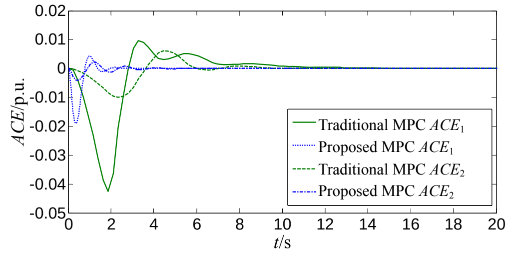

Figure 5. The area control error responses in case 1

Fig. 4 and Fig. 5 show the frequency deviation and area control error response. Compared with the traditional MPC method in Fig. 4, the frequency response with the proposed method obviously has the lower overshoot and shorter adjustment time of frequency fluctuation in each area. Similarly, ACE of the AGC system with the proposed method has the lower overshoot and shorter adjustment time. In addition, the number of generator adjusting action is also reduced. As shown in Fig. 6, the tie-line exchange power with the proposed method needs only 8s to recover, while that with the traditional method needs 18s. Besides the overshoot of exchange power with the proposed method is much lower than that with traditional method.

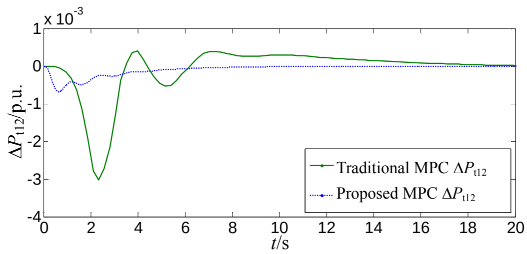

Figure 6. The tie-line switching power responses in case 1

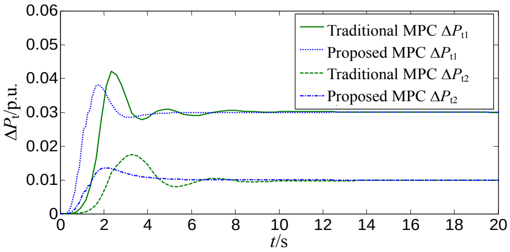

Figure 7. The tie-line switching power responses in case 1

The dynamic performance of generator unit to the load disturbance with the proposed method has obvious improvement in Fig. 7. The simulation results show that the proposed method can equip the networked AGC system with excellent dynamic performance under the condition of random communication delay, and hence the proposed method is effective.

5 Conclusion

Aiming at the problems of communication delay and data packet loss of networked AGC system, this paper proposes a new control method for interconnected power system networked AGC control, which is based on time-lag model predictive control to realize the online rolling optimization control and supply the effective prediction compensation control command for communication delay. And the buffer provides the suboptimal control command when the date packet loses.

According to the simulation results of test cases with random communication delay, maximum communication delay and loss of data packet, it is clear that the proposed method can maintain the networked AGC system with excellent dynamic response to the random and severe communication delays conditions. The proposed method has stronger robustness than the traditional MPC method under the operating condition changing of AGC system. Thus, the proposed method is corrective and effective, and has strong adaptability and robustness for the fluctuations of communication delay.

References

[1] Jiang L., Yao W., Wu Q.H., et al: Delay-dependent stability for load frequency control with constant and time-varying delays, IEEE Trans. Power Syst., 2012, 27, (2), pp. 932-941.

[2] Bevrani H., Hiyama T. On load-frequency regulation with time delays: Design and real-time implementation, IEEE Trans. Energy Convers., 2009, 24, (1), pp. 292-300.

[3] Bhowmik S., Tomsovic K., Bose A. Communication models for third party load frequency control, IEEE Trans. Power Syst., 2004, 19, (1), pp. 543-548.

[4] Mohagheghi S., Venayagamoorthy G.K., Harley R.G. Optimal wide area controller and state predictor for a power system, IEEE Trans. Power Syst., 2007, 22, (2), pp. 693-705.

[5] Saikia L.C., Mishra S., Sinha N., et al. Automatic generation control of a multi area hydrothermal system using reinforced learning neural network controller, Int. J. Electr. Power Energy Syst., 2011, 33, (4), pp. 1101-1108.

[6] Bevrani H., Hiyama T. Robust load-frequency regulation: A realtime laboratory experiment, Optimal Control Appl. Methods, 2007, 28, (6), pp. 419–433.

[7] Hess R.A., Jung Y.C. Application of generalized predictive control to rotorcraft terrain-following flight, IEEE Trans. Syst. Man Cybern., 1989, 19, (5), pp. 955-962.