On Robust Load Frequency Regulation In a New Multi-Machine Power System Structure

Hassan Bevrani*, Yasunori Mitani and Kiichiro Tsuji (Osaka University)

1. Abstract

The siting of numerous generator units in distribution areas is being encouraged by the current deregulation of the industry is likely to have an impact on the frequency regulation of the existing power systems, which designed to operate with large and central generating facilities. An approach based on μ-synthesis technique is proposed for the design of robust load frequency controller in response to the new Load Frequency Control (LFC) technical demand for multi-machine power systems. An example for a multi-machine area is given to illustrate the proposed approach. The resulting controller is shown to minimize the effect of disturbances and achieve acceptable frequency regulation in presence of uncertainties and load variation.

2. Introduction

Currently, the electric power industry is in transition from large, vertically integrated utilities providing power at regulated rates to an industry that will incorporate competitive companies selling unbundled power at lower rates. On the other hand with increasing the various demands the number of small and large generators in private or regular format is increased. These changes introduce a set of significant uncertainties in power system control and operation, especially on LFC problem solution. The classical LFC based on the conventional Area Control Error (ACE) is difficult to implement in the new structure and comes the need for novel control strategies to maintain the reliability and eliminates the frequency error (Δf). Under current organization, several scenarios are recently proposed by authors [1-3].

This paper addresses the new design of robust load frequency controller based on μ-synthesis technique for a possible structure in the new multi-machine environment. The new power system structure consists of a collection of control areas interconnected through high voltage transmission lines or tie-lines. Each control area has its own load frequency controller and is responsible for tracking its own load and honoring tie-line power exchange contracts with its neighbors.

Therefore, according to this scenario the large scale power system is divided to some distribution areas and each area-system is modeled as a collection of independent generator units to supplying the area-load. In the proposed strategy one generator unit is responsible for tracking the load and hence performing the load frequency control task by securing as much transmission and generation capacity as needed. We will discuss on area example including three generator units and we will show that designed controller guarantees robust stability and robust performance for a wide range of operating conditions.

3. Design Methodology

The objective is to formulate the LFC problem as a μ-control design problem. To achieve our objectives and according to μ-synthesis requirements we have proposed the control strategy as shown in Fig. 1. G_0 denotes the augmented nominal area system and can be shown by the following state-space model:

$$\begin{aligned} \dot{x} &= Ax + Bu + Fw \\ y &= Cx + Ew \end{aligned} \qquad (1)$$

where x corresponds to state variables vector, u corresponds to the control input of LFC-responsible generator unit, and w is a disturbance vector which includes both of area load disturbance (ΔP_L) and incoming disturbance from other areas (d).

Depending on the given area power system, we can focus on the most important uncertainty. Δu block models the uncertainty as a multiplicative type and W_u is associated weighting function. According to requirement performance and practical constraint on control action, three fictitious uncertainties W_{P1}, W_{P2} and W_{P3} are added to power system model. The W_{P1} on the control input sets a limit on the allowed control signal to penalize fast change and large overshoot in the control action. This is necessary in order to guarantee implement ability of the resulting controller.

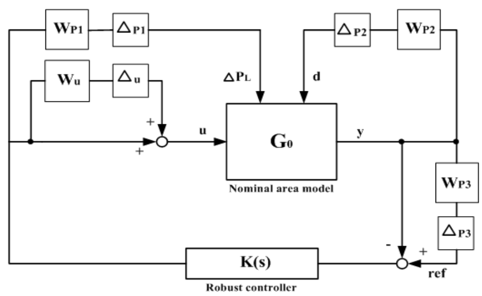

Fig. 1. The synthesis framework

The weights W_{P2} and W_{P3} at the output sets the performance goal e.t. tracking/regulation on the output area control signal. Further more it is notable that in order to reject disturbances and to good tracking property, W_{P2} and W_{P3} must be such select that singular value of sensitivity transfer function from control input u to output y be reduced at low frequencies. Δp_1, Δp_2 and Δp_3 are uncertainty blocks associated with W_{P1}, W_{P2} and W_{P3} respectively. We can redraw the Fig. 2 as a standard M-△ configuration, which is shown in Fig. 2.

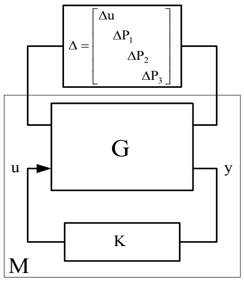

Fig.2. M-△ configuration.

G includes the nominal model of area power system, associated weighting functions and scaling factors. The block labeled *M*, consists of *G* and controller *K*. Based on the μ-synthesis, the robust stability and robust performance holds for a given closed-loop M-△ configuration (Fig. 2), if and only if

$$\inf_{K} \sup_{\omega \in R} \mu[M(j\omega)] < 1 . \qquad (2)$$

Using the performance robustness condition and the well-known upper bound for μ, the robust synthesis problem reduces to determine

$$\min_{K} \inf_{D} \sup_{\omega} \bar{\sigma}(D M(j\omega) D^{-1}) , \qquad (3)$$

or equivalently $\min_{K,D} \left\| D M(G,K)(j\omega) D^{-1} \right\|_{\infty}$,

by iteratively solving for *D* and *K* (*D-K* iteration algorithm) [4]. Here *D* is any positive definite symmetric matrix with appropriate dimension and $\bar{\sigma}(.)$ denotes the maximum singular value of a matrix.

4. Apply to an example

A typical multi-generator distribution area is shown in Fig. 3. In this example the Generator unit 2 (Gunit 2) and Generator unit 3 (Gunit 3) are the main suppliers for area-load and Generator unit 1 (Gunit 1) is considered to LFC responsibility. In other word the area delivers firm power from Gunit 2 and Gunit 3, and enough power from Gunit 1 to supply its load and support the LFC task. Generator units produce electric power that is delivered to the load either directly or through the transmission unit (Tunit). In a deregulated power system, Gunit 1, Gunit 2 and Gunit 3, can be corresponded to three independent Generator company (Genco), and, Tunit corresponds to a Transmission company (Transco).

The objective is supplying power to area load at a nominal frequency. In case of a load disturbance Gunit 1 will adjust its output accordingly to track the load changes and maintain the energy balance. Connections of this area to other areas are considered as disturbances (*d*).

For this example the open-loop system (1) is unstable. Calculation the eigenvalue sensitivity of matrix *A* in (1) to the parameters shows that the unstable mode is most sensitive to H_1 (the inertia constant of Gunit 1). Therefore in this paper, our focus (in viewpoint of uncertainty) is concentrated on variation of H_1 parameter in a wide range.

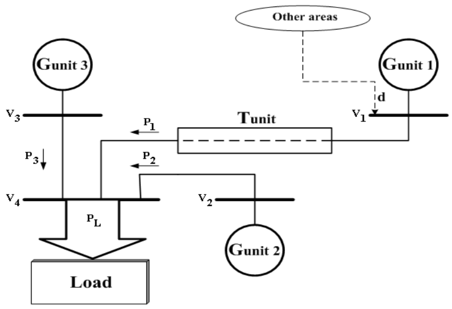

Fig.3. A distributed generation area

For the problem at hand (Fig. 3), we have set our objectives (robust stability and performance) as follow:

1-Holding stability in presence of H_1 variation between 4 and 10; $4 \le H_1 \le 10$. The nominal value is $H_1 = 6$.

2-Holding stability and desired reference tracking for $0 \le \Delta P_L(\%) \le 10$.

3-Minimizing the effectiveness of input step disturbance from outside area (*d*).

4-Maintaining acceptable overshoot and settling time on frequency deviation and power changing at Gunits' terminals.

5- Set reasonable limit on control action signal in change speed and amplitude viewpoint.

Based on above objectives, a suitable set of uncertainty and performance weighting functions are obtained. An important issue in regard to selection of the weights is the degree to which they can guarantee the satisfaction of design objectives.

The controller *K(s)* is found at the end of the Three D-K iteration yielding the value of about 0.9992 on the upper bound on μ, thus guaranteeing robust performance. The resulting controller has a high order (24*th*). The controller is reduced to an 8*th* order with no performance degradation, using the standard Hankel Norm reduction.

Simulation results demonstrated that the designed controller is capable to guarantee the robust stability and robust performance such as precise reference frequency tracking and disturbance attenuation under a wide range of parameter variation and area-load conditions. In summary because of the flexibility of synthesis procedure to modeling uncertainty, possibility of direct formulation of performance objectives and practical constraints, the proposed control strategy can be chosen as an appropriate control scenario for competitive distributed generation power systems.

5. Reference

(1) H. Bevrani, "Robust Load Frequency Controller in a Deregulated Environment: A μ-synthesis Approach," *Proc. of IEEE Int. Conf. on Control applications*, USA, pp. 616-621,1999.

(2) H. Bevrani, Y. Mitani, and K. Tsuji, "Robust Low-order Load Frequency Controller in a Deregulated Environment," *Proc. of 5th Asia-Pacific Conf. on Control and Measurement (APC CM)*, China, 2002.

(3) H. Bevrani, "A novel approach for power system load frequency controller design," *Proc. of IEEE/PES T&D Asia pacific*, Japan, pp. 184-189, 2002.

(4) G.J. Balas, et. al. : μ-Analysis and Synthesis Toolbox for use with MATLAB, The MathWorks Inc., 1995.