ROBUST POWER SYSTEM STABILISER DESIGN BASED ON μ - SYNTHESIS

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Abstract - This paper deals with the design and evaluation of a μ-synthesis based PSS using the state space approach. μ-synthesis design method leads to a fixed-structure and fixed- parameter robust controller. An essential prerequisite in the synthesis of μ-synthesis is to obtain a nominal linear system model. Uncertainties in the model are taken into account in the specification of the cost-function weights.

The effectiveness of the proposed PSS is demonstrated under different operating regimes. A comparative study of the proposed PSS with a conventional PSS such as PI controllers has been performed and the superiority of the μ-synthesis based PSS in improving the transient stability of the power generator is demonstrated in a simulation environment.

Keywords*: Robust control, H∞, μ analysis and synthesis Power system Stabilizer, optimal control*

1 INTRODUCTION

One of the most important problems arising from large scale power systems is the low frequency oscillation. Excitation control or Automatic Voltage Regulator (AVR) is well known as an effective means to improve the overall stability of the power system. Power System Stabilisers (PSS) are introduced in order to provide additional damping to enhance the stability and the performance of the electric generating system. The output of the PSS as supplementary control signal is applied to the machine voltage regulator terminal.

Conventional PSS have been widely used in power systems. Such PSS ensures optimal performance only at a nominal operating point and does not guarantee good performance over an entire range of the system operating conditions. Several techniques have been proposed for the design of more robust PSS structures.

To guarantee the desired performance, this paper describes the control design models of a PSS based on μ-synthesis, μ-analysis and H∞ control methods, which is returned when the system configuration changes. The control law is presented in both frequency domain and time domain.

2 SYSTEM DESCRIPTION

The power system considered in this study is modelled as a synchronous generator connected to a constant voltage bus through a double transmission line. In Fig.1 is represented the system structure including the PSS unit.

A simplified model describing the system dynamics used in this study is given by the following state space equations [1], [2], [3], [4],and [5].

$$\dot{x}(t) = Ax(t) + Bu(t) + Ld(t)$$
$$y(t) = Cx(t) + Du(t)$$

Where u represents the system input and d is an external disturbance with

$$d = [\Delta V_{ref} \quad \Delta GSC]^T$$

Where ΔGSC is governor speed changer (produces a change in the mechanical torque T_m)

The state variables and the system output are respectively

$$x = [\Delta\delta \quad \Delta\omega \quad \Delta e_q^{'} \quad \Delta e_{FD} \quad \Delta V_r \quad \Delta V_E \; \Delta T_m]^T$$
$$y = [\Delta\omega \;\; \Delta\delta]^T$$

The transfer function form of the nominal model is given by

$$G_{nom}(s) = C_0(sI - A_0)^{-1}.B_0.D_0$$

Where

$$Y(s) = G_{nom}(s).U(s)$$

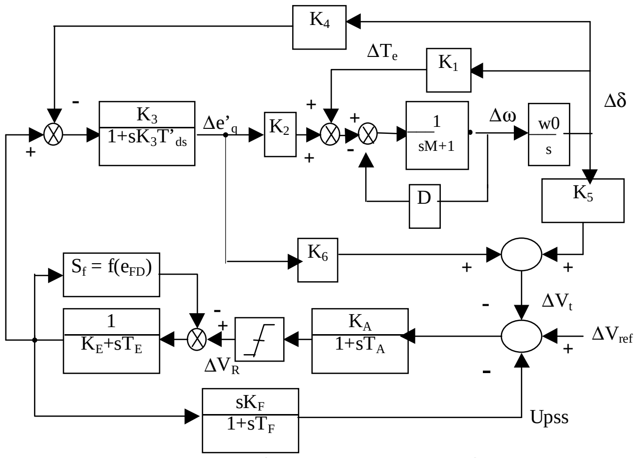

Fig. 1 Block diagram of the linear model of the alternator

Let the generator operating point is defined by

$\xi = [P\ Q\ x_e]$

These operating points are associated with a set models (A_i, B_i, C_i, D_i, L_i). For these models, uncertainties may be defined and taken into account in the controller design stage.

3 PSS DESIGN BASED ON μ-SYNTHESIS AND D-K ITERATION

3.1 Problem formulation

A diagram for the closed-loop systems, which includes the feedback structure of the plant and elements associated with the uncertainty models and performance objectives, is shown in Figure 2. W_{del} and Δ, which parametrize the uncertainty in the model.

This type of uncertainty is called multiplicative uncertainty at the plant input , for obvious raisons.

The transfer function W_{del} is assumed known, and reflects the amounts of uncertainty in the model. The transfer function Δ is assumed to be stable and unknown, except for the norm condition, $\|\Delta\|_\infty < 1$. The performance objective is that the transfer function from d to e is small, in the $\|.\|_\infty$ sense, for all possible uncertainty transfer functions Δ.

The weighting function W_p is used to reflect the relative importance of various frequency ranges for which performance is desired.

The objective of designing a robust power system stabilizer K is to make the overall stable within the normal operating conditions and some extreme situation such as fault, and at the same time maintain degree of system performance. With $\|\Delta\|_\infty < 1$, the perturbed closed–loop system remains stable, and the perturbed weighted sensitivity transfer function,

$$S(\Delta) := W_p (I + G(I + W_{del}.K.\Delta)^{-1}$$

has $\|S(\Delta)\|_\infty < 1$ for all such perturbations. Recall that mathematical objectives exactly fit in the structured singular value framework.

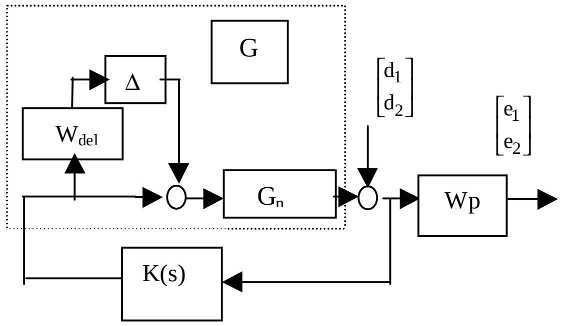

Fig. 2 Systems closed-loop interconnection structure

The rotor angle Δδ and generator rotor speed Δω are used as the stabilizing signals in this design example.

In Fig. 3, P_0 is interconnected system which consists of nominal plant G_{nom} and all uncertainty models.

a stabilizing controller K achieves closed-loop, robust performance if only and only if for each frequency $\omega \in \Re^+$, the structured singular value

$$\mu_\Delta[F_L(P,K)(j\omega)] \prec 1$$

Using the upper bound for μ, we can attempt to minimize the peak closed-loop μ value by posing the minimization problem

$$\min_{\substack{K \\ \text{stabilizing}}} \ \min_{\substack{D(s)\in \mathbf{D} \\ \text{stable, min-phase}}} \left\| \hat{D}.F_L(P,K)D^{-1} \right\|_\infty$$

This optimization is currently "solved" by iterative approach , referred to as " D-K" iteration

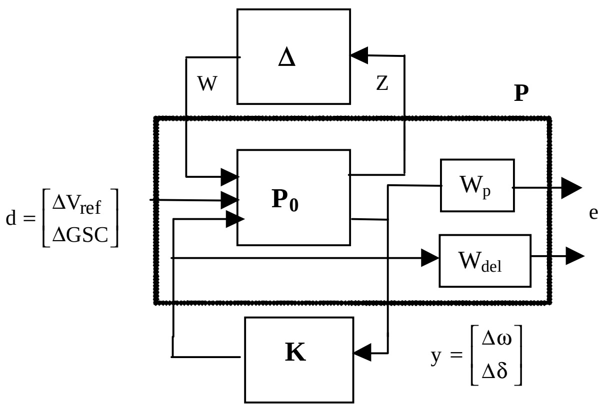

Fig. 3 Complete LFT structure.

3.2 PERFORMANCE AND EVALUATION

The PSS based on μ-synthesis design approach is evaluated in simulation on different conditions of work (change of point of working, profile of the line, variation of reference voltage, as well as the mechanical torque). The results are illustrated by Fig. 4,5,6 and 7 for the operating points defined by $\xi = [\,P \quad Q \quad X_e\,]$.

W_p and W_{del} are chosen as:

$$W_{del} = \mathrm{diag}\left(0.1\frac{1+0.0286s}{1+0.0167s},\ 0.6\frac{1+0.0286s}{1+0.0167s}\right)$$

$$W_p = \mathrm{diag}\left(7.3\frac{1+0.25s}{1+10s},\ 10.5\frac{1+0.25s}{1+10s}\right)$$

Using μ-synthesis, it is possible to find a controller that stabilizes the power systems with the appearance of the system uncertainty and also realize the robust performance.
nevertheless the software tools employed in the present work [5] allow an approximate solution based on the iterative procedure known as D-K iteration.
A minimum value $\mu \le 1$ is desired to satisfy the robust performance criteria. The final result of the robust power system stabiliser design and nominal performance are shown in Fig. 4.

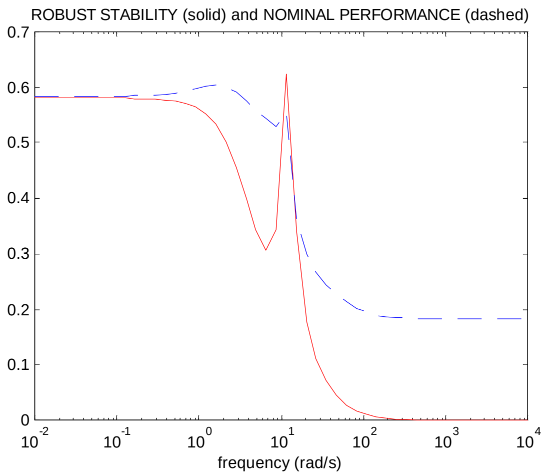

Fig. 4 Robust stability, and nominal performance μ plot.

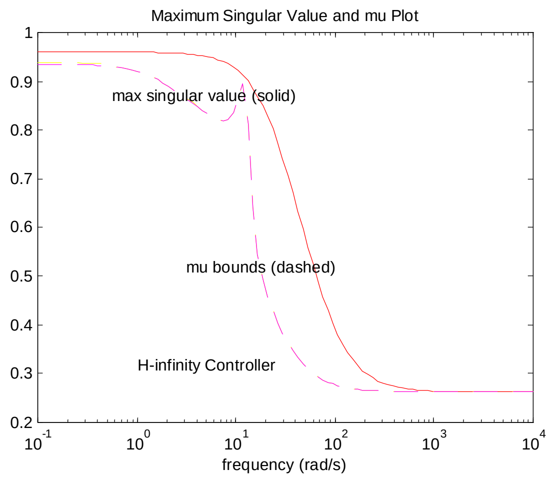

Fig. 5 maximum Singular value and μ plot.

Robust stability and robust performance have peak values that are less than unity, which implies the robustness of these properties with respect to the modelled perturbations.
the modes of operation tested on the generator are illustrated by figures 4,5,5,and 7. The reference voltage is of 0.5 p.u., GSC is given by 0.10.
One notes an improvement of response time of the loop system closed compared to regulator PI.
The present face 8 the program in Matlab and simulink of system turbo-generator with the μ-synthesis control.

4 CONCLUSION

The robustness of the controller has been evaluated with respect to model uncertainties of the power generator. A comparative study of the proposed PSS with a conventional PI controller has been conducted.
The results demonstrate the superiority of the μ-controller and that, in this case, robust performance can be achieve with no need for a very complicated controller structure, by modelling plant uncertainties according to the described LFT structure.

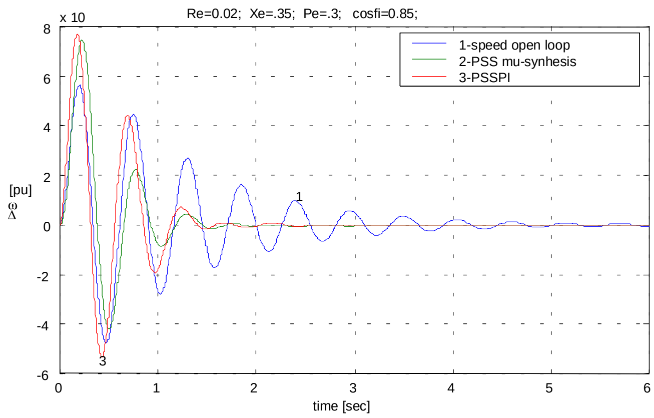

Fig. 4 Step responses of the closed-loop plant in operating point 1 with ΔVref =5% and ΔGSC = 10%

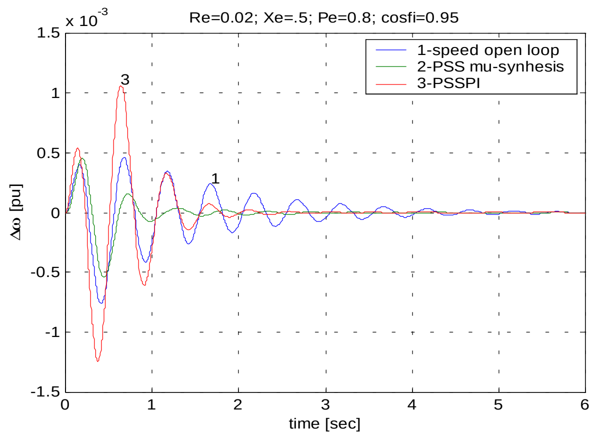

Fig. 5 Step responses of the closed-loop plant in operating point 2 with ΔVref =5% and ΔGSC = 10%

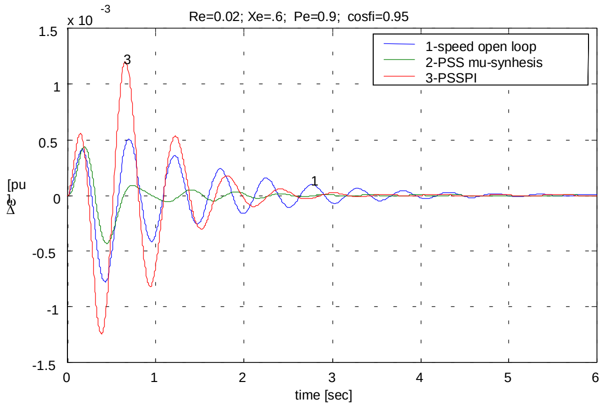

Fig. 6 Step responses of the closed-loop plant in operating point 3 with ΔVref =5% and ΔGSC = 10%

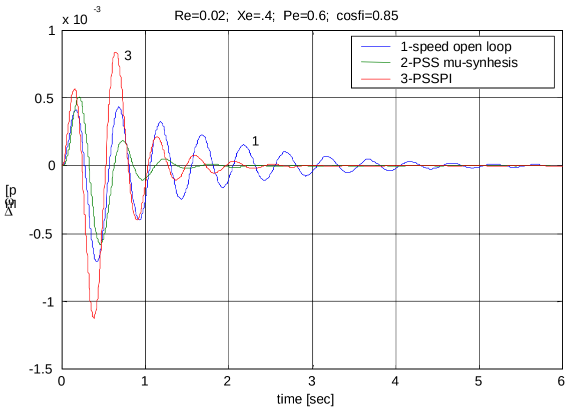

Fig. 7 Step responses of the closed-loop plant in nominal operating point 1 with ΔVref =5% and ΔGSC = 10%

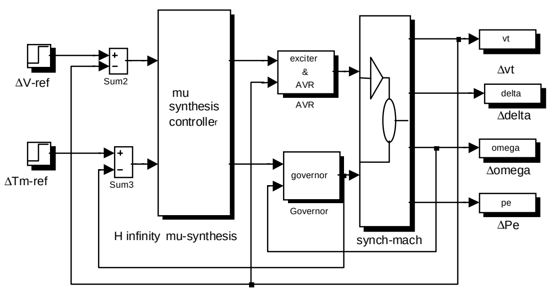

Fig. 8 block diagrams of turbo-generator with μ-synthesis control by Matlab/simulink environment

APPENDIX

A1 Nomenclature

ω speed
EP Electric output
Vt Terminal voltage
Pm Power Mechanic
D coefficient damping
P Active power
Q Reactive power
X_E Reactance of the line of the network

Δ Small deviation around the point of operation

A2 Parameters of the generator

The characteristics of the group turbo alternator are [1]:
x_d =1.7, x_q = 1.64, x'_d = 0.245, V_{t0} =1.172, r =0.001096, t'_{d0} = 5.9, K_A = 400, T_A= 0.05, K_F =0.0250, T_F = 1, M=4.7, R_e = 0.02, D = 0, K_E =0.17, T_E =0.95.

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