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Two Parameter Controller for a Single Machine Infinite Bus System

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Abstract

This paper shows the application of two parameter controller with internal-Model principle to a single machine- infinite bus system (SMIB), to achieve design specifications and disturbance rejection. In the two parameter model the feedback- compensator is used to achieve required transient response by pole placement and input compensator is used to achieve required steady state response. Finally this method concludes that the method is systematic, general and yields good results.

Keywords: power system stabilizer, Two-parameter controller, internal model principle, disturbance rejection.

1. Introduction

The importance of the excitation control [3] in improving the dynamic stability of synchronous generator is widely recognized, to improve the damping characteristics of a synchronous generator under disturbance conditions, power system stabilizers have been widely employed. Actually, the stabilization of a synchronous machine connected to an infinite bus through a two-parameter controller is discussed in the following sections.

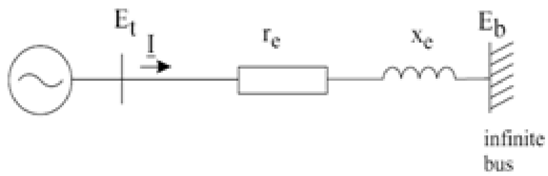

Figure 1. One machine to infinite bus.

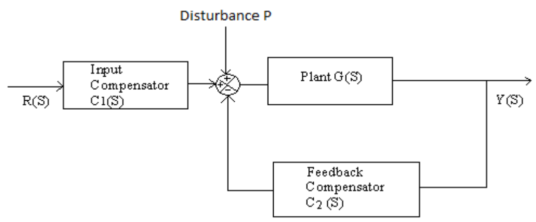

Figure 2. Two Parameter controller configuration.

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So far in the power-systems controller designs, all the design specifications are not achieved simultaneously with single-parameter controller configuration. To achieve all (transient stability, steady state stability, tracking and disturbance rejection property) simultaneously there is a need of two-parameter control.

A previous article by Chen [1] in IEEE Control Systems Magazine discussed some basic issues in the design of two- parameter controller and showed how to solve pole zero assignment and model matching by solving set of linear algebraic equations. If this two-parameter controller is applied to SMIB, meets all the specifications by tracking the reference input with large error for a disturbance occurred in the plant.

In order to deal with noise and disturbance by tracking reference input with zero steady state error two-parameter controller with internal model principle design [2] is applied to SIMB.

2. Two Parameter Controller Design Procedure

The two-parameter controller configuration which is shown in Fig. 2, where G(s) is plant transfer function, $C_1(s)$ and $C_2(s)$ are the two compensators, the two compensators will be chosen to have same denominator and have the form

$$C_1(s) = L(s)/A(s).$$

$$C_2(s)=M(S)/A(S). \quad (1)$$

Where L(S), M(S) and A(S) are polynomials to be determined. We will now discuss the implementation of an implementable transfer function in the two-parameter configuration. The transfer function from Y to R is

$$Y(S)/R(S) = N(s)L(s)/[A(s)D(s)+M(s)N(s)]$$

$$= N_0(s)/D_0(s)=G_0(s) \quad (2)$$

Assume G(s) to be strictly proper; given G(S)=N(s)/D(s), where N(s) and D(s) are co-prime and the degree of N(s) is less than the degree of D(s) that is equal to ‘n’, now the design procedure for the implementation of the overall-transfer function is as follows:

Step 1**:** compute the following rational function

$$G_0(s)/N(s) = N_0(s)/D_0(s)N(s) = N_p(s)/ D_p(s) \quad (3)$$

Where $N_p(s)$ and $D_p(s)$ are coprime, if $N_0(s)$ and $D_0(s)$ are coprime, common factors may exist only between $N_0(s)$ and N(S) cancel all common factors between them.

Step2**:** If degree of $D_p(s) = p < 2n-1$, introduce an arbitrary polynomial E(s) of degree 2n-1-p. Because this polynomial will be cancelled in the design, its roots should be chosen inside an acceptable pole zero cancelation region. If deg of $D_p(s) = p$, set E(s)=1. In most applications we have deg $D_p(s) \leq 2n-1$.The case in which deg $D_p(s) > 2n-1$is not considered. If G(s) is bi-proper i.e., deg N(s) equals to deg D(s), then the above procedure in step 2 is modified as if deg $D_p(s) = p < 2n$, introduce an arbitrary polynomial E(s) of degree (2n-p).

Step 3: Rewrite Eq. (3) as

$$G_0(s) = [N(s)N_p(s)]/D_p(s)$$

$$= N(s)[N_p(s)E(s)]/[D_p(s)E(s)] \quad (4)$$

Comparison of Eq. (2) and (4) yields the following

$$L(s)= N_p(s)E(s) \quad (5)$$

$$A(s)D(s)+M(s)N(s)=D_p(s)E(s) = F(s) \quad (6)$$

The degree of F(s) is the sum of the degrees of $D_p(s)$ and E(s), and equals to 2n-1.The degree of the denominator A(s) of the compensator is n-1.The polynomial equation in (6) can be solved directly using polynomial manipulation. It is, however, complicated we shall now solve it by matching coefficients. Matching coefficients leads directly to solving a set of linear algebraic equations. Now write polynomials A(s),D(s),F(s),M(s) and N(s) explicitly as

$N(s) = N_0 + N_1 s + \ldots + N_n s^n$, $N_n=0$

$D(s) = D_0 + D_1 s + \ldots + D_n s^n$, $D_n \neq 0$

$A(s) = A_0 + A_1 s + \ldots + \ldots A_{n-1} s^{n-1}$

$L(s) = L_0 + L_1 s + \ldots + \ldots L_{n-1} s^{n-1}$

$M(s) = M_0 + M_1 s + \ldots + \ldots M_{n-1} s^{n-1}$

$F(s) = F_0 + F_1 s + \ldots + \ldots F_{2n-1} s^{2n-1}$

The solution of eq. (6) and L(s) in eq. (5) will then implement $G_0(s)$. These are the reasons for introducing E(s) in eq. (4) if we don't introduce E(s), the compensators M(S)/A(S) computed from eq. (6) may not be proper. However, if we introduce E(s) as suggested in step 2, then both M(S)/A(S) and L(S)/A(S) will be proper, and the resulting system is well posed. Thus the introduction of E(s) in the design procedure is crucial. The design involves pole zero cancelations. The canceled poles are the roots of E(s), which are chosen by the designer. Thus, if $G_0(s)$ is stable and E(s) is Hurwitz, then the system is totally stable

2.1. Implementability Conditions

Consider a plant with proper transfer function

G(s) =N(s)/D(s)

Then $G_0(s)$ is implementable if and only if, $G_0(s)$ is stable and $G_0(s)/G(s)$ is stable and proper.

2.2. Alternative Implementability Conditions

Consider a plant with proper transfer function G(s) =N(s)/D(s). Then $G_0(s)$ is implementable if and only if.

(1) $D_0(s)$ is Hurwitz
(2) The deg of $D_0(s)$ minus the degree of $N_0(s)$ is greater than or equal to the degree of D(s) minus the degree of N(s) (pole-zero excess inequality).
(3) All closed right of plane zeros (including the imaginary axis) of N(s) are retained in $N_0(s)$ (retainment of non minimum phase zeros).

2.3. Two Parameter Controller With Internal Model Principle

Consider the two-parameter controller configuration shown in Fig. 2 the system is sad to achieve step disturbance rejection if output due to any step disturbance with an un- known amplitude approaches zero as time becomes infinite. Let H(s) be the transfer-function from disturbance p to output y then we have

H(s)=N(s)A(s)/[A(s)D(s)+M(s)N(s)]

Using the final-value theorem it can be readily shown that the system achieves step disturbance rejection if and only if H(0)=0, generally N(0) is not zero thus the only way to achieve H(0)=0 is to make A(0)=0. This can be achieved by increasing degree of the two parameter controller [2]. If the degree of the compensator is not increased then the polynomial A(s) which is uniquely determined by Eq. (6) and we have no freedom in assigning A(0) = 0.

3. Choice of Over All Transfer Function

From the discussion in the preceding sections, we see that once an overall transfer function is chosen, the rest of the design is rather straight forward. There four the crux of the design is how to choose an overall transfer function. This choice appears to be based on the concept of dominant poles, Minimization of the integral of time multiplied by absolute error (itae) and Quadratic performance index method. The choice of method prefers to choose over all transfer function $G_0(s)$ is discussed by chi-Tsong [2], in this paper dominant pole technique is employed to choose overall transfer function.

4. Blok Diagram Representation of SMIB System

The block diagram of SMIB in figure 3 is taken from the reference [3], where armature resistance and saturation are neglected, and the mechanical power in-put is assumed to be constant. The linearized model parameters k1 to k_6 vary with the operating point, with the exception of k_3.

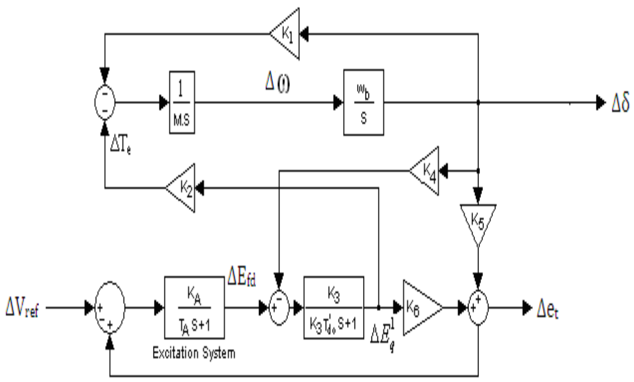


Figure 3. Small perturbation block diagram of SMIB

Where
ΔTe,ΔTm=electrical and mechanical torques respectively,
D=damping factor, H=inertia constant, M=inertiacoeffi- cient=2H(sec), T^1_{d0}=field open circuited time constant,
K_A, T_A=AVR time constant respectively.

5. Two Parameter Controller Design For SMIB

The parameter values of SMIB are considered [3], K_A=200, K_1=1.1272, K_2 =1.152, K_3 =0.36, K_4 =1.6089 , K_5 =-0.0745 , K_6 =0.4177, T_A =0.05. The un-compensated SMIB system transfer function is

$$G(s) = \frac{\Delta\delta}{\Delta V_{ref}}$$

$$= \frac{-28950}{s^4 + 20.46s^3 + 330.2s^2 + 857.9s + 14150}$$

Above un-compensated system is unstable one. By using the procedure presented in section-II we shall find A(s), M(s) and L(s) so that the transfer function from Y to R in Fig. 2 is

$$G_0(s) = \frac{480}{s^4 + 19s^3 + 134s^2 + 416s + 480}$$

Choose the degree of compensator to 4 [2]. Arbitrarily, We Choose E(s) = $(s+10)^4$. This polynomial will be cancelled in design. In the literature, it is suggested that canceled poles be chosen three or four times faster than the poles of $G_0(s)$. By solving eq. (6) and from eq. (5) the compensator parameters are obtained, the solution is

$L(s) = 480(s+10)^4$.

$M(s) = (0.4801 + 0.7306s – 0.1944s^2 + 0.0156s^3 + 0.0014s^4)10^6$

$A(s)= (0.2509s – 1.0864s^2 – 0.116s^3 – 0.0029s^4)10^6$

These compensators will then implement G_0 (s).

6. Simulation and Results

Simulations are first carried out on un-compensated system for a step input, response is observed shown in Figure 4 which is increasingly oscillatory.

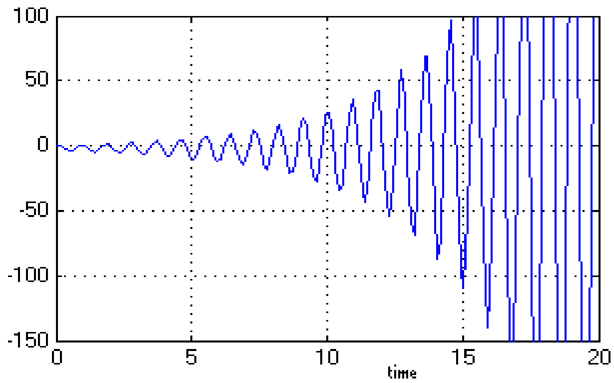


Figure 4. Response of an un- compensated system.

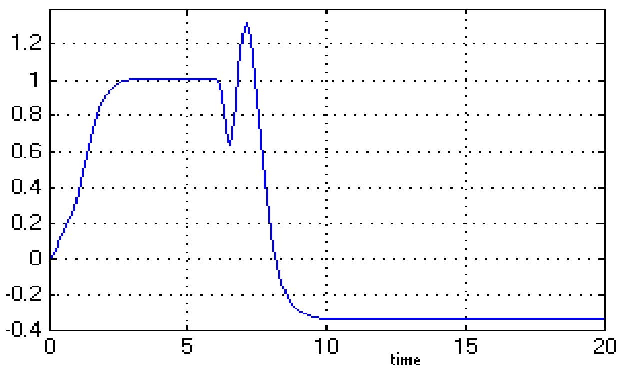
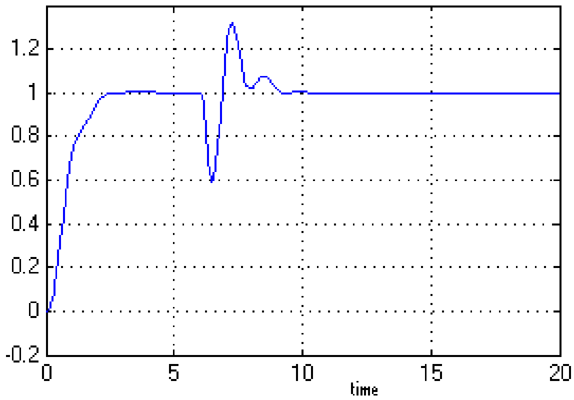


Figure 5. Response for a disturbance, without using internal model-principle design

After making the compensation with two-parameter controller, response is stabilized and tracks the reference in-put up to 6 sec, at t=6sec a disturbance is occurred causing the response to deviate from its steady state position, and again it reaches steady state with a large error, shown in Figure 5.

Finally it is observed from Figure 6 that the two-parameter controller with internal-model principle design achieves all design specification even for a disturbance occurred in the plant.



Figuere 6. Response for a disturbance, with internal model principle design

7. Conclusion

In this paper studies are carried out on single machine infinite bus system, the actual un-compensated system response is increasing oscillations. By incorporating two parameter controller with internal model principle, the total system rejects the disturbance by tracking the reference input with zero steady state error, the procedure is straightforward and yields better results. The problem of choosing over-all transfer function is also discussed.

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