DESIGN AND SIMULATION OF TWO ADAPTIVE SELF-TUNING CONTROLLERS WITH APLICATION TO A POWER SYSTEM

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Abstract: The paper presents considerations regarding to design and simulation of two adaptive controllers (self-tuning controller with feedback and respectively reference compensation) with application to a power system. The self-tuning control strategy is applied for the excitation control of a synchronous generator. There are analyzed the performances of the both considered self-tuning control structures.

Keywords: self-tuning control, synchronous generator, adaptive control, criteria function.

1 INTRODUCTION

Due to the enhanced performances shown by the self-tuning control structures in the case of complex systems placed in a stochastic environment, the following structures presents themselves as a viable and easy implementing alternative in the context of an outstanding development of the computer technology. Although the theoretical basis of the self -tuning control structures is already well known, these control algorithms present themselves as actual solutions. [2],[3]

2 SYNTHESIS OF THE SELF-TUNING CONTROL STRUCTURES

In the following paragraphs two control structures are presented: self-tuning controller with feedback compensation; self-tuning controller with feedback and reference compensation.

2.1 Self-tuning controller with feedback compensation (J_1 criterion).

The starting point is represented by the following minimization criterion:

$$J_1 = E\left\{\left[y(t+1) - w(t)\right]^2 + \left[Q'\left(z^{-1}\right)u(t)\right]^2\right\} \tag{1}$$

The linearised model of any considered process has the following relation (the last member of the relation is the transfer function of the synchronous generator considered for the following study cases):

$$H(z^{-1}) = z^{-1}\frac{B(z^{-1})}{A(z^{-1})} = z^{-1}\frac{b_3 z^{-3} + b_2 z^{-2} + b_1 z^{-1} + b_0}{a_4 z^{-4} + a_3 z^{-3} + a_2 z^{-2} + a_1 z^{-1} + 1} \tag{2}$$

where: *y(t)* - process output; *u(t)*–process input; *e(t)* – stochastic sequence of independent random variables, of zero average and σ^2 dispersion (white noise); *d* – steady state regime process output (for a zero input); z^{-1} – one step delay operator, and

$$C(z^{-1}) = 1 + c_1 z^{-1} + c_2 z^{-2} + c_3 z^{-3} + c_4 z^{-4}$$

a stabile polynomial (noise filter). Minimizing the criteria function described by (1) and considering

$$Q(q^{-1}) = \frac{Q'(0)Q'(z^{-1})}{b_0}$$

there is obtained the following result:

$$u(t) = \frac{C(z^{-1})w(t) - F(z^{-1})y(t) - d}{B(z^{-1}) + Q(z^{-1})C(z^{-1})} \tag{3}$$

where: $F(z^{-1}) = z[C(z^{-1}) - A(z^{-1})]$.

Further, if $C(z^{-1}) = 1$ and $d=0$ we obtain $F(z^{-1}) = z[1 - A(z^{-1})]$ and

$$u(t) = \frac{w(t) - z[1 - A(z^{-1})]y(t)}{B(z^{-1}) + Q(z^{-1})} \tag{4}$$

Taking into account that the $A(z^{-1})$ and $B(z^{-1})$ (also for $F(z^{-1})$) polynomial's parameter that occur in control law (relations (3) and (4)) are practically estimations of the real process parameters, the control law can be depicted as follows:

$$u(t) = \frac{w(t) - z[1 - \hat{A}(z^{-1})]y(t)}{\hat{B}(z^{-1}) + Q(z^{-1})} \tag{5}$$

where ^ marks the estimations.

Adapting the control laws for the particular expressions of the $A(z^{-1})$ and $B(z^{-1})$ polynomial leads to the following calculus of the adaptive self-tuning command, specific to the considered process:

$$u(t) = \frac{w(t) + \hat{a}_1 y(t) + \hat{a}_2 z^{-1} y(t) + \hat{a}_3 z^{-2} y(t) + \hat{a}_4 z^{-3} y(t)}{\hat{b}_0 + \hat{b}_1 z^{-1} + \hat{b}_2 z^{-2} + \hat{b}_3 z^{-3} + Q(z^{-1})} \tag{6}$$

A general form adopted for the $Q(z^{-1})$ polynomial is $Q(z^{-1}) = \rho(1 - z^{-1})$ [1]

2.2 Self-tuning controller with feedback and reference compensation (J$_2$ criterion)

In this case the criterion function to be minimized is:

$$J_2 = E\left\{[y(t+1) - w(t)]^2 + \left[Q'\left(z^{-1}\right)[u(t) - u_r(t)]\right]^2\right\} \tag{7}$$

where: $w(t)$ - reference input; $u_r(t)$ - steady state regime command.

Similarly with the previous calculus methodology results:

$$u(t) = \frac{w(t) - F(z^{-1})y(t) + Q(z^{-1})u_r(t)}{B(z^{-1}) + Q(z^{-1})} \tag{8}$$

A convenient choice for the $Q(z^{-1})$ polynomial is $Q(z^{-1}) = \rho$ (considering a reference compensation that assures already the removal of steady state regime error). This case leads us to the following result:

$$u(t) = \frac{w(t) - z[1 - A(z^{-1})]y(t)}{B(z^{-1}) + \rho} + \frac{\rho}{B(z^{-1}) + \rho} u_r(t) \qquad (9)$$

In steady state regime *y(t)=w(t)*, so $A(z^{-1})w(t) = z^{-1}B(z^{-1})u_r(t)$ we obtain:

$$u_r(t) = z\frac{A(z^{-1})}{B(z^{-1})} w(t) \qquad (10)$$

By noting $k_f = \frac{A(1)}{B(1)}$, in steady state regime (*z=1*) we obtain: $u_r(t) = k_f w(t)$. If w(t)=ct. results $u_r(t)$=ct., where $1/k_f$ is the process gain coefficient in steady state regime. The proposed solution is $\widehat{k}_f = \frac{\hat{A}(1)}{\hat{B}(1)}$ (the permanent estimation of the $\widehat{k}_f$ coefficient on the basis of process parameters estimations). This solution is valid also in the case of a time variable reference. [4] Similarly with the previously case, taking into account that the parameters that occur in the control law are practically estimations of the process's parameters, the control law can be written as follows (for $Q(z^{-1})=\rho$):

$$u(t) = \frac{-z[1 - \hat{A}(z^{-1})]y(t)}{\widehat{B}(z^{-1}) + \rho} + \frac{1 + \rho \widehat{k}_f}{\widehat{B}(z^{-1}) + \rho} w(t) \qquad (11)$$

where through ^ are noted the estimations.

Defining:

$$\widehat{k}_c \overset{\Delta}{=} 1 + \rho \widehat{k}_f = 1 + \rho \frac{\hat{A}(1)}{\hat{B}(1)} \qquad (12)$$

where: $\widehat{k}_c$ is the reference compensation parameter. This parameter assures a reference (*w(t)*) compensation in order to remove any possible steady state regime error. For the considered process we have:

$$u(t) = \frac{\hat{a}_1 + \hat{a}_2 z^{-1} + \hat{a}_3 z^{-2} + \hat{a}_4 z^{-3}}{(\hat{b}_0 + \rho) + \hat{b}_1 z^{-1} + \hat{b}_2 z^{-2} + \hat{b}_3 z^{-3}} y(t) + \frac{1 + \rho \hat{k}_f}{(\hat{b}_0 + \rho) + \hat{b}_1 z^{-1} + \hat{b}_2 z^{-2} + \hat{b}_3 z^{-3}} w(t)$$

where: $$\hat{k}_c = 1 + \rho \hat{k}_f = 1 + \rho \frac{\hat{a}_1 + \hat{a}_2 + \hat{a}_3 + \hat{a}_4}{\hat{b}_0 + \hat{b}_1 + \hat{b}_2 + \hat{b}_3} \qquad (13)$$

3 STUDY CASES

3.1 The case of self-tuning control structure based on the minimization of the J_1 criterion

Simulation conditions: the torque records a 0.2 [relative units] step deviation; the RLSE estimator has a forgetting factor of $\lambda = 0.998$; the process is perturbed by a stochastic noise of zero average and $\sigma^2 = 10^{-8}$ variance; penalty factor is $\rho = 0.01$ (with internal integrative component).

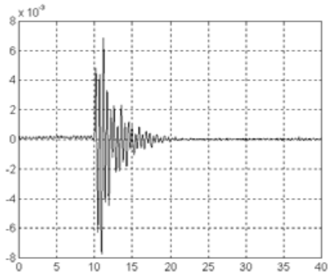

Figure 1.a. Output voltage (controlled output)

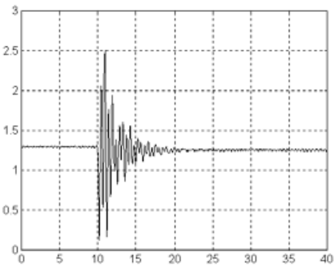

Figure 1.b. Command variable (regulator's output)

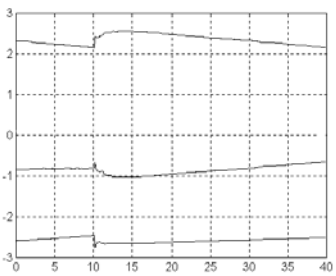

Figure 1.c. *A* polynomial's estimated parameters

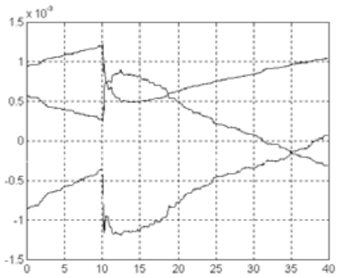

Figure 1.d. *B* polynomial's estimated parameters

The command variable (of excitation), presented in figure 1.b. shows a quite large variation. In figure 1.a. there can be noticed a good performance of the control structure.

In the next case the simulation conditions are: $\rho = 0.01, \lambda = 0$, with the specification that there is considered a higher noise level ($\sigma^2 = 10^{-6}$). The obtained results are good (figures 2.a and 2.b), proving the robustness of the controller, even under the condition of a tougher stochastic noise. As it can be noticed, the parameters estimates are highly influenced by the noise. However, this fact doesn't alter the control performances.

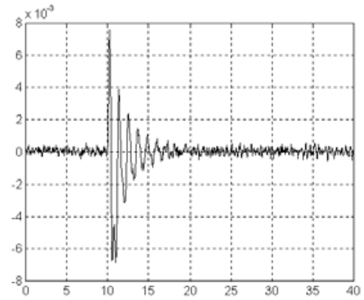

Figure 2.a. Output voltage (controlled output)

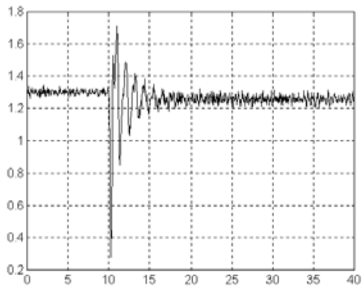

Figure 2.b. Command variable (regulator's output)

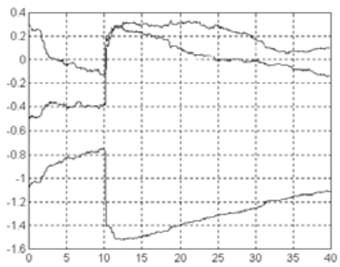

Figure 2.c. *A* polynomial's estimated parameters

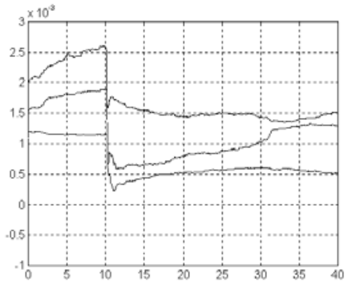

Figure 2.d. *B* polynomial's estimated parameters

The same conclusions can be stated regarding the command's components based on the depicted figures 2. Comparing with the previous case, there can be noticed a higher level of the command in the steady state regime, in order to reduce the output's variation which is highly affected by the stochastic noise.

3.2 The case of self-tuning control structure based on the minimization of the J_2 criterion

The simulation conditions are identical with the first previously case ($\lambda = 0.998$ $\rho = 0.01$ $\sigma^2 = 10^{-8}$).

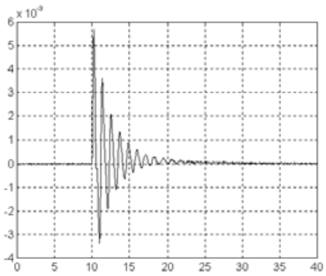

Figure 3.a. Output voltage (controlled output)

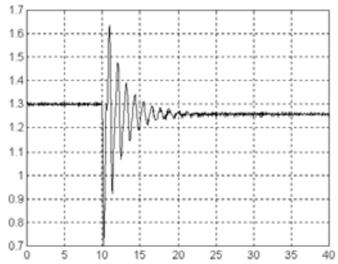

Figure 3.b. Command variable (regulator's output)

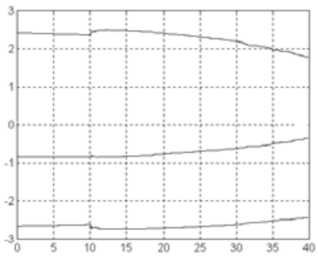

Figure 3.c. *A* polynomial's estimated parameters

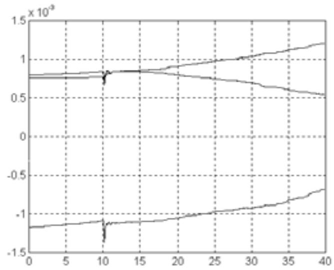

Figure 3.d. *B* polynomial's estimated parameters

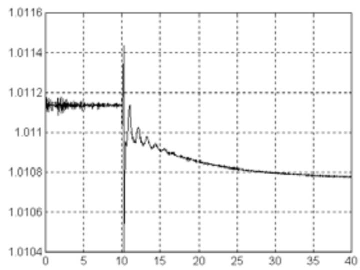

Figure 3.e. The reference compensation parameter

There can be noticed that in the case of a step variation of the mechanical torque the overall performance of the control structure is good. (figures 3.a,b). In the case where is considered a forgetting factor of $\lambda = 0.995$ there can be obtained evolution of the reference compensation parameter as depicted in figure 3.e., result that highlights a relative slowly evolution to the steady state regime value, due to the reduced estimator's dynamic. The command variable variance is significantly reduced in comparison with the previous case study (figure 3.b.). The figures 3.c,d. represent the evolution of the estimated parameters, where can be noticed a different evolution in comparison to the previous case.

In the next case the simulation conditions are the following: $\rho = 0.01, \lambda = 0.98, \sigma^2 = 10^{-8}$. The reduced value of the forgetting factor leads towards a faster reference's compensation parameter steady state regime value, but with higher transients values. These oscillations are mainly caused by the step test signal.

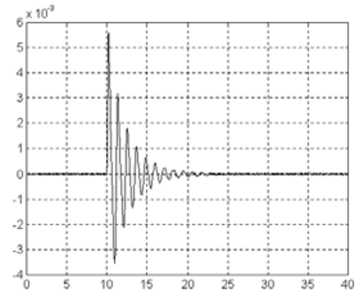

Figure 4.a. Output voltage (controlled output)

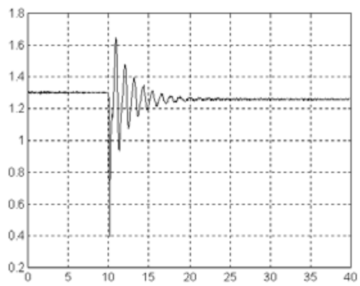

Figure 4.b. Command variable (regulator's output)

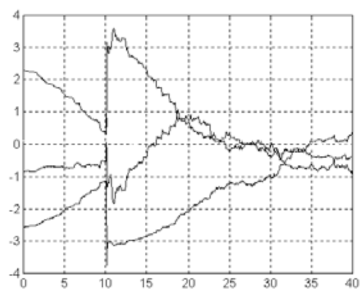

Figure 4.c. *A* polynomial's estimated parameters

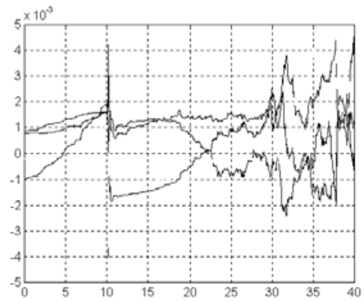

Figure 4.d. *B* polynomial's estimated parameters

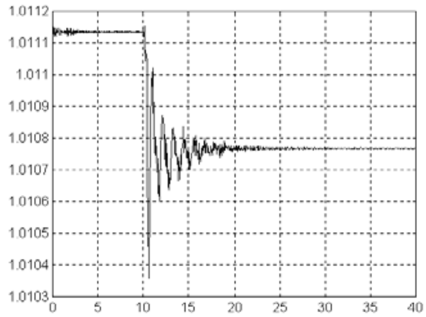

Figure 4.e. The reference compensation parameter

The effects on the control performances can be easily noticed: the transients of the controlled output have shorter time period, concomitantly with a higher output command variation (figure 4.b. versus figure 4.c.). There can be concluded that a choice of an intermediary value for the forgetting factor (as shown in the previous cases) can assure a much better compromise.

Conclusions

The conducted studies prove that both presented self-tuning control structures assure good performances, considering the evolution of the controlled output (the synchronous generator's output voltage). The reference compensation structure assures a smaller command variance (the excitation command voltage). Both control structures present similar performances even in the condition of different regimes (noise level, penalty factor).

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