Algirdas BASKYS

Vilnius Gediminas Technical University

Controller for systems affected by the electromagnetic disturbances

***Abstract**. The EMD resistant controller for the industrial applications has been suggested. The controller is based on the Integral control method with the variable integral constant, which is an exponential function of the control error. The proposed controller provides more stable operation of the control system as compared to the popular PI controller in the case when the control system is affected by the electromagnetic disturbances.*

***Streszczenie.** W artykule zaproponowano odporny na zaburzenia EM sterownik do zastosowań przemysłowych. Sterownik opiera się na metodzie sterowania całkowego ze zmienną stałą całkowania, która jest funkcja wykładniczą błędu sterowania. W przypadku, kiedy regulowany system jest narażony na zaburzenia elektromagnetyczne proponowany sterownik zapewnia stabilniejsze działanie systemu w porównaniu z popularnym kontrolerem PI. (**Sterownik systemów narażonych na zaburzenia elektromagnetyczne**).*

Keywords: Electromagnetic disturbances, controller, integral control method, variable integral constant.
Słowa kluczowe: zaburzenia elektromagnetyczne, sterownik, całkowa metoda sterowania, zmienna stała całkowania.

Introduction

The controllers used in the real applications are often influenced by EMD. The widely used Proportional – Integral – Derivative (PID) and Proportional – Integral (PI) controllers are EMD sensitive because they include Proportional and Derivative terms [1–3]. The controllers based on the pure Integral (I) control method (I controllers) are much more EMD resistant as compared to the PID and PI controllers. They guarantee stable operation of control systems for most types of stable plants as well [4–8]. However, the response of the control system based on the I controller is characterized by the relatively long settling time. The controller based on the Integral control method with the exponential variable integral constant (eI controller) is proposed in this work. The eI controller provides a shorter control system response settling time as compared to the I controller and guarantees more stable operation of the control system affected by the EMD as compared to the case when PID and PI controllers are used. The proposed eI controller should be used in the situations when, on the one hand, the duration of the control system response transient is not of the first importance but, on the other hand, the controller easily adjustable to the plant dynamics and compatible with electromagnetic disturbances is needed.

Control algorithm

The feature of the proposed eI controller is that the integral constant of the controller is a function of the control error, i.e. it is not constant in fact. This feature allows us to reduce the control system response transient settling time (t_S) as compared with the case when the I controller, which realizes the I control method, is used. The algorithm of the eI control method, which is employed in the eI controller, is as follows:

(1) $$U(t) = K_1 \exp\left[K_2 \left|e(t)\right|\right] \int e(t)dt,$$

where $U(t)$ is the controller output, t is time, K_1 and K_2 are real valued positive constants, $e(t)=Y_d - Y_a(t)$ is the control error (controller input), where Y_d is set point (desired) and $Y_a(t)$ is the actual value of the plant parameter, which is controlled. In a specific case, when $K_2 = 0$, algorithm (1) coincides with the algorithm of the I control method. It is seen (1) that in the suggested eI method the integral constant is an exponential function of $e(t)$

(2) $$K_i = K_1 \exp\left[K_2 \left|e(t)\right|\right]$$

and the value of K_i increases when $e(t)$ increases. Consequently, when the value of $e(t)$ is high, the force of the controller is additionally increased and at a low value of $e(t)$ – decreased as compared with the I controller. This feature allows reducing the t_S of the control system and at the same time guarantees its stable operation.

Investigation procedure

The analysis of the eI controller was provided using the dynamic system simulation software SIMULINK for plants with the dynamics, which is described by the following transfer functions:

(3) $$G_1(s) = \frac{e^{-1s}}{(s+1)^2},$$

(4) $$G_2(s) = \frac{e^{-5s}}{(s+1)^3},$$

where s is the Laplace variable.

Functions (3) and (4) present the plants that are characterized by the response with the time–delay. The plants with such transfer functions are typical in the process industry [9].

The simulation of the control systems was performed in accordance with the block diagram presented in Fig.1, where $N(t)$ is the signal produced by the EMD, which affects the $Y_a(t)$ measurement circuit and adds up with the feedback signal. The $D(t)$ in Fig.1 is the load disturbance that influences the plant.

The investigation of the eI controller was provided with the emphasis on EMD resistance of the controller, which is especially important in the industrial control systems. The results of analysis were compared with the results for I and PI controllers only, since these controllers are characterized by significantly higher EMD resistance as compared with the PID controller [1, 2].

Firstly, the set point unit step (Y_d =1) response transient of the control system for analyzed plants and controllers when the system is not affected by EMD and plant load disturbance ($N(t)$, $D(t)$ =0) was simulated and t_S was estimated for tolerance band of the controlled parameter of the plant $Y_a(t)$=1±0.05.

Secondly, the set point unit step response of the control system affected by the *N(t)* and disturbance *D(t)* for eI and PI controllers was simulated for the following situations:

1. All the time the control system is affected by the EMD, which produces a random signal *N(t)* with the amplitude A_n=0.2 (Fig.2). The plant load disturbance *D(t)*=0;

2. The *N(t)* with the amplitude A_n =1 and plant load disturbance *D(t)*=1 start to affect after the transition of the control system set point step response has finished.

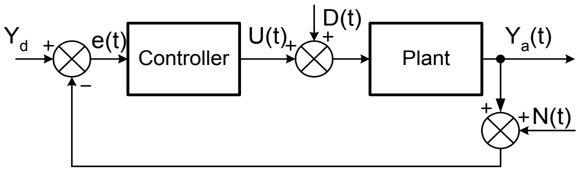


Fig.1. Block diagram of the control system

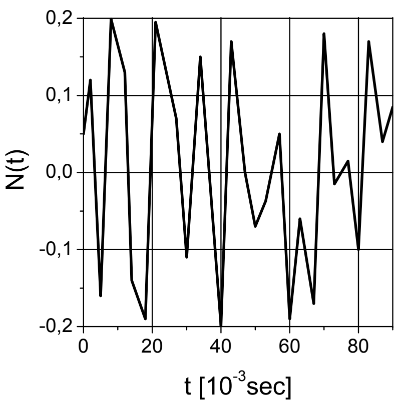


Fig.2. The random signal with the amplitude A_n =0.2 produced by the EMD

Investigation results

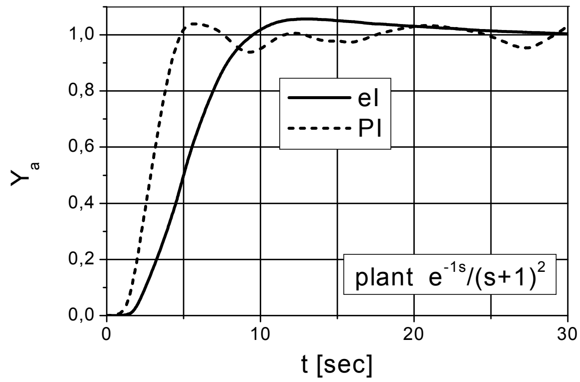
The controller parameters, which were used during the investigations, are given in Table 1. The t_S of the control system for analyzed controllers and plants for the case when the system is not affected by the EMD and plant load disturbance is presented in Table 1 as well. It is evident that the control system with the eI controller for investigated plants is characterized by a shorter t_S as compared with the control system based on the I controller. On the other hand, the eI controller provides a longer t_S as compared with situations when the PI controller is used. It is seen that t_S of the control system based on the eI controller becomes shorter when the value of the coefficient K_2 increases.

The results of simulation of the control system set point unit step response for the case when the system all the time is affected by the random signal *N(t)* with amplitude A_n= 0.2 for eI with K_2=1 and PI controllers are presented in Fig.3. It is seen that the eI controller provides more stable operation of systems as compared with the situation when the PI controller is used.

The situations, when irregular high EMD flashes affect the control system and make operation of the system unstable, often appear in the industry. Duration of the control system set point step response transient is usually infinitesimal in comparison with the control system operation duration. Because of this, the predominant state of the control system is the state when the set point step response transient is over and the system is affected by the plant load disturbances. Consequently, it is important to analyze the situations when the control system is affected by *N(t)* with high amplitude and by load disturbance of plant *D(t)* after the transition of set point step response is over.

Table 1. Controller parameters and t_S [sec] of the control system

Controller	Plant	
	$G_1(s)$	$G_2(s)$
eI with K_2=1	K_1=0.09 t_S =8.7	K_1=0.03 t_S =21.6
eI with K_2=2	K_1=0.04 t_S =7.7	K_1=0.013 t_S =19.4
eI with K_2=3	K_1=0.02 t_S =7.2	K_1=0.005 t_S =18.2
I	K_i=0.17 t_S =10.6	K_i=0.06 t_S =27
PI	K_P=0.72 K_i=0.35 t_S =4.3	K_P=0.4 K_i=0.10 t_S =14



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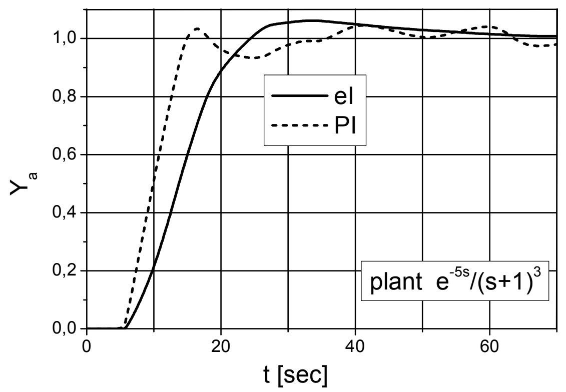

b

Fig.3. Set point unit step response of the control system with eI and PI controllers and plants $G_1(s)$ (a), $G_2(s)$ (b) affected by a random signal N(t) with A_n =0.2 produced by EMD. EMD start to affect at *t*=0

The results of simulation of control system based on eI with K_2=1 and PI controllers, when a random signal *N(t)* with A_n =1 and disturbance *D(t)*=1 start to affect after the control system set point step response transient has finished for investigated plants are presented in Fig.4 and Fig.5. It is seen that control system based on the PI controller operates unstably in such a case. The fluctuation of $Y_a(t)$ caused by *N(t)* is higher for plants witch are characterized by process with a longer time delay. For example, the fluctuation of $Y_a(t)$ of the control system with plant $G_1(s)$ caused by given *N(t)* can reach 20% (Fig.4), while with plant $G_2(s)$ – 30% (Fig.5).

The operation of the control system based on the eI controller under the same conditions remains stable for investigated plants (Fig.4 and Fig.5). This feature allows us to use the eI controller in control systems that operate in the environment of high EMD.

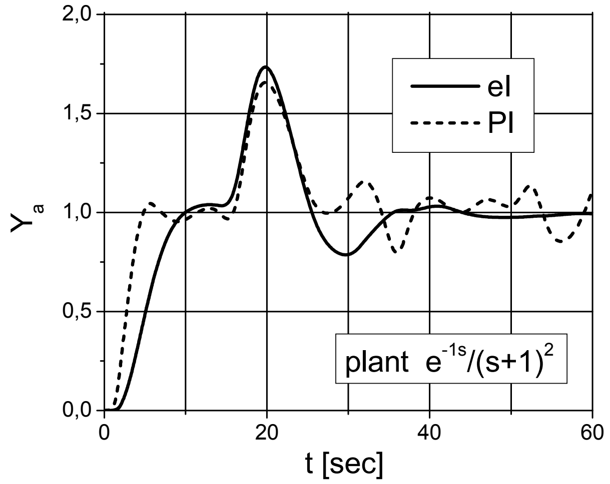

Fig.4. Set point unit step response of the control system with plant $G_1(s)$ affected by load disturbance $D(s)$=1 and random signal N(t) with amplitude A_n =1 produced by EMD for eI and PI controllers. EMD start to affect at t=10sec and load disturbance – at t=15sec

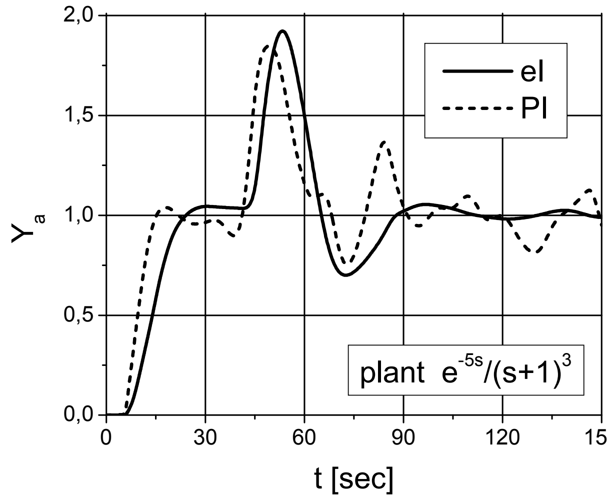

Fig.5. Set point unit step response of the control system with plant $G_2(s)$ affected by load disturbance $D(s)$=1 and a random signal N(t) with amplitude A_n =1 produced by EMD for eI and PI controllers. EMD start to affect at t=30sec and load disturbance – at t=40sec

The control system based on the I controller affected by a random signal *N(t),* which is produced by EMD, for all above analyzed cases operates stably but in such a situation the t_S of the control system is longer as compared with the case when the eI controller is used.

The eI controller is applied in frequency converters for automatic control of AC induction motor rotation speed. The frequency converters with the embedded eI controller are developed and produced in Center for Physical Sciences and Technology.

Conclusions

1. Employment of the eI controller allows us to reduce the control system response transient settling time as compared with the case when the I controller is used.

2.The control system based on the eI controller is characterized by a longer response transient settling time but in case of plants with time-delayed processes*,* which are typical in the process industry, is more EMD resistant as compared with the situation when a popular PI controller is used.

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Author: *prof. dr. Algirdas Baskys, Computer Engineering Department of Vilnius Gediminas Technical University, Naugarduko str. 41, 03227 Vilnius, Lithuania, E-mail: algirdas.baskys@vgtu.lt.*