NEW IDENTIFICATION AND PI CONTROLLER DESIGN METHODS FOR NEW STATIONARY STATE SYSTEM WITH NON-OSCILLATORY OPENED LOOP RESPONSE

[1]Linda Christelle Mevalaza, [2]Randriamanantenasoa Njeva, [3]Andrianantenaina Tsiory Patrick, [4]Jean Claude Rakotoarisoa, [5]Hervé Mangel, [6]Jean Nirinarison Razafinjaka

[1] *PhD Student, Doctoral School, Thematic Renewable Energies and Environment, University of Antsiranana, Madagascar,*
[2,3,4,5,6] *Dr Eng. Department of Electricity, Higher Polytechnic School, University of Antsiranana, Madagascar,*

ABSTRACT: *This study has two goals: proposal of a new empirical method to identify a new stationary state system (NSSS) with non-oscillatory in opened loop response and a proposal of new PI controller design. The objectives are to establish only one program for these methods and to applied this program for real sites or to dedicate it to work practice students. Indeed, the platform LabView provided with its peripheral NI-6009 is well adapted. The new empirical method is based on Broïda's one and the new PI controller design starts from the flat-criteria proposed by Pr. Bühler. The program is easy to be implemented. Simulation results show that the proposals give better performances.*

KEYWORDS: *Identification, Empirical method, PI Controller, Design.*

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1. INTRODUCTION

The Strjec's method, Broïda's method [1] and Ziegler Nichols 'one [2] are well-known empirical methods. An empirical method is based on observation and experiences but not on theory. The two first cited are for systems identification and the third is devoted to controllers' design, especially for P, PI and PID. The methods are applied on new stationary state system with-non oscillatory in opened loop response. Currently several proposals are given to improve or to optimize them [3], [4], [5]. The principal rests to store or to record the output according the time. Figure 1 presents the case where the input, time and the response are stored: x[k], t[k], y[k]. There are N components (measurements) for each vector.

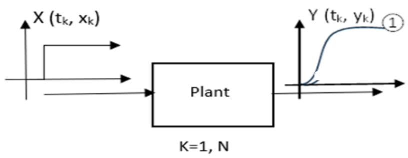


Fig. 1 Principle of the two methods

The paper is organized as follows: first, data acquisition is started, followed by the Broïda's identification. In identification, it is important to do validation: it consists to compare the experimental curve with the response obtained by Broïda's model. Then, the new method called "Njaka's method" (NM) is presented followed by the comparison. At the end, the analysis in closed loop with a PI controller for the different models are given. This kind of controller is naturally chosen because of the function transfer form (TF) proposed by Broïda: a first order system with a time delay. Several models are taken into account and a new method called "General method" (GM) which generalizes the flat-criteria is proposed.
Figure 2 shows the general flowchart of the program. As said above, the experimental curve is obtained by numerical values.

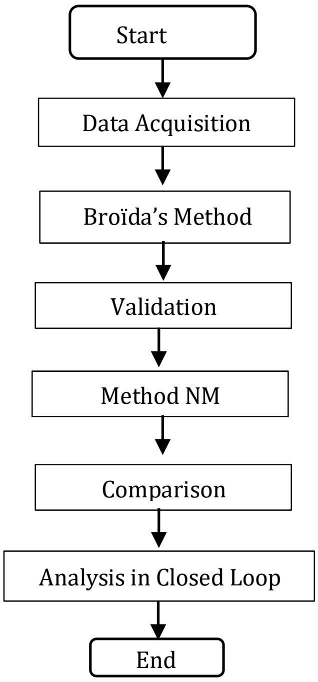


Fig. 2 General flowchart

2. SYSTEM IDENTIFICATION

In this section, two methods are presented: the Broïda's method and the new empirical method (NM).

2.1 Broïda's method

The identification is based on Broïda's method who proposes the transfer function (TF) of the system as follows:

$$G(p) = g\,\frac{e^{-pTo}}{(1+pT)} \qquad (1)$$

Where, g is the static gain, T is the constant time and *to* the delay time.
The determination of these three parameters is given according the Figure 2.

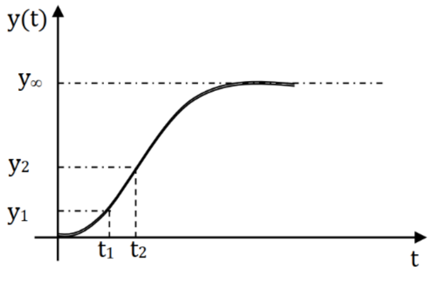


Fig. 3 Broïda's method

Having the final value y_∞, two output values y_1 and y_2 and the corresponding times t_1, t_2, are calculated as:

$$\begin{cases} y_1 = y(t_1) = 0,28.y_\infty \\ y_2 = y(t_2) = 0,4.y_\infty \end{cases} \qquad (2)$$

And,

$$\begin{cases} g = \dfrac{\Delta y}{\Delta x} \\ T = 5,5(t_2 - t_1) \\ To = 2,8.t_1 - 1,8.t_2 \end{cases} \qquad (3)$$

Relations (2) and (3) constitute the empirical Broïda's proposal.

2.1.1 Application

Figure 4 shows a curve obtained by simulation of a known system. It is only the measurements which are stored and taken into account. This corresponding curve defined by measurements is considered as the experimental one. Here, a step input is applied and relations (2) and (3) give:

$$\begin{cases} y_\infty = 0,833 \\ y_1 = 0,233 \\ y_2 = 0,333 \end{cases} \qquad \begin{cases} t_1 = 1,018\ [s] \\ t_2 = 1,418\ [s] \end{cases} \tag{4}$$

Then,

$$\begin{cases} g = 0,833 \\ T = 2,20\ [s] \\ To = 0,299[s] \end{cases} \tag{5}$$

The resulting TF is:

$$G_B(p) = 0,833 \frac{e^{-0,299\,p}}{1+2,20\,p} \tag{6}$$

Figure 5 gives both the curve resulting by Broïda's method and the experimental one

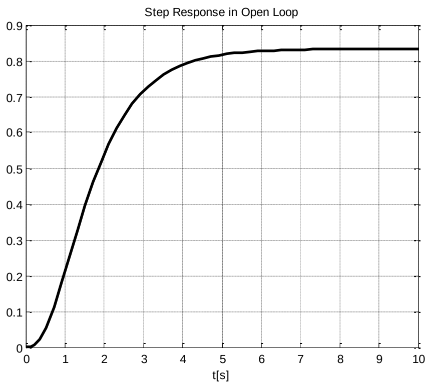


Fig.4 Experimental curve

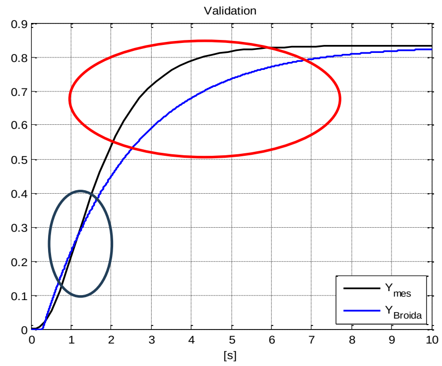


Fig. 5 Curves: Experimental and from Broïda

Discussion

- The curve obtained by Broïda shows a rather notable dynamic error.
- However, there is correspondence around the points y_1 and y_2 and the final value is reached.
- This difference is due to the time constant value. By looking at Fig. 4, T is greater than the real time constant.

A new empirical method is now introduced.

2.2 New empirical method (NM)

The new proposal takes into account all the remarks said above. It proposes to bring correction or amelioration by introducing a third expression in relation (2) and changing completely relation (3). Fig.5 shows the principle of the method.

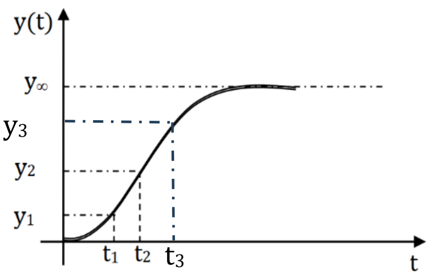


Fig. 6 Principle of NM

The new proposed equations are as follows:

$$\begin{cases} y_1 = y(t_1) = 0,28.y_\infty \\ y_2 = y(t_2) = 0,40.y_\infty \\ y_3 = y(t_3) = 0,75.y_\infty \end{cases} \quad (7)$$

$$\begin{cases} g = \dfrac{\Delta y}{\Delta x} \\ T_{NM} = 1,45.(t_3 - t_2) \\ To_{NM} = 2,9.t_1 - 1,8.t_2 \end{cases} \quad (8)$$

The two first expressions are the same like as Broïda. The third expression giving y_3 is introduced. The constant time is calculated by using t_3 and t_2.

2.2.1 Application

The NM method is applied to the same experimental measurements (Fig. 3). Eq. (7) and (8) give:

$$\begin{cases} y_1 = 0,233 \\ y_2 = 0,333 \\ y_3 = 0,625 \end{cases} \qquad \begin{cases} t_1 = 1,018[s] \\ t_2 = 1,418[s] \\ t_3 = 2,419[s] \end{cases} \quad (9)$$

Then,

$$\begin{cases} g = 0,833 \\ T_{NM} = 1,46\ [s] \\ To_{NM} = 0,40[s] \end{cases} \quad (10)$$

The new TF is as follows:

$$G_{NM}(p) = 0,833 \frac{e^{-0,4p}}{1+1,46p} \quad (11)$$

Figure 6 presents the comparison of the curves resulting from the two methods and the experimental one and Figure 7, the zooms.

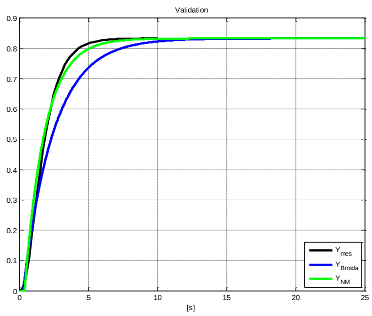
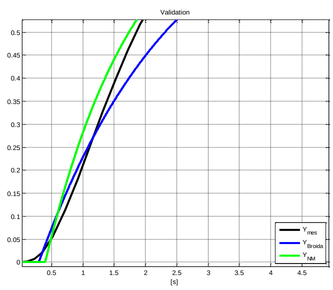
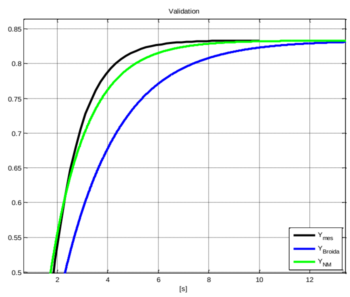


Fig. 6 Comparison between different curves



(a)



(b)

Fig. 7 zooms: (a) starting and (b) final

It is here highlighted that the new empirical method leads to better result: the curve follows better the experimental one. Because of the new time-constant T_{NM} less than the Broïda's one T, the step response by NM method is faster and reaches the final value earlier.

3. ANALYSIS IN CLOSED LOOP

In this section, a PI controller is specially chosen because of the system order: a first order one with time delay. The product form is adopted. Figure 8 shows the functional scheme (FS).

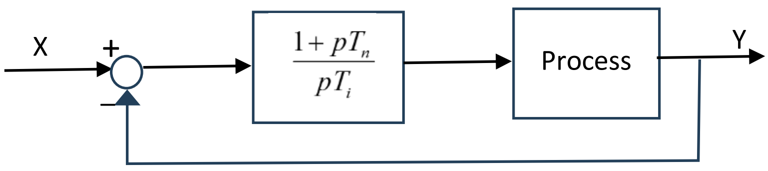


Fig. 9 Functional scheme in closed loop with PI controller

The TF of the PI controller is:

$$G_R(p) = \frac{1+pT_n}{pT_i} \quad (12)$$

With T_n is the proportioning correlation for integral time and T_i is the integral constant-time.
In [6], Bühler et *al* propose the flat-criteria for new stationary system with non-oscillatory opened loop response. Generally, the flat-criteria is not applicable on system with pure first order. However, if the time delay T_o is taken into account and considered as a little constant time, the flat-criteria can be used. The two parameters are given as follows:

$$\begin{cases} T_n = a.T \\ T_i = bKT_p \end{cases} \quad (13)$$

With $\boldsymbol{a} \geq 0$, $\boldsymbol{b} > 0$ and T_p is the little constant time ($T_p < T$).

3.1 Flat criteria (FC)

For the flat criteria, $\boldsymbol{a} = 1$ and $\boldsymbol{b} = 2$. It means that the constant time T is cancelled. In this case, the time delay is considered as a little constant time ($T_p = To$). Then,

$$\begin{cases} T_n = T \\ T_i = 2KT_O \end{cases} \quad (14)$$

The TF in opened loop (TFOL) with the PI controller is,

$$G_o(p) = G_R(p).G(p) \quad (15)$$

By considering, Eqs (1), (12) and (14), Eq (15) becomes,

$$G_o(p) = \frac{e^{-pTo}}{2.pT_o} \quad (16)$$

Here, $g = K$.

3.2 General method (GM)

Considering Eqs (1), (13) and (15) and taking into account the conditions for the constants $\boldsymbol{a}$ and $\boldsymbol{b}$, the TFOL is,

$$G_o(p) = \frac{1+paT}{b.pT_o}\frac{e^{-pTo}}{(1+pT)} \quad (17)$$

It is here highlighted that the GM generalizes the flat-criteria. It gives more possibilities to design the PI controller.

3.3 Applications

By considering that the time delay To small compared with the constant time T ($To < T$), a linear form can be obtained by considering the enter development in series of the exponential term, limited at the first order:

$$e^{-pTo} \approx \frac{1}{(1+pTo)} \quad (18)$$

Then, Eq. (1) becomes,

$$G(p) = \frac{1}{(1+pT_o)} \cdot \frac{K}{(1+pT)} \tag{19}$$

3.3.1 FC and GM

The flat criteria (FC) and the general method (GM) are applied to the system with T_o and with the linearized system. Then, a comparison with the responses obtained by the Broïda's method and the (NM) method are presented. Fig.9 presents the different curves.

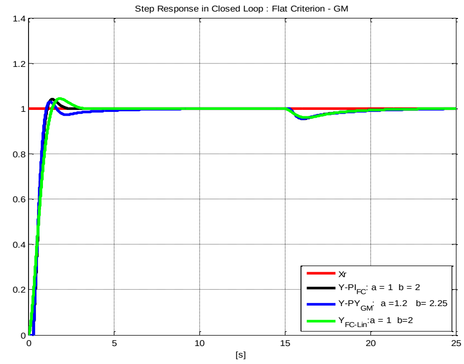
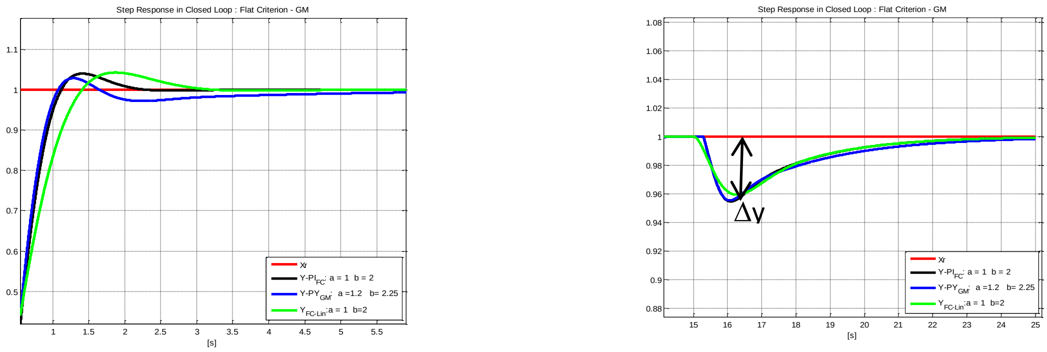


Fig.10 Step responses of the three models in closed loop

At t = 15 [s], a load is applied. Fig. 11 shows each zoom at the beginning and during the application of a load.



(a) (b)

Fig. 11 Zooms at the beginning (a) and during load application (b)

Table 1 resumes the performances of the three models.

Table 1 Performances of the three models

	System with To		Linear system
	PI- FC	PI-GM	PI-FC
D1 [%]	4,0	2,9	4,3
tp [s]	1,44	1,26	1,85
□y	0,045	0,045	0,04

With D1 [%] is the overshoot and tp [s], the peak time.

- The system provided by GM -PI controller is faster than the system with PI controller designed by flat criteria but however, the system with GM-PI controller has less overshoot.
- It is seen here that they have the same reaction during load application.
- The linearized system is slower than the others but it is less sensitive to the disturbance.

3.3.2 Models Broïda and NM

To compare the results obtained by the two models, first the same PI controller designed by FC and then results from PI-FC and PI-GM are presented. Fig.11 shows the curves of Broïda and the new model with PI-FC.

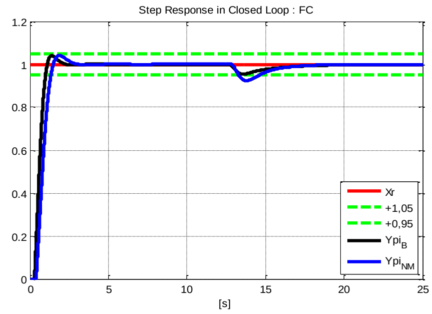


Fig. 11 Step responses in closed loop for the two models

Even if the time-constant T_{NM} is smaller than the Broïda's one, the step response for the new model is slower than the other. Moreover, it can be noted that it is more sensitive to the disturbances. It suggests that the time delay *To* has an effect on the dynamic behavior of the system.

Fig.12 shows the step responses in closed loop obtained by the Broïda's model with PI-FC and by the new model with PI-GM and their respective zooms. In this last case,

$$\begin{cases} a = 1,22 \\ b = 2,15 \end{cases} \tag{20}$$

The response of the new model with PI-GM is little slower than the other and it presents a less overshoot D1. It is more sensitive to disturbances. The two curves have a response time t_R in the band of ± 5% except for the NM model during disturbance application.

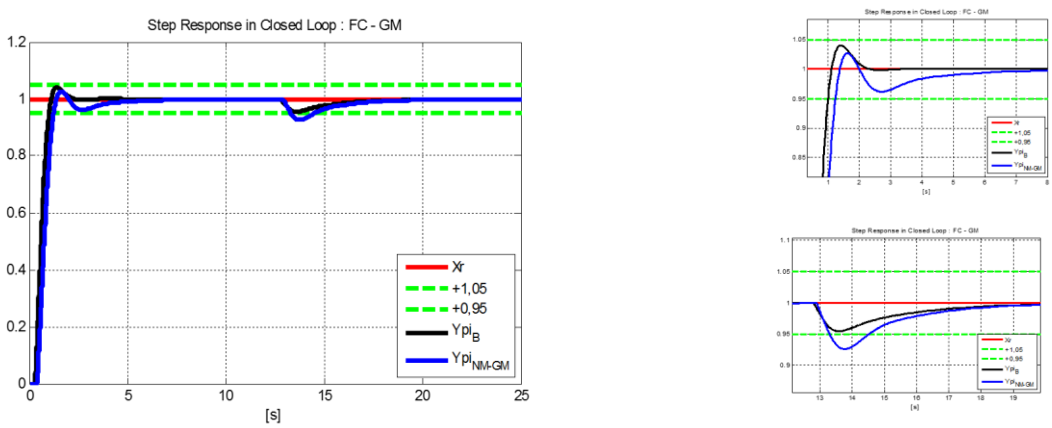


Fig. 12 Step responses in closed loop by the two models and zooms

CONCLUSIONS

In this paper, a new empirical method is proposed to improve or to optimize the Broïda's one. The obtained results are better. However, because the system is defined by numerical measurements, the higher the number of measurements N is, the more the two methods are precise.

In another hand, a generalized method to design PI controller is done. Simulation results show that GM method offers more possibilities by being able to change the two parameters (***a***, ***b***) and it generalizes the FC. It should be noted that advanced methods as using neural, fuzzy logic or genetic algorithm can be used but, in this paper, the aim is to adopt a simple method which can be applied directly in industrial sites or applied as practice works for students.

REFERENCES

1. Mikleš, J., Fikar, M., Process Modelling, Identification and Control, Springer, Verlag Berlin Heidelberg, 2007.
2. J.G. Ziegler, N.B. Nichols, Optimum settings for automatic controllers, Trans. ASME, 64, pp. 759-768, 1942.

3. Dawid Ostaszewicz, Krzysztof Rogowski, Application of Genetic Algorithms for Strejc Model Parameter Tuning, Electronics, MDPI, *Electronics* 2024, *13*, 3652. https://doi.org/10.3390/electronics13183652.
4. Holiarimanga Mariette Randriamanjakony, Andrianantenaina Tsiory Patrick, Jean Nirinarison Razafinjaka, New PI Controller Design and Applications, International Journal of Engineering Research and Technology, Vol. 11, Issue 04, April 2022, pp 318-325.
5. Jean Nirinarison Razafinjaka, Andrianantenaina Tsiory Patricka, Andriamanjakony Holiarimanga Mariette, Linda Christelle Mevalaza, Automatic Programming of Ziegler-Nichols and Strejc Methods based on Opened Loop Response, International Journal of Multidisciplinary and Current Research, DOI: https://doi.org/10.14741/ijmcr/v.12.5.4, pp 600-605.
6. H. Bühler, Conception des systèmes automatiques, Presses Polytechniques Romandes, Lausanne, 1988.