Rev. Roum. Sci. Techn.– Électrotechn. et Énerg.
Vol. **70**, *4*, pp. 543–548, Bucarest, 2025

SIGNIFICANT NOTES AND NEWLY DEFINED ACCURATE TERMS REGARDING CONTROLLED LINEAR SYSTEMS

ABDELHAMID DJARI[1], NOUREDDINE BOUARROUDJ[2], YEHYA HOUAM[2], RIADH DJABRI[1]

Keywords: Linear systems; Performances; Maximum overshoot; Settling time; Step response; Ramp response; Steady state.

In certain instances, the conventional performance definitions can lead to misinterpretations in the control of linear systems. Hence, it becomes imperative to rectify these definitions. This paper presents new, precise definitions of performance metrics, along with significant insights into the transient and steady-state phases. Specifically addressing step responses, we refine conventional definitions of overshoot, rise time, and settling time for systems with final response values of zero. Furthermore, we give due consideration to the open-loop phase margin in stable systems. For the ramp response of controlled systems, where final values tend to infinity, we introduce new, accurate definitions of overshoot and settling time that apply in such cases. Numerous illustrative simulation examples are provided for each appended note.

1. INTRODUCTION

Modern control techniques for robotics, industry, and cybernetics are incorporated into automatic regulation, which is recently dubbed "automatic control". This is mostly because electronics first emerged, followed by the microprocessor in the Sixties and data processing as a result. However, it is important to emphasize that even in fields as complicated as nuclear power, the traditional methods of regulation are still commonly employed. The goal of the automation engineer or control designer is always to raise the regulated systems' performance and bring them up to the required standards. The stability, which is defined by the final value in a steady state, the initial overshoot in a transient state, and the speed, which is determined by the rise time and settling time, are among these performances.

Most analog system designs have oscillatory transient behavior, which is unacceptable because it causes incorrect input sequence interpretation and an improper sequence of control operations. Maximum overshoot is a crucial and obvious indicator of the effectiveness of transitory responses. This index has drawn the attention of several authors, who view it as the most significant indicator of the stability of regulated systems [1–3].

The control systems are designed in accordance with the minimum value of the settling time. It considers it as a performance to increase the speed in controlling systems, according to the bibliographic references [4–8]. These recent publications demonstrate the significance of this parameter in control systems.

A positive phase margin is sought after by the authors of certain recent studies to ensure stability [9–10]; however, many systems, such as non-minimum phase systems, can be stabilized with a negative phase margin [11,12].

For stable step responses in the steady state with final values that are not zero, all these performances have been precisely described. Sadly, certain parameter definitions must be altered if the result is zero. The fact that the responses in the case of system tracking follow this ramp and suggest that the final value tends towards infinity means that we also need other definitions of these performances in addition to the ramp responses. Particularly dependent on the control and tracking of linear systems are several works and bibliographical references linked to this topic [11–15].

This paper's key contribution is the development of new valid definitions for some traditional properties of linear controlled systems, including overshoot, rise time, settling time, and phase margin. Nevertheless, we reformulate these results using fresh, accurate formulas tailored to specific step- and ramp-response scenarios.

The main contribution of this article is divided into two parts: The first part focuses on a significant modification of two key parameters related to the time-domain performance of linear system responses. Additionally, it highlights an important observation regarding systems with **negative phase margins**, which affects their stability in the frequency domain. The two parameters in question are **overshoot** and **settling time**, specifically in cases where the steady-state response tends to zero. These parameters hold practical significance for control system designers aiming to enhance **stability** and **speed** during the transient phase.

The second part introduces, for the first time, **new definitions** of **overshoot** and **settling time** for systems subjected to a **ramp input** in the time domain.

The content of the paper is as follows: Section 2 presents comments on the performance of step responses, including maximum overshoot, settling time, and phase margin. Revised definitions for maximum overshoot and settling time in ramp time responses are also provided in this section. Section 3 summarizes the conclusions.

2. REFORMULATION OF PERFORMANCE DEFINITIONS

In this paragraph, some remarks on temporal performance, such as settling time, maximum overshoot, and final value, are included, along with their new definitions. Additionally, an important note on frequency performance, specifically phase margin, is added.

2.1 FOR STEP INPUT RESPONSE

Numerous systems, when stimulated by a step input, generate stable step responses, leading to final values approaching non-zero finite values. However, some systems yield final values that are close to zero. In such instances, the definitions of specific performance parameters mentioned earlier need to be adjusted due to these zero final values, as

[1] Electrical Engineering Department, Echahid Cheikh Larbi Tebessi University, Tebessa, Algeria. (corresponding author).
[2] Unité de Recherche Appliquée en Énergies Renouvelables, URAER, Centre de Développement des Énergies Renouvelables, CDER, Ghardaïa, 47133, Alegria.
E-mails: riadh.djabri@univ-tebessa.dz, n.bouarroudj@cder.dz; yahiahouam@gmail.com, riadh.djabri@univ-tebessa.dz

DOI: 10.59277/RRST-EE.2025.70.4.4

elaborated in the subsequent paragraphs.

2.1.1 MAXIMUM OVERSHOOT

The conventional definition of maximum overshoot is outlined as follows:

- Maximum overshoot (MO): It represents the vertical gap between the maximum peak of the response curve and the horizontal line from unity (the final value).
- Percent overshoot (PO%): it quantifies the extent to which the underdamped step response surpasses the steady-state or final value at the peak time, expressed as a percentage of the steady-state value [11, 13]. This definition can be formulated using the following equation [13–16]:

$$PO\% = \left(\frac{M_{tp}-f_v}{f_v}100\right)\ \%. \quad (1)$$

In the context of this definition, where M_{tp} represents the time response's peak value, and f_v is the response's final value. In situations where the final value converges to zero (or nearly zero), as depicted in Fig. 1, it can be inferred from this definition that the percent overshoot tends towards infinity. It's important to note that this scenario signifies the system's relative stability.

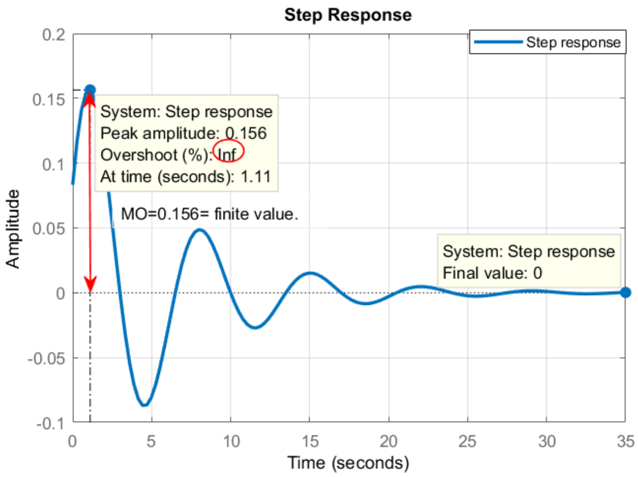

Fig. 1 – Stable step response in a closed loop where the percent overshoot tends to infinity.

- New definition of maximum overshoot

The magnitude of the highest overshoot is referred to as the maximum overshoot (MO), and it typically occurs initially. As indicated in equation (3), the MO is a concluding value; hence, it can be recalculated in relation to the input value rather than the final value, as follows:

$$PO\% = \lim_{u\to\alpha}\frac{(M_{tp}+u)-(f_v+u)}{(f_v+u)} \times 100\% = \frac{M_{tp}}{\alpha} \times 100\%. \quad (2)$$

For the transient response to a unit-step input ($u = \alpha = 1$), the maximum overshoot is defined as follows:

$$PO\% = M_{tp}\text{x}100\%. \quad (3)$$

This value is well justified for the designer, as it results in a finite percentage. In contrast, the conventional definition indicates an overshoot tending toward infinity, which would imply that the system is unstable. However, the system remains stable.

✓ ***Remark 1*:** When ($u = \alpha = 0$) (system enslaved to tracking zero value), directly use the PO% value described in equation (3).

✓ ***Example 1:*** Consider a linear system defined by its open-loop transfer function $G(p)$:

$$G(p) = \frac{p(p+12)}{p^2+2p+111}. \quad (4)$$

This system is placed in a closed loop with unit feedback (Fig. 2).

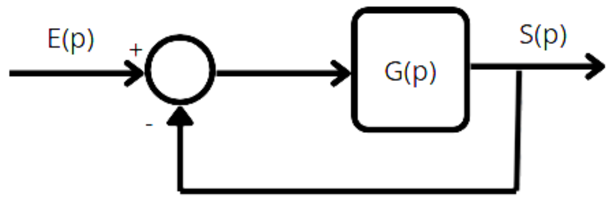

Fig. 2 – Simple control loop.

The step response (system excited by a unit step) of this closed-loop system is illustrated in Fig. 3.

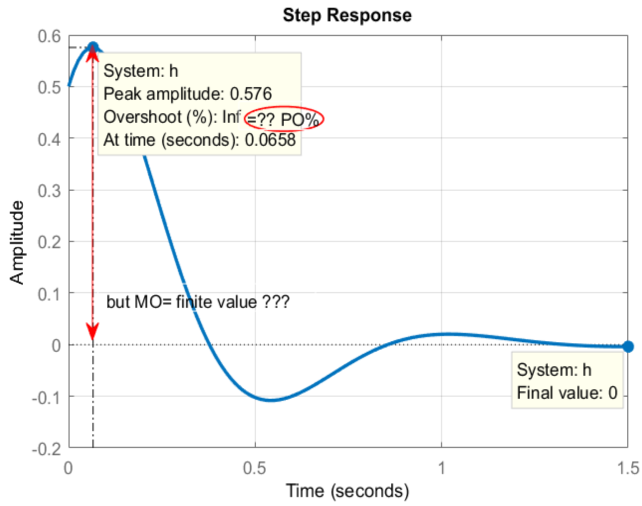

Fig. 3 – Stable step response in a closed-loop where the percent overshoot tends to infinity.

Figure 3 indicates that MO is approaching infinity, even though the response is stable and tends towards a finite value of zero. This poses a challenge for the designer in deciding whether to add a regulator to the closed loop to reduce the overshoot.

According to the traditional eq. (1), the overshoot value is infinite, which fails to provide a meaningful indication of stability, even though the system is stable in steady state. Additionally, the distance between the peak response and the final value remains finite (see Fig. 3). Therefore, it becomes necessary to modify formula (1) and replace it with the proposed alternative (3) to account for this specific case accurately.

Applying eq. (3), where the overshoot is determined by the excitation input value, yields a result of $MO\% = M_{tp} \times 100\% = 57.6\%$. This value signifies that the maximum deviation is 57.6% compared to the unit step, Fig. 4.

This new overshoot value indicates that the system is stable since it remains finite. Additionally, the designer takes this finite value into account to develop an appropriate control strategy aimed at minimizing oscillations during the transient response.

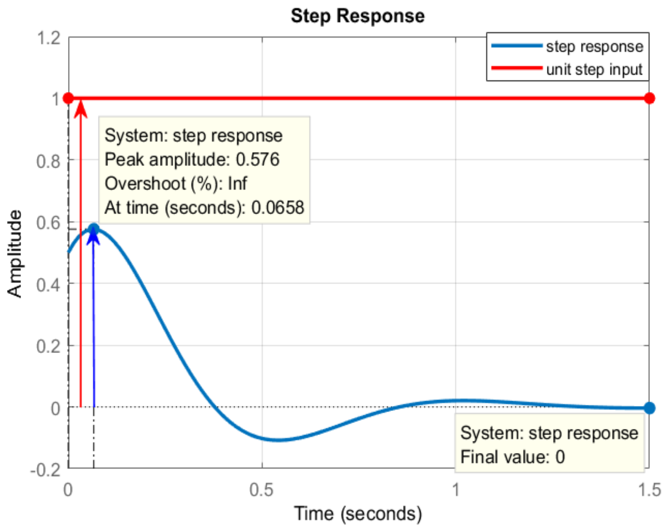

Fig. 4 – The percentage overshoot is calculated using a unit step input.

2.1.2 SETTLING TIME

The classical definition of settling time is commonly explained in various books and research papers as follows: Settling time, denoted as t_s is the duration required for system transients to decay [17-18]. Alternatively, it is defined as the time it takes for an output $s(t)$ to reach and remain within a tolerance range surrounding the final value f_v (± 10%, ± 5%, or ± 2%) [15]. This definition can be expressed quantitatively (in the case of ±5%) as follows:

$$s(t_s) = f_v \pm (t_{sx\%}) \text{x} f_v. \qquad (5)$$

To calculate the value of t_s, one must solve equation (5).

Several recent practical studies have used this important parameter to measure the speed of control systems, such as power systems [19].

However, when $f_v = 0$ the solution of the above equation remains the same for all percentage cases (2%, 5%, ...). Therefore, the classical definition of settling time needs to be redefined with a new definition suitable for the scenario of a zero final value in the controlled system response. It is imperative to re-solve equation (5) using the following new definition.

- New definition of settling time

Settling time (t_s) represents the duration for the step response to stabilize and maintain a specific distance from its final value. Commonly used percentages for this distance are 2% and 5% [14]. The conventional expression for settling time, as defined in eq. (5), needs to be rephrased for systems where responses converge to a final value of zero, resulting in the new formulation (Fig. 5):

$$s(t_s) = \pm(t_{sx\%}). \qquad (6)$$

where: $t_{sx\%} = 2\% = 0.02$ or $t_{sx\%} = 5\% = 0.05$.

Figure 5 shows that the analytical solution (settling time) for the response time of equation (6) is $t_{s5\%} = 1.18\ s$.

✓ ***Remark 2:*** The settling time corresponds to the maximum instant among the solutions to eq. (6) based on the preceding definition and computation of t_s (see Fig. 5).

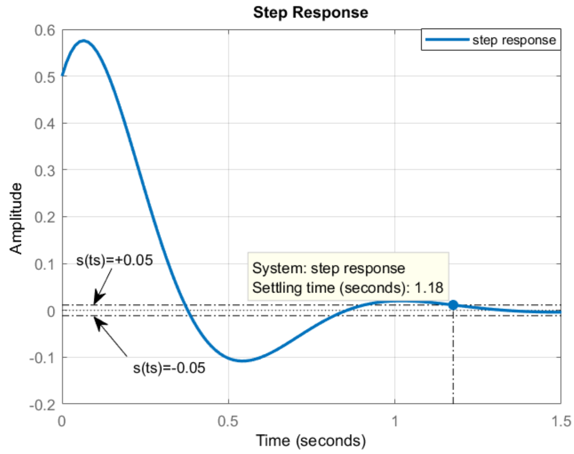

Fig. 5 – Determination of the settling time where the final value equals zero.

2.1.3 PHASE MARGIN

In cases where the phase margin is negative, the authors cited in the bibliographic reference [5] assert that the system is considered unstable. However, it can be deduced from several simulation instances that a negative phase margin value (evidently in open loop) does not always signify instability in the closed loop (refer to Fig. 6). Following the "Nyquist" reverse criterion, the system is deemed stable in a closed loop if the Nyquist diagram positions the critical point (-1, 0) to its left [16, 18, 20]. This implies that the intersection of the curve with the unit circle produces either a positive or a negative phase margin.

✓ ***Example 2:*** The following linear system, defined by its open-loop transfer function, is considered:

$$G(p) = \frac{p^2}{p^2+p+1}. \qquad (7)$$

Figure 6 illustrates the Nyquist Diagram of the open-loop system.

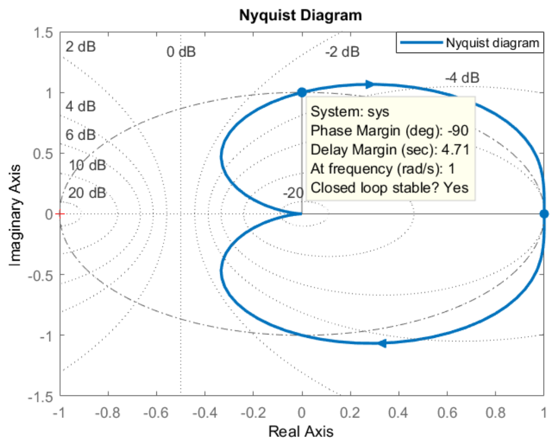

Fig. 6 – Negative phase margin according to the Nyquist diagram.

Despite having a negative phase margin, the system is stable in a closed loop (Fig. 6). However, most designers tend to immediately conclude that the system is unstable solely based on its negative phase margin.

✓ ***Remark 3:*** Sometimes the stable transfer function is multiplied by a negative gain, which causes the issue of the phase margin value having a negative sign. The error signal can be thought of as the output feedback signal minus the reference signal to obtain a positive phase margin value [21–24].

2.2 FOR RAMP INPUT RESPONSE

This section furnishes various definitions for the performance metrics mentioned earlier, including the settling time in the ramp response. Conversely, considering the potential risk of compromising the closed-loop control system when an undesirable maximum overshoot value is present within specified criteria, the significance of the maximum value of the first half-wave in the ramp response is highlighted by the initial overshoot. This provides insight into the accuracy of tracking the ramp in a transient state.

2.2.1 MAXIMUM OVERSHOOT

- Case of non-unitary ramp input

The procedures listed below can be used to determine the proper formulation of the maximum overshoot in the case of a non-unitary ramp input.

Given that the input follows the form of equation (8):

$$y(t) = at. \qquad (8)$$

with: $\tan(\theta) = a$ or $\theta = \mathrm{atan}(a)$.

The line with slope a (parallel to the reference line) passes through the point (t_{max}, y_{max}) and intersects the line $t = 0$ at point $(0, b)$; the equation for this line is as follows:

$$y(t) = at + b. \qquad (9)$$

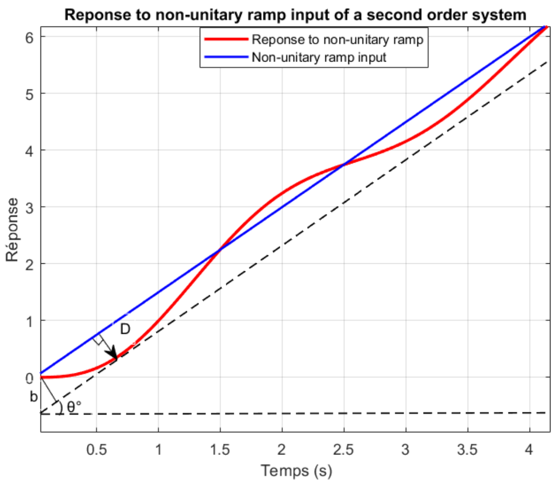

Fig. 7 – Maximum overshoot of the response to a non-unit ramp.

In this instance, from equation (9) the extreme points are given by equation (10).

$$\frac{\mathrm{d}y(t)}{\mathrm{d}t} = a. \qquad (10)$$

The first moment is obtained by setting $t_{max} = \min(t_i)$, and the greatest value y_{max} of the response is obtained at this instant, $y_{max} = y(t_{max})$.

The value of b can be calculated using eq. (9) as:

$$y_{max} = a.t_{max} + b \quad \Rightarrow \quad b = y_{max} - at_{max}. \qquad (11)$$

Equation (12) can then be used to determine the value of the maximum overshoot, as shown in Fig. 7.

$$\cos(\theta) = \frac{|D|}{|b|} \quad \Rightarrow \quad |D| = |b|\cos(\theta). \qquad (12)$$

Equation (12) allows us to reformulate the maximum overshoot equation for a non-unitary ramp input as follows:

$$|D|\% = \frac{|b|\cos(\theta)}{100}. \qquad (13)$$

- Case of unit ramp input

In this case, setting the response's derivative to 1 (directly parallel to the unitary ramp) yields the output's maximum value:

$$\frac{\mathrm{d}y(t)}{\mathrm{d}t} = 1. \qquad (14)$$

The solution of this equation yields instances of the values of extremes (minimums and maximums); $y_{max} = y(t_{max})$ is the response's maximum value at the precise moment t_{max}. When cutting the line $t = 0$ at point (0, b), the line with slope 1 (parallel to the reference line) passes through point (t_{max}, y_{max}) and bears the following equation:

$$y = t + b. \qquad (15)$$

One can determine the value of b from the point (t_{max}, y_{max}) as follows:

$$y_{max} = t_{max} + \mathrm{b} \quad \Rightarrow \quad \mathrm{b} = y_{max} - t_{max}. \qquad (16)$$

On the other hand, Fig. 8 shows that one can calculate the overshoot's absolute value as follows:

$$\sin\left(\frac{\pi}{4}\right) = \cos\left(\frac{\pi}{4}\right) = \frac{|D|}{|b|} = \frac{1}{\sqrt{2}} \qquad (17)$$

$$\Rightarrow |D| = \frac{|b|}{\sqrt{2}}. \qquad (18)$$

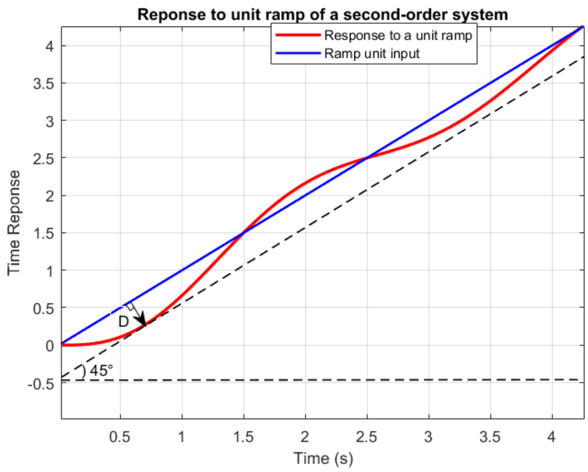

Fig. 8 – Maximum response overshoot to a unit ramp.

Substituting of eq. (16) in eq. (18) gives:

$$|D| = \frac{|y_{max} - t_{max}|}{\sqrt{2}}. \qquad (19)$$

In the case of unit ramp input and based on Equation (19), the maximum overshoot expression can be rewritten as follows:

$$|D|\% = \frac{|y_{max} - t_{max}|}{100\sqrt{2}} \qquad (20)$$

2.2.2 SETTLING TIME

In this study, the settling time expression is reformulated for two input scenarios: unit and non-unitary ramp.

- Case of non-unitary ramp input

The equation of the line cut by the response curve in the case of a non-unitary ramp input is provided by: $y(t) = a't + b'$, and the settling time to $\delta\%$ is derived as follows (Fig. 9). We have:

$$\sin\left(\frac{\pi}{2} - \theta\right) = \frac{\delta/100}{b'} = \cos(\theta) \Rightarrow b' = \frac{\delta}{100\cos(\theta)} \quad (21)$$

with $\theta = \text{atan}(a')$.

Finally, the settling time δ% must correspond to the last instant ts among the eq. (22) solutions:

$$y(t_s) = a't_s \pm \frac{\delta}{100\cos(\theta)}. \quad (22)$$

Example 3: Consider a unit feedback tracking loop with a linear system of the transfer function $G(p)$:

$$G(p) = \frac{12}{2p^2 + p + 0.01}. \quad (23)$$

A ramp with a 1.5 slope ($r(t) = 1.5t$) is used to excite the system. Figure 9 illustrates the system's response to this reference. To obtain the 5% response time, the formulas quoted above are applied: $\theta = \text{atan}(a') = \text{atan}(1.5) = 56.3103°$

and from equation (22) one can obtain:

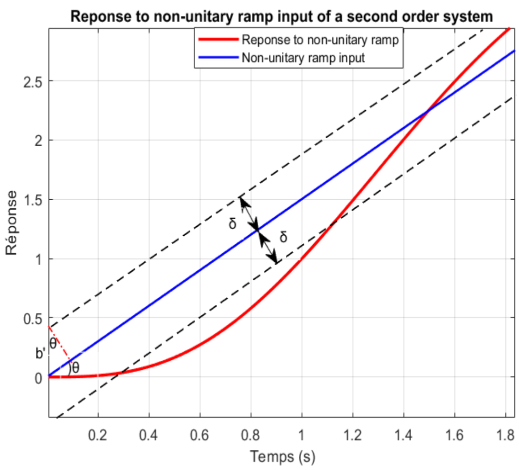

Fig. 9 – Settling period of a non-unit ramp's response.

$$y(t_s) = a't_s \pm \frac{\delta}{100\cos(\theta)} = 1.5t_s \pm \frac{5}{100\cos(56.3103°)}. \quad (24)$$

$$\Rightarrow \quad y(t_s) = 1.5t_s \pm 0.0901. \quad (25)$$

On the other hand, the expression of the response is obtained using the Laplace transform:

$$H(p) = \frac{G(p)}{1+G(p)} = \frac{Y(p)}{R(p)} = \frac{6}{p^2+0.5p+6.005} \quad (26)$$

$$\Rightarrow \quad Y(p) = H(p).R(p) = \frac{6}{p^2+0.5p+6.005} \cdot \frac{1.5}{p^2} = \frac{9}{p^2(p^2+0.5p+6.005)} \quad (27)$$

$$\Rightarrow y(t) = TL^{-1}(Y(p)) = 1.4988t - 0.1248 + e^{-0.25t}[0.1248\cos(2.4377t) - 0.6020\sin(2.4377t)] \quad (28)$$

Equation (29) can be created using eq. (25) and (28), and it takes the following form:

$$1.4988t_s - 0.1248 + e^{-0.25t_s}[0.1248\cos(2.4377t_s) - 0.6020\sin(2.4377t_s)] = 1.5t_s \pm 0.0901. \quad (29)$$

We'll search for any moments that meet the two equations that follow, which are derivations of equation (29):

$$-0.0012t_s - 0.2149 + e^{-0.25t_s}[0.1248\cos(2.4377t_s) - 0.6020\sin(2.4377t_s)] = 0, \quad (30)$$

or

$$-0.0012t_s - 0.0347 + e^{-0.25t_s}[0.1248 \times \cos(2.4377t_s) - 0.6020\sin(2.4377t_s)] = 0. \quad (31)$$

Within the time range [0, 20], the solutions of eq. (30) and (31) that were found are, respectively:

$t_1 = 1.6000$; $t_2 = 2.3756$; and $t_1 = 0.0603$; $t_2 = 1.4052$; $t_3 = 2.6128$; $t_4 = 4.0226$; $t_5 = 5.1393$; $t_6 = 6.6823$; $t_7 = 7.6115$; $t_8 = 9.4875$; $t_9 = 9.9275$.

In accordance with the definition of settling time, the last solution (*i.e.*, t_9) will be selected. So, the settling time will be: $t_{s5\%} = 9.9275$ s.

Now, to calculate the overshoot, the eq. (10), (11), and (12) are used:

$$\frac{dy(t)}{dt} = 1.4988 - e^{-0.25t}[1.4987\cos(2.4377t_s) + 0.1537\sin(2.4377t_s)]. \quad (32)$$

We set $\frac{dy(t)}{dt} = a = 1.5$; this yields the following equation:

$$\frac{dy(t)}{dt} = 1.4988 - e^{-0.25t}\begin{bmatrix}1.4987\cos(2.4377t) + \\ 0.1537\sin(2.4377t)\end{bmatrix} = 1.5, \quad (33)$$

$$\Rightarrow \quad -0.0012 - e^{-0.25t}\begin{bmatrix}1.4987\cos(2.4377t) + \\ 0.1537\sin(2.4377t)\end{bmatrix} = 0 \quad (34)$$

The solutions of eq. (34) in the time interval [0, 20] are:

$t_1 = 0.6866$; $t_2 = 1.9745$; $t_3 = 3.2645$; $t_4 = 4.5515$; $t_5 = 5.1393$; $t_6 = 5.8425$; $t_7 = 7.1281$; $t_8 = 8.4215$; $t_9 = 9.7035$; $t_{10} = 12.2780$; $t_{11} = 13.5835$; $t_{12} = 14.8492$; $t_{13} = 16.1699$; $t_{14} = 17.4151$; $t_{15} = 18.7645$; $t_{16} = 19.9693$;

The first solution (the first moment) will be chosen, as indicated in sub-subsection 2.2.1; so $t_{max} = 0.6866\ s$.

This solution is used for the calculation of a constant b as follows.

$$y_{max} = y(t_{max}) = 0.3891 \Rightarrow \quad b = y_{max} - a.t_{max} = 0.3891 - 1.5 * 0.6866 \quad \Rightarrow \quad b = -0.6408. \quad (35)$$

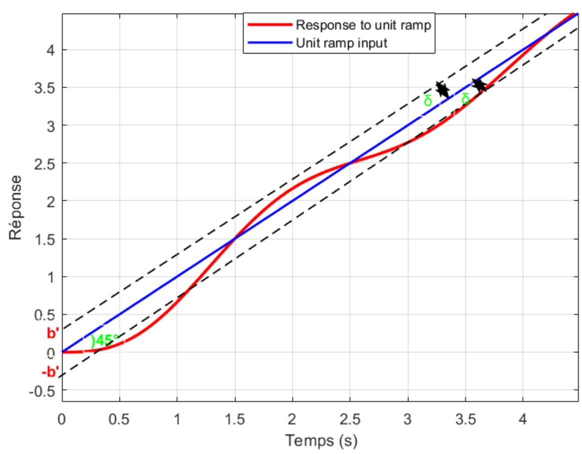

Fig. 10 – Settling time of the response to a unit ramp.

Then, the value of the maximum overshoot will be:

$$|D| = |b|\cos(\theta)$$

$$\Rightarrow \quad |D| = |-0.6408|\cos(56.3103^\circ)$$

$$\Rightarrow \quad |D| = 0.3554 \Rightarrow \quad |D|\% = 35.54 \ \% \qquad (36)$$

- Case of unit ramp input

In the case of unit ramp input, the settling time δ% is defined by cutting the response to the line of the equation $y(t) = t \pm b'$, as shown in Fig. 10.

We can calculate b' as follows:

$$\sin\left(\frac{\pi}{4}\right) = \frac{\delta/100}{b'} = \frac{1}{\sqrt{2}} \quad \Rightarrow \quad b' = \frac{\sqrt{2}\delta}{100}. \qquad (37)$$

The first switching time t_s is determined as the settling time to

$$\delta\%: \quad y(t_s) = t_s \pm \frac{\sqrt{2}\delta}{100}. \qquad (38)$$

3. CONCLUSIONS

This paper endeavors to draw attention to specific insights pertaining to the efficacy of time and frequency responses within dynamic linear systems, especially when the ultimate values or equilibrium points converge towards zero. Furthermore, novel interpretations of overshoot and settling time are presented within the framework of excitation induced by a ramp. These performance metrics carry substantial significance, emphasizing the imperative for automation engineers to meticulously incorporate them into their assessments to avert potential instabilities, particularly during transient states. Depending solely on traditional definitions of settling time, maximum overshoot, and phase margin may lead to misconstrued findings, thereby negatively impacting the understanding of outcomes.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Abdelhamid Djari: writing – original draft, review & editing, formal analysis.
Noureddine Bouarroudj: writing – review & editing, supervision.
Yehya Houam: writing – original draft & investigation.
Riadh Djabri: methodology & investigation

Received on 10 February 2024

REFERENCES

1. O. Somefun, K. Akingbade, and F. Dahunsi, *Uniformly Damped Binomial Filters: Five-percent Maximum Overshoot Optimal Response Design*, Circuits, Systems, and Signal Processing, **41**, *6*, pp. 3282–3305 (2022).
2. A.A.M. Yusuf, N.J. Agung, and S. Unang, *Implementation of real value genetic algorithm to determine three PID parameters*, In 2015 International Conference on Control, Electronics, Renewable Energy and Communications (ICCEREC), pp. 198–202 (2015).
3. S. Tiwari, M.V. Fischetti, and S.E. Laux, *Overshoot in transient and steady-state in GaAs, InP, Ga/sub 0.47/In/sub 0.53/As, and InAs bipolar transistors*, In International Technical Digest on Electron Devices, pp. 435–438 (1990).
4. C. Liu and Y. Liu, *Finite-time stabilization with arbitrarily prescribed settling-time for uncertain nonlinear systems*, Systems & Control Letters, **159**, 105088 (2022).
5. G. Giustolisi and G. Palumbo, *Design of CMOS three-stage amplifiers for near-to-minimum settling-time*, Microelectronics Journal, **107**, 104939 (2021).
6. H. Aminzadeh and D.M. Colombo, *Analysis and Design Procedures of CMOS OTAs Based on Settling Time*, Journal of Integrated Circuits and Systems, **17**, *1*, pp. 1–11 (2022).
7. R. Arivalahan, S. Venkatesh, and T. Vinoth, *An effective speed regulation of brushless DC motor using a hybrid approach*, Advances in Engineering Software, **174**, 103321 (2022).
8. A. Barreiro, A. Baños, and E. Delgado, *Reset control of the double integrator with finite settling time and finite jerk*, Automatica, **127**, 109536 (2021).
9. D. Wang, *Synthesis of phase-lead/lag compensators with complete information on gain and phase margins*, Automatica, **45**, *4*, pp. 1026–1031 (2009).
10. M. Cupelli, A. Riccobono, M. Mirz, M. Ferdowsi, and A. Monti, *Modern control of DC-based power systems: A Problem-Based Approach*, Academic Press is an imprint of Elsevier (2018).
11. R.C. Dorf and R.H. Bishop, *Modern Control Systems*, 12th edition, Prentice Hall (2011).
12. I. Saidi and N. Touati, *Learning control for trajectory tracking of nonlinear inertia wheel inverted pendulum*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **68**, *4*, pp. 424–430 (2022).
13. R.O. Dukkipati, *Analysis and design of control systems using Matlab*, Published by New Age International (P) Ltd (2006).
14. A.K. Mandal, *Introduction to control engineering: modeling, analysis and design*, Published by New Age International (P) Ltd (2006).
15. I.D. Landau and G. Zito, *Digital Control Systems: Design, Identification and Implementation*, Springer (2006).
16. Y. Granjon, *Automatique, systèmes linéaires, non-linéaires…*, 2e édition, DUNOD (2010).
17. C. Houpis, S. Sheldon, and J. D'Azzo, *Linear Control System Analysis and Design: Revised and Expanded*, CRC Press (2003).
18. G.F. Franklin, J.O. Powell, and A. Emami-Naeini, *Feedback control of dynamic systems*, 7th edition, PEARSON (2014).
19. A. Khelloufi, B. Sari, and S. Chouaba, *H∞ Control-Based Robust Power System Stabilizer For Stability Enhancement*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **67**, *2*, pp. 175–180 (2022).
20. H. Egon, M. Marie, and P. Porée, *Traitement du signal et automatique*, Hermann (2000).
21. M. Atia, N. Bouarroudj, A. Ahriche, A. Djari, and Y. Houam, *Maximum power harvesting from a PV system using an improved two-stage MPPT scheme based on incremental conductance algorithm and integral controller*, International Journal of Modelling, Identification and Control, **40**, *2*, pp. 176–191 (2022).
22. N. Bouarroudj, B. Benlahbib, Y. Houam, M. Sedraoui, V. Feliu Batlle, T. Abdelkrim, D. Boukhetala, and F. Boudjema, *Fuzzy-based incremental conductance algorithm stabilized by an optimal integrator for a photovoltaic system under varying operating conditions*, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects (2021).
23. N. Bouarroudj, B. Benlahbib, M. Sedraoui, V. Feliu-Batlle, M. Bechouat, D. Boukhetala, and F. Boudjema, *A new tuning rule for stabilized integrator controller to enhance the indirect control of incremental conductance MPPT algorithm: Simulation and practical implementation*, Optik - International Journal for Light and Electron Optics, **268**, 169728 (2022).
24. S. Latreche, A. Bouafassa, B. Babes, and O. Aissa, *Efficient DSP-Based Real-Time Implementation of an ANFIS Regulator For Single-Phase Power Factor Corrector*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **69**, *2*, pp. 141–146 (2024).