

Comparative Speed-Response Performance of Conventional PID and IMC-PID Control for a Three-Phase Induction Motor

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Abstract: This study compared the simulated speed responses of a three-phase induction motor operated without a speed-feedback controller, with a conventional proportional–integral–derivative (PID) controller, and with an internal model control based PID (IMC-PID) controller. A direct–quadrature reference-frame motor model was implemented in MATLAB/Simulink using the project's stated motor parameters and a reference speed of 1300 rpm. Performance was assessed through rise time, settling time and percentage overshoot, using the numerical results reported for each configuration. The uncontrolled case recorded a rise time of 1.7579 s and overshoot of 52.7846%; its settling time was not determined. Conventional PID control produced a rise time of 2.0910 s, settling time of 8.1010 s and overshoot of 2.2980%. The corresponding IMC-PID values were 0.5031 s, 1.1103 s and 0.8876%. Relative to conventional PID, IMC-PID reduced the reported rise time by 75.94%, settling time by 86.29% and overshoot by 61.38%. The individual response plots show a rapid approach to the final level under IMC-PID control and a large transient excursion without speed feedback. The results indicate that the IMC-PID arrangement achieved the most favourable combination of the three reported metrics under the nominal simulation conditions. Controller gains, the selected IMC filter value and underlying time-series data were unavailable for independent recalculation, while separate disturbance and parameter-variation tests were not reported. The findings therefore support a bounded comparison of the supplied simulations. Exporting the original response signals and documenting controller settings would enable reproducible assessment and further testing under defined operating changes

Keywords: Three-phase induction motor; speed control; internal model control; IMC-PID; conventional PID; transient response; settling time; MATLAB/Simulink.

1. Introduction

Many applications that need a spinning drive to run at a specific speed employ three-phase induction motors. Their reaction during a speed change is important because achieving the desired speed rapidly is simply one aspect of successful operation; the driven process may also be disrupted by a significant transient peak or protracted fluctuation. Therefore, metrics that characterise the initial reaction, its greatest excursion, and the time needed to settle are frequently used to assess speed-control performance.

Electrical and mechanical dynamics are combined in an induction motor. Rotor motion changes in electrical input affect rotor motion, which is also influenced by changes in electrical input, which in turn alter magnetic flux and electromagnetic torque. A controller may be assessed prior to actual deployment by modelling these interactions. A recognised foundation for modelling electric machine transients and examining their control behaviour is a direct-quadrature (dd–qq) reference-frame model [1]. The discrepancy between the desired and output speeds provides the error signal used to modify the motor drive in a speed-feedback setup.

Getting a reaction that quickly approaches and stays close to the target operating level is the practical control challenge. An unregulated reaction may show significant overshoot or fail to settle over the observation period, even when it crosses a rise-time threshold early. As a result, comparing response measures collectively yields greater insight than evaluating performance using a single statistic.

Proportional-integral-derivative (PID) control offers a well-known framework for controlling speed based on feedback mistakes. Its derivative, integral, and proportional actions can be adjusted to modify transitory behaviour, decrease chronic error, and change the reaction pace. Despite this structure's seeming simplicity, there are still tuning trade-offs to consider: settings that prioritise a quick reaction may impact overshoot, oscillation, or stability margins [2]. Because of these characteristics, a traditional PID implementation offers a beneficial comparison for assessing alternative tuning strategies.

Internal model control (IMC) provides a model-based approach to selecting controllers. Its design specifies elements of the intended closed-loop response using a filter and a representation of the process. An IMC-derived controller may be described in PID form for appropriate process models, enabling model-based tuning inside a traditional feedback structure [3]. Additionally, the filter offers an explicit design decision whose impact needs to be evaluated in relation to how well the model captures the regulated process [4].

For induction-motor speed regulation, it is therefore worthwhile to compare an IMC-PID setup with a conventionally tuned PID controller. Whether the specific implementations result in different observed responses under the same claimed motor circumstances is the pertinent topic. A positive nominal simulation result should be separated from more general assertions on robustness or disturbance rejection, which call for tests intended for those objectives.

The reported speed-response performance of a three-phase induction-motor model is assessed in this work in three different configurations: without a speed-feedback controller, with traditional PID control, and with an IMC-based PID controller. Using the motor specifications provided in the source project and a specified reference speed of 1300 rpm, the simulations were created in MATLAB/Simulink. The standard metrics for comparing the reactions are rise time, settling time, and percentage overshoot.

The simulated motor's behaviour without the assessed speed-feedback controllers is determined by the uncontrolled scenario. The response attained by the project's comparison controller is displayed in the traditional PID example. Then, given the specified simulation settings, the IMC-PID scenario examines whether the model-based tuning arrangement enhances the reported transient measures. It is feasible to differentiate between a quick initial increase and prolonged settling and minimal overshoot by displaying the three separate response plots next to a combined numerical table.

The contribution of the work is a concentrated, internally coherent description of this particular three-case simulation comparison. It compiles the stated response metrics, resolves inconsistent controller ranking descriptions in the source project, and analyses the findings in light of the provided evidence. Specifically, it assesses whether IMC-PID simultaneously improves many response measures while avoiding assertions that cannot be supported by the given plots, including performance under different motor settings or quantified disturbance rejection. The comparison that results serves as a foundation for further simulations that allow for the complete reporting of controller settings, exported speed signals, and specifically defined test inputs.

2. Materials and methods

2.1. The motor model and specified simulation settings

A MATLAB/Simulink R2021a mathematical model of a three-phase induction motor was employed in the investigation. The source project used a synchronously rotating direct–quadrature (dd–qq) reference frame to depict the motor's three-phase electrical values. This model relates the generated electromagnetic torque to rotor motion and uses dd- and qq-axis values to characterize the electrical behavior of the stator and rotor. For the uncontrolled, traditional proportional-integral-derivative (PID) and internal model control-based PID (IMC-PID) simulations, it supplied the common motor model.

A 40 kW rated power and a 50 Hz supply frequency were specified for the motor. Stator resistance of 0.7384, rotor resistance of 0.7402 Ω , stator and rotor inductances of 0.003045 H each, and mutual inductance of 0.1241 H were the stated electrical characteristics. 0.0343 $\text{kg}\cdot\text{m}^2$ was the stated inertia. Table 1 summarizes these parameters along with the specified reference speed of 1300 rpm. Since the source's parameter table does not provide a unit for stator resistance, its numerical value is replicated without one.

The three simulation configurations were compared using the same specified motor specs. Under the stated simulation settings, this common model is required to understand variations in their responses as variations related to the control arrangements. The model description, response charts, and numerical performance data provided in the project are used in this research. The simulations are not handled like readings from a real motor.

Table 1: Motor specifications and simulation conditions

Parameter	Reported value
Motor power	40 kW
Reference speed	1300 rpm
Supply frequency	50 Hz
Stator resistance	0.7384 (unit unstated)
Rotor resistance	0.7402 Ω

Parameter	Reported value
Stator and rotor inductance	0.003045 H each
Mutual inductance	0.1241 H
Inertia	0.0343 kg.m ²
Software	MATLAB/Simulink R2021a

Caption: Reported motor parameters and conditions used in the speed-control simulations.

2.2. Uncontrolled, PID and IMC-PID simulation arrangements

Three arrangements were considered, as summarised in **Figure 1**. In the first, the induction-motor model operated without a speed-feedback controller. Its output established the uncontrolled response against which the two controlled responses were described. “Uncontrolled” in this paper denotes the absence of the PID or IMC-PID speed-feedback loop; it does not imply that the motor had no electrical input.

The second arrangement used a conventional PID controller. A speed reference was compared with the simulated motor-speed output to form a speed-error signal. The controller acted on that error through proportional, integral and derivative terms, producing a command for the motor-drive arrangement represented in the project. In general form, the controller action can be written as

$$u(t) = K_p e(t) + K_i \int e(t) dt + K_d \frac{de(t)}{dt},$$

where $ee(t)$ is the difference between reference and output speed, $u(t)$ is the controller output, and K_p , K_i and K_d are the PID gains. The project identifies this case as its conventional PID comparison.

The third arrangement retained a PID control structure but derived its design within an internal model control framework. In the project’s description, an approximate model of the motor-speed process is used to formulate an IMC controller, and a low-pass filter with tuning parameter λ regulates the desired response. The equivalent feedback controller is then expressed in PID form. As with the conventional PID case, simulated output speed is fed back and compared with the reference. The distinction between the controlled cases is thus the stated method of controller design and tuning, rather than a different motor specification.

Figure 1 is a simplified comparison schematic. It shows the reference, comparison point, controller, inverter, motor and feedback path for the two controlled arrangements; it is not a reproduction of every internal Simulink block. Numerical controller gains and the selected IMC filter value are not specified in the results available for this comparison and are therefore not assigned values here.

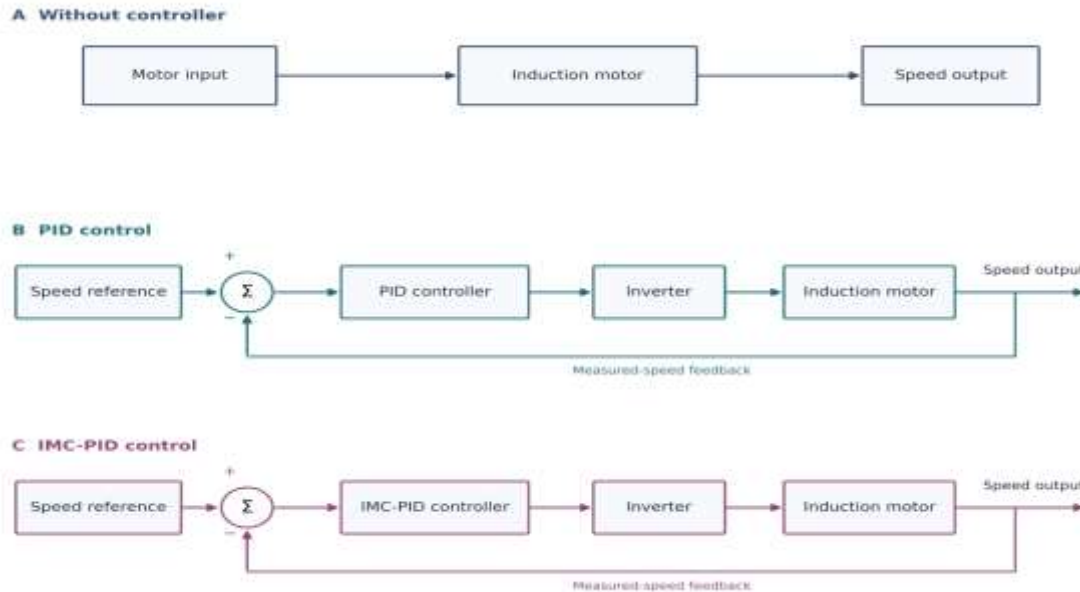


Figure 1: Simulation arrangements for uncontrolled, PID and IMC-PID motor operation. Schematic of the three configurations compared in the project: (A) motor operation without speed feedback, (B) conventional PID speed control and (C) IMC-PID speed control. The controlled arrangements compare the reference and measured speeds before sending the controller output through the inverter to the induction motor. The diagram shows the comparison architecture, rather than the detailed Simulink implementation.

2.3. The process of reference-speed simulation and comparison

The motor responses were assessed in relation to a specified reference speed of 1300 rpm. Different simulations using IMC-PID control, traditional PID control, and no speed controller were shown. Every speed-response graphic that is produced has a duration of 0–10 seconds. The two controlled arrangements' responses were analysed after the uncontrolled model's. A descriptive comparison of the response shapes and the supplied numerical metrics for each example is made possible by this sequence.

Figures 2–4 show the individual speed-response charts that were kept from the project. Table 2 was created by combining the numerical numbers presented in its individual and aggregated results tables. These tabulated results were used to create a separate comparison of the two controlled cases, as shown in Figure 5. Because the labels on the individual answer plots clash with the PID and IMC-PID legend assignments, the project's initial three-response overlay was not utilised.

The comparison focuses on rise time, settling time and percentage overshoot. Differences between PID and IMC-PID were also expressed as relative changes using the conventional PID value as the denominator:

$$\text{Relative reduction (\%)} = \frac{\text{PID value} - \text{IMC-PID value}}{[\text{PID value}]} \times 100.$$

This calculation describes the difference between the **reported simulation values**; it is not a statistical estimate. No repeated simulation runs, uncertainty intervals or significance tests were reported for these comparisons. Although the source discusses load disturbances, it does not present a separate disturbance input and corresponding quantified recovery response. Accordingly, this manuscript evaluates the supplied speed-response cases and does not calculate a disturbance-rejection metric.

2.4. Response metrics

Rise time refers to the duration required for a reaction to transition between designated lower and higher percentages of its ultimate value following the application of the reference. The approach of the source delineates the 10%–90% standard. A reduced rise time signifies that the output attains proximity to its ultimate value more quickly; when evaluated in isolation, it does not confirm that the response stays close to that value.

Settling time refers to the duration necessary for the reaction to reach and consistently stay within a defined range surrounding its ultimate value. The reference indicates a range of around $\pm 2\%$. The outcomes include quantitative settling durations for both the PID and IMC-PID scenarios, but the uncontrolled scenario is noted as NaN. To clarify, Table 2 shows that the settling time for the uncontrolled scenario remains undetermined. This result indicates that the stated metric is inaccessible because it does not specify a numerical settling time or make a distinct mathematical stability claim.

Percentage overshoot expresses the extent to which the response exceeds its reference or final level at its maximum excursion. For a response evaluated relative to a positive reference y_{ref} , it may be expressed as

$$M_p (\%) = \frac{[y_{max} - y_{ref}]}{y_{ref}} \times 100,$$

where y_{max} is the peak response. This equation states the interpretation of the reported overshoot metric; the percentages in **Table 2** are taken from the project rather than recalculated from plot images.

The three measures address different aspects of performance. Rise time describes the initial approach, settling time the sustained approach, and overshoot the maximum excursion. They are therefore reported together. The source plots label their vertical axes "Speed (m/s)," whereas the simulation parameters state a 1300 rpm reference. Because the underlying plotted signal and any conversion were not supplied, the original plot axes are preserved and precise response metrics are taken from the project's numerical tables.

3. Results

3.1. Unregulated motor reaction

The motor response simulation lacking a speed-feedback controller is illustrated in Figure 2. Commencing from a near-zero point, the graphed output ascends steeply and attains a significant peak about 4 seconds later. It subsequently declines, has more significant oscillations, and stays far behind its prior peak by the conclusion of the 10-second show. The reply does not exhibit a consistent, stable adherence to the specified 1300 rpm benchmark throughout the depicted duration.

The project indicates a rising time of 1.7579 seconds and a percentage overrun of 52.7846% for this scenario (Table 2). Its settling-time entry is undefined, indicated here as indeterminate. The comparatively brief documented rising time must be interpreted in conjunction with the significant overshoot and ensuing alterations in the response. Achieving a rapid ascent to the top rise-time limit did not correlate with maintaining proximity to the intended operational level. The unregulated simulation acts as the reference standard for evaluating the two speed-feedback configurations.

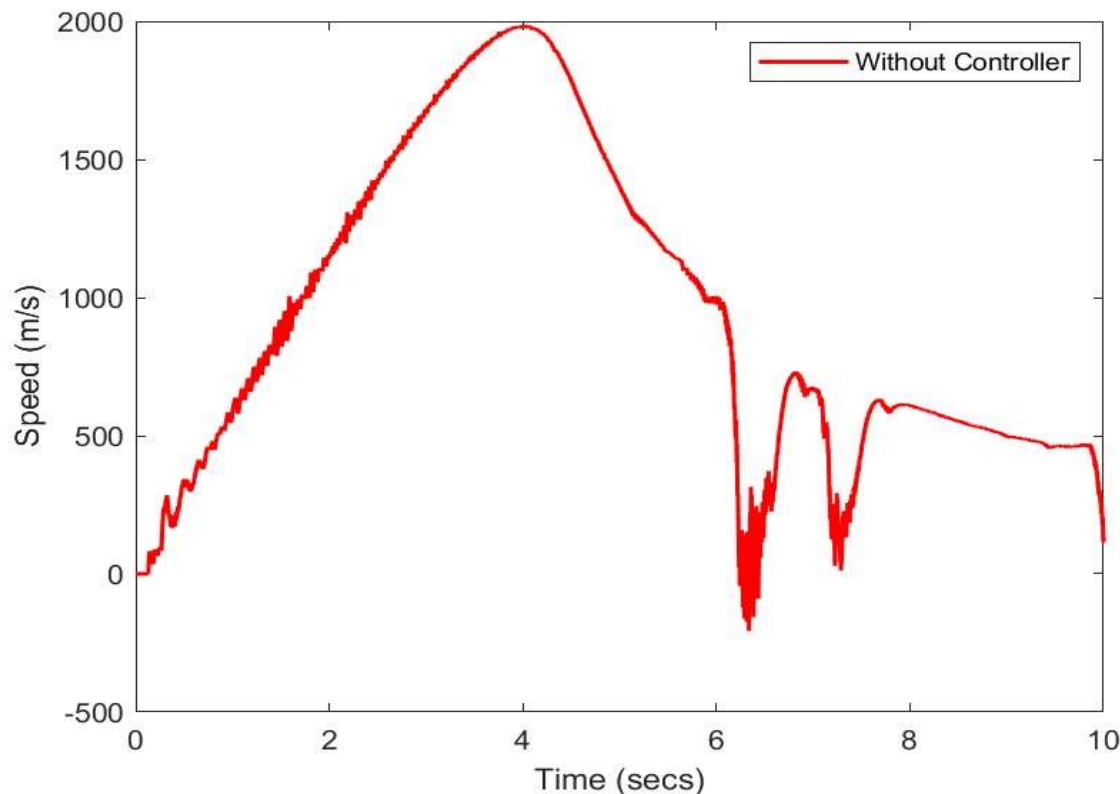


Figure 2: Uncontrolled motor speed response. Simulated response of the three-phase induction motor without a speed controller over 10 seconds, reproduced from the project's original plot. The response rises to a pronounced peak and does not settle during the displayed interval. The vertical axis retains the source plot's "**Speed (m/s)**" label. I have left the recorded curve and its label intact rather than assigning an unverified unit.

3.2. Traditional PID reaction

Through traditional PID control, the simulated output ascends to its ultimate value without the significant deviation observed in the uncontrolled scenario (Figure 3). The initial rise is succeeded by a more steady trend, exhibiting minor oscillations in the latter part of the reaction. The narrative suggests that the incorporation of speed feedback alters both the form and intensity of the transient reaction within the specified simulation parameters.

The documented PID increase time is 2.0910 seconds, beyond the 1.7579 seconds noted for the uncontrolled scenario (Table 2). The PID configuration, however, exhibits a much reduced overrun of 2.2980%, in contrast to 52.7846% when no controller is utilised. The documented settling time is 8.1010 seconds, but no settling time was established for the uncontrolled reaction. These figures illustrate that rise time should not be the exclusive criterion for assessing control performance: the PID response requires more time to traverse its designated rise interval yet significantly restricts the maximum deviation in this simulation.

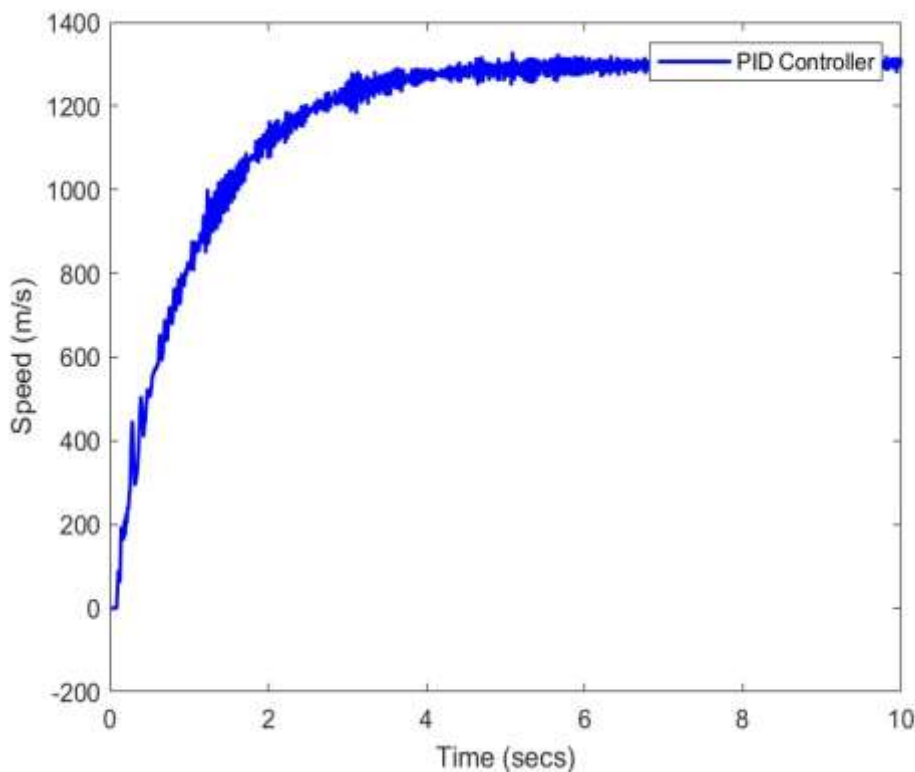


Figure 3: Motor speed response under conventional PID control. Simulated response of the three-phase induction motor with a conventional PID controller over 10 seconds, reproduced from the project's original plot. The response approaches the stated speed reference gradually.

3.3. IMC-PID reaction

The reply related to the IMC-PID configuration is seen in Figure 4. The graph's output ascends swiftly in the initial phase of the simulation and then stabilises near its ultimate value throughout the duration shown. In the individual response graphs, the IMC-PID trace reaches that level more rapidly than the traditional PID trace. It also does not exhibit the significant deviation seen in the uncontrolled reaction.

The project indicates an IMC-PID rising time of 0.5031 seconds, a settling time of 1.1103 seconds, and an overshoot of 0.8876% (refer to Table 2). Of the three assessed examples, this one exhibits the briefest documented rising time and the minimal recorded percentage overshoot. Of the two instances with a specified settling time, it is also the briefest. The minor overshoot value is derived

from the project's numerical findings; its exact extent cannot be accurately seen from the depiction of the response curve. The illustration primarily enables a visual examination of a rapid advance followed by a relatively stable reaction.

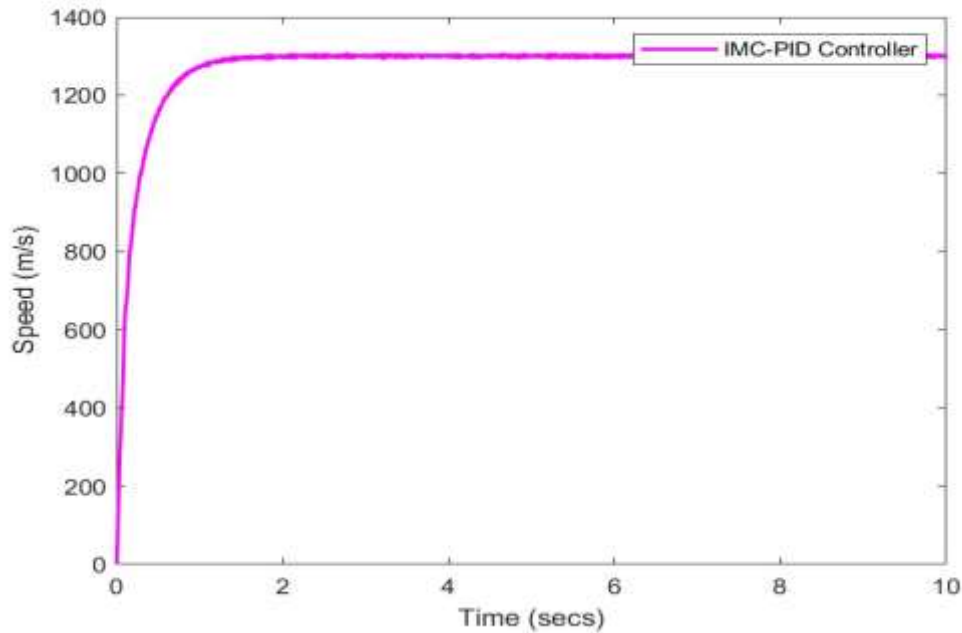


Figure 4: Motor speed response under IMC-PID control

3.4. Direct evaluation of stated metrics

Table 2 aggregates the three metrics recorded for every setup, whereas Figure 5 presents the numerical juxtaposition of the two controlled situations. The sequence is determined by the measure under consideration. The sequence of rising times, arranged from the briefest to the most prolonged, is IMC-PID (0.5031 s), uncontrolled (1.7579 s), and PID (2.0910 s). Regarding overshoot, the progression from minimal to maximal is IMC-PID (0.8876%), PID (2.2980%), and uncontrolled (52.7846%). Settling periods may only be quantitatively compared in controlled instances: 1.1103 seconds for IMC-PID and 8.1010 seconds for PID.

Utilising standard PID as the point of reference for a direct controlled-case evaluation, the variation in the noted rise time is 1.5879 seconds. This indicates a reduction in rise time by 75.94% with the application of IMC-PID. The settling time has been shortened by 6.9907 seconds, indicating an 86.29% decrease in relation to the PID value. The overrun varies by 1.4104 percentage points, transitioning from 2.2980% using PID to 0.8876% with IMC-PID. When compared to the PID's overshoot, this represents a reduction of around 61.38%. Percentage points and relative percentage decrease represent unique numbers that are differentiated in this context.

The evaluation further demonstrates why the uncontrolled rise-time result ought not to be viewed as proof of enhanced overall regulation relative to PID. While the uncontrolled response reaches the rise-time threshold more rapidly than the PID instance, it has a markedly higher peak excursion and an undefined settling time. When evaluating all three given criteria collectively, the IMC-PID setup produces the most beneficial numerical result in these simulations.

The monitored response data correspond with the substantial variation in approach time detailed in Table 2: the distinctly identified IMC-PID trace increases at a faster rate than the distinctly identified PID trace. Figure 5 depicts the values from the table rather than deriving them individually from the photos. These comparisons delineate the offered simulation instances; the project fails to present any replicated runs from which variability or statistical significance may be derived.

Table 2: Reported speed-response performance

Metric	Without controller	PID	IMC-PID
Rise time (s)	1.7579	2.0910	0.5031

Metric	Without controller	PID	IMC-PID
Settling time (s)	Not determined	8.1010	1.1103
Overshoot (%)	52.7846	2.2980	0.8876

Caption: Reported response metrics for the three simulated configurations. The source gives NaN for uncontrolled settling time; “not determined” expresses that result clearly.

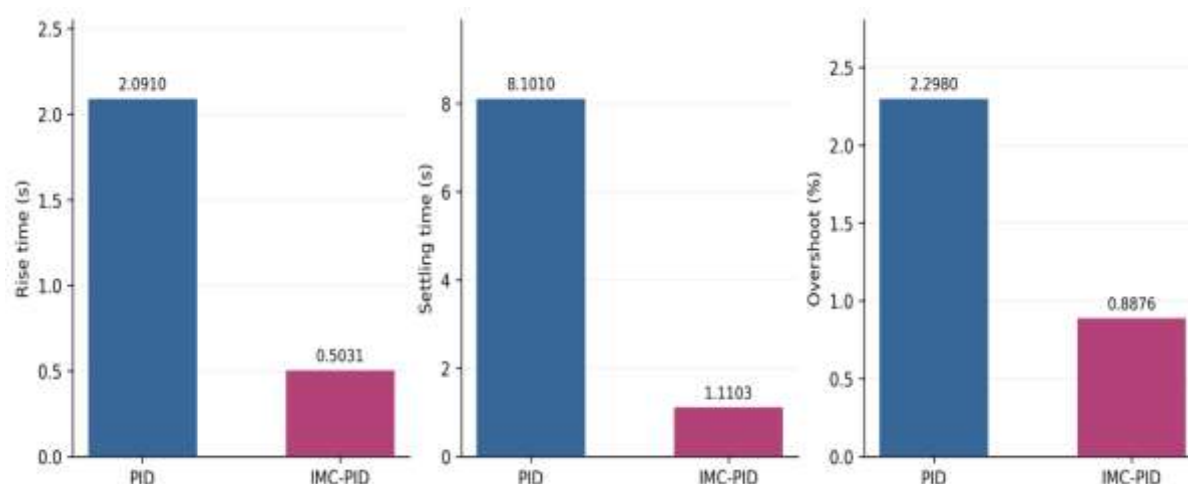


Figure 5: Comparison of reported PID and IMC-PID response metrics Rise time, settling time and percentage overshoot for the conventional PID and IMC-PID simulations. Values are taken from the project’s reported results tables. Each panel has its own vertical scale and unit; the bars represent reported simulation values, without error bars or statistical comparisons

4. Discussion

4.1. Variations in reaction velocity and settling characteristics

The documented reactions differentiate the initial velocity of approach from the duration required to stay close to the ultimate result. Traditional PID control yielded a rising time of 2.0910 seconds and a settling time of 8.1010 seconds, whereas the IMC-PID values were 0.5031 seconds and 1.1103 seconds (Table 2; Figures 3–5). In comparison to traditional PID, these indicate decreases of 75.94% and 86.29%, respectively. The separate graphs corroborate the general trend: the IMC-PID response attains its final output level swiftly, whereas the traditional PID response does so more slowly.

Rise and settling times assess distinct characteristics of a reaction. A brief rising time indicates an early intersection of established output thresholds; settling time further necessitates that the output stay within a designated range. A controller can enhance one metric without necessarily augmenting the other. PID tuning often entails harmonising response velocity with overshoot, oscillation, and stability thresholds, rather than only minimising any individual parameter in isolation. In the current simulations, IMC-PID exhibited reduced values for both rising and settling time compared to the traditional PID configuration.

The disparity in settling time is particularly evident when the latter halves of Figures 3 and 4 are juxtaposed. The traditional PID trace steadily approaches and shows little observable variation; the IMC-PID trace stabilises sooner within the time frame shown. Figure 5 presents the relevant numerical comparison, albeit derived from the project's results table and not an autonomous assessment of either trace.

These results pertain to the specified motor model and the specific controller applications employed in the project. The specific conventional PID gains and IMC filter configuration were not accessible for a detailed parameter-by-parameter elucidation of the disparity. It may be inferred that the documented IMC-PID implementation exhibited a quicker response and stabilisation in this analysis; the provided data does not confirm that all conceivable IMC-PID tuning methods would surpass every traditional PID tuning method.

4.2. Exceedance and the unregulated reaction

The unregulated simulation demonstrates that rising time alone provides an insufficient understanding of speed control. The documented rising time of 1.7579 seconds is less than the standard PID value of 2.0910 seconds; nevertheless, the recorded overshoot is 52.7846%, in contrast to 2.2980% with PID control (Table 2). Figure 2 illustrates a significant peak succeeded by considerable fluctuations in the output over the rest of the shown duration. A settling time was not established for this instance. The unregulated outcome thus attained the specified increase range without generating a prolonged reaction close to the indicated reference within the 10-second observation period.

Both regulated instances exhibited significantly decreased reported overshoot. The IMC-PID value of 0.8876% was 1.4104 percentage points lower than the standard PID value, representing a 61.38% relative decrease with PID as the reference. The two values ought not to be characterised as equivalent. The individual response graphs (Figures 3 and 4) exhibit no deviation comparable to the uncontrolled peak, although the little discrepancy between the controlled overshoot figures is most well illustrated by Table 2 and Figure 5.

In feedback-control analysis, swift response and constrained peak deviation are evaluated concurrently, as assertive control measures can enhance reaction velocity but may lead to an unfavourable transient peak. The documented IMC-PID outcome amalgamated the briefest rising time with the minimal overshoot. This is the distinguishing characteristic of this specific comparison. The graphical representations do not display the regulated peak values to four decimal points; hence, their exact percentages are derived from the project's numerical findings rather than visual estimations.

The unregulated trace also fluctuates significantly long after its original apex. The initiative fails to recognise a scheduled input alteration linked to the subsequent modifications. They ought to be characterised as attributes of the documented uncontrolled output, without attributing a particular physical source or regarding them as a quantified load-disturbance assessment.

4.3. What advantages does IMC-based tweaking offer in this simulation?

The IMC framework presents a model-driven strategy for designing controllers. Within the defined paradigm, a process model, alongside a filter, is used to mould the intended response, and for fitting model types, the ensuing controller might be represented as a PID structure [3]. This establishes the relevance of IMC-PID in relation to standard PID systems: both have a traditional feedback-controller format; however, their tuning processes differ.

Within the given motor simulation, the design variation is linked to the response pattern outlined in Table 2. The IMC-PID setup produced a rising time of 0.5031 seconds, a settling time of 1.1103 seconds, and an overshoot of 0.8876%. Standard PID produced results of 2.0910 seconds, 8.1010 seconds, and 2.2980%, respectively. As a result, the findings of this investigation reveal a quicker and less overshooting simulated response for the designated IMC-PID setup, employing the identical motor specs and reference-speed parameters as the comparator.

The findings are in harmony with the aim of an IMC filter: its tuning parameter facilitates a methodical approach to define the expected response, taking into account model-based design elements [3, 4]. It would, nonetheless, be beyond the boundaries of this investigation to contend that a certain value of that parameter resulted in the numerical advancement. The project discusses the filter idea, but it doesn't go into detail about the filter parameters and controller gains that are needed to separate the effects of tuning choices.

The comparison similarly does not indicate greater resilience to variations in motor parameters. Model-centric designs demand vigilance regarding the distinctions between the process model and the process under control [4]. There were no modifications noted regarding the declared motor resistance, inductance, or inertia. The validated observation is superior nominal simulated speed-response functionality in the shown scenarios, rather than empirically confirmed durability.

4.4. Boundaries of interpretation and ramifications for further evaluations

This investigation presents a direct juxtaposition utilising a singular set of reported motor specifications and a declared reference speed of 1300 rpm. The numerical data and individual response charts jointly reveal that the IMC-PID configuration presented the optimal mix of rising time, settling time, and overshoot. Dynamic simulation is a valuable tool for investigating the transient dynamics of machines and controllers, contingent upon the model and parameters being representative of the desired system [1]. Consequently, this comparison ought to be seen as proof of the offered simulation setups, rather than as a validated performance warranty for a physical drive.

Three constraints inherent in the sources inform that view. To begin with, the given material does not include information on controller gains, the specified IMC filter value, or any iterations; hence, the comparison cannot evaluate tuning sensitivity or uncertainty. In addition, although the research examines disturbance rejection, it does not offer a well-delineated load-disturbance input or a measured recovery response. Third, the primary plot axes display "Speed (m/s)", while the simulation parameters delineate a 1300 rpm reference point. This irregularity obstructs an independent conversion or exact re-evaluation of the tabulated data derived from the photos.

A beneficial progression would retain the identical motor model and unveil all controller parameters, then export the essential time-speed arrays and determine each response measure using explicitly articulated thresholds. Separate simulations for reference-step and load-step would clarify the distinction between tracking and disturbance recovery. Modifying certain motor characteristics would later assess how responsive the comparison is to model inconsistencies. These actions would bolster the interpretation of the optimistic nominal response shown here without modifying what the existing data reveal.

5. Conclusion

This research analysed the speed responses of a three-phase induction motor simulated without a speed-feedback controller, with a traditional PID controller, and employing an internal model control-based PID (IMC-PID) controller. All three instances were submitted with identical motor specs and a reference velocity of 1300 rpm. Their replies were evaluated based on rising time, settling time, and percentage overshoot.

In the two controlled circumstances, IMC-PID yielded the most advantageous reported outcome for each evaluated criterion. The rising time was 0.5031 seconds, in contrast to 2.0910 seconds for traditional PID; the settling time was 1.1103 seconds, as opposed to 8.1010 seconds; and the overshoot was 0.8876%, compared to 2.2980%. In comparison to PID, these figures indicate a decrease of 75.94% in rising time, 86.29% in settling time, and 61.38% in overshoot. The uncontrolled scenario had a rise time of 1.7579 seconds; nevertheless, its 52.7846% overshoot and indeterminate settling time illustrate that a swift initial rise can not be regarded as adequate speed management alone.

The personal reaction graphs corroborate the extensive numerical analysis. The IMC-PID output reached its final level more rapidly than the traditional PID output, while both controlled responses circumvented the significant deviation seen by the uncontrolled simulation. The combined findings suggest that the specific IMC-PID configuration used in the project enhanced nominal simulated speed-response efficacy compared to its traditional PID counterpart. They do not demonstrate that the identical enhancement will last across all controller calibrations, motor states, or physical configurations.

The analysis is constrained by the data provided by the first simulations. The controller gains and the chosen IMC filter value were not disclosed in the materials utilised for this paper. The foundational time-series data were likewise inaccessible for autonomous recalculation of the response metrics. Furthermore, the vertical-axis measurement depicted on the response graphs diverges from the specified reference-speed unit. No distinct quantified load disturbance or motor parameter variation assessment was provided. These constraints hinder inferences on repeatability, disturbance mitigation, and robustness; however, they do not alter the sequence of the numerical findings as presented in the project.

The subsequent actionable measure involves exporting the initial simulation signals and recording the PID gains, IMC filter configuration, displayed speed units, and metric calculation guidelines. The regulated instances can thereafter be executed again using aligned reference steps, succeeded by clearly delineated load modifications and variations in motor parameters. This would evaluate if the benefit shown in the current notional comparison persists under circumstances more like those faced by a functioning induction-motor drive.

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