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Three-Phase Induction Motor Speed Controlled By An Internal Model Control Based Proportional Integral Derivative Controller (Imc-Pid)

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ABSTRACT: *Creating a control strategy for an integrating process is challenging, and it gets considerably more challenging when dead time is included. Because it can derive the controller within the framework of a proportional-integral-derivative controller (PID), internal model control (IMC) is fascinating when developing control methods. The performance of a controller has been observed to improve with the addition of a filter, and several researchers have suggested PID with filter. An extensive review of modern IMC-PID controllers for three-phase induction motor speed control is included in this paper. Several PID forms for the same process are generated by the filter postulation in IMC, which is explored. Many standard performance indices are used to measure performance. The IMC filter topologies used in IMC-PID tuning for different integrating processes, such as tuning relations and time delay approximations, are summarised in this article.*

Keywords: Speed control, three phase induction motor, IMC-PID, speed sensorless drives

1. Introduction

An induction motor's speed regulation has been a significant problem ever since French physicist François Arago discovered it in 1824. The induction motor is composed of two separate components: the rotor, also known as the armature core windings, which rotate, and the stator, which is stationary. An electric machine that runs on alternating current and generates torque through excitation is called an induction motor (Singh and Choudhuri, 2002). Because the stator core windings rotate around a fixed point, the torque is produced by an electromagnetic induction from the magnetic flux (Zhu et al., 2005).

The most widely used electrical device in contemporary industries is the induction motor. Because of its many benefits, it has become so well-liked. High efficiency, low cost, good self-starting, simplified design, lack of collecting brooms, and minimal inertia are some of the many benefits. It has many benefits, but it also has very few drawbacks. One of the drawbacks of induction motors is that they are not naturally able to operate at varied speeds, and their mathematical model is complicated, multivariable, and nonlinear (Chan, 2007). Industrial process control techniques have advanced significantly during the last few decades.

Many control techniques have been researched, including fuzzy control, neural control, and adaptive control (ZL, 2004). The most well-known of them is the proportional integral derivative (PID) controller, which is in widespread usage due to its straightforward design and reliable operation under a variety of operating circumstances. Sadly, because many industrial facilities frequently struggle with issues like high orders, time delays, and nonlinearities, it has been very challenging to appropriately tune the gains of PID controllers. (Chih-Cheng Kao and others, 2006).

Many heuristic approaches have been put out over time for PID controller tuning. The first approach made use of Ziegler and Nichols' (2004) classical tuning criteria. Generally speaking, many industrial plants find it challenging to use the Ziegler-Nichols formula to determine optimal or nearly optimal PID parameters (Ang et al., 2005). Adding new features to PID controllers is therefore quite desirable in order to expand their capabilities. Numerous Artificial Intelligence (AI) techniques have been used to make a variety of plants' controllers perform better while maintaining their fundamental traits. For the correct tuning of PID controller settings, artificial intelligence (AI) techniques including neural networks, fuzzy systems, and neuro-fuzzy logic have been widely used (Rujisak et al., 2008).

Induction motor simulation and dynamic modelling are important for both businesses and academia because of the widespread use of induction motors in a variety of industrial sectors (Sengamalai et al., 2022). The steady-state and dynamic studies of an induction motor are difficult. Dynamic modelling has the benefit of helping to comprehend asyn chronous motor behaviour in dynamic mode. Time, torque, and speed are among the mechanical equations utilised in dynamic modelling. The differential voltages, flux connections, and currents between the revolving rotor and static stator can also be simulated using dynamic modelling (Sengamalai et al., 2022). An induction motor is usually driven by an inverter equipped with a speed sensor. This speed sensor could, however, increase investment costs and decrease system reliability. It is also difficult to implement. To get around this problem, a number of studies employ induction motors with speed sensorless drives. A good transient specification for six-phase drives is provided by PI and PID controllers, which typically supply fuzzy controllers, which depend on the class of intelligent controller (Gregor et al., 2008; Zhao et al., 2003; Akpama and Anih, 2015; Vukosavic et al., 2005; Rinkevi ciene et al., 2023).

Due to its ease of use and adjustment, cheap cost and power consumption, and adequate performance without the need for sophisticated methodologies, complexity, or computing, PID controllers are essential to the industry (Maghfiroh et al., 2020). Furthermore, the controller's tuning parameters may be based on neural networks (Naung et al., 2019), fuzzy logic control (Ozturk and Celik, 2012; Manuel et al., 2023), or various metaheuristic algorithms (Rodríguez-Molina et al., 2019; Braik et al., 2022) that enhance the system response sufficiently. To increase system reactions, a speed control system is cascaded with the PID controller (Saravanan et al., 2025). Unwanted responses in the operational characteristics are caused by any changes in the system parameters. PID controllers help lower error and are used in electric vehicle (EV) systems (Baidya et al., 2023). The feedback system's configuration is continuously measured in the system response and contrasted with a reference signal. (Saravanan et al., 2025) The controller minimises the inaccuracy caused by the speed signal discrepancy. In addition to increasing the sensitivity of the closed-loop reactions, the PID controller also controls and meets the necessary criteria and lessens the effect of disturbances on the system output. According to Saravanan et al. (2025), the system response eventually approaches the expected value as a result of the successive steps of speed measurement and controller tuning.
To tune PID controllers in closed loop systems, the traditional way employs the Cohen-Coon and Ziegler-Nichols method (Joseph & Olaiya, 2017; Celik & Ozturk, 2018). The usual approaches for higher-order dynamics take longer, but the tuning time is always as short as possible (Ang et al., 2005). Recently, the researcher used stochastic search techniques and metaheuristic approaches, which are excellent at exploring a large solution space, to better tune PID controller gains (Purnama et al., 2019; Kushwah & Patra, 2014; Ekinci et al., 2020). Examining earlier research on the design and implementation of an Internal Model Control Based Proportional Integral Derivative Controller for three-phase induction motor speed control is the main goal of the current project.

2. Fundamental Theory

2.1 Three-phase induction motor

Converting electrical energy into mechanical energy is what an induction motor does. The fundamentals of three-phase induction motor functioning are as follows: ns = 120 f/p, or synchronous speed rotation of the magnetic field, occurs when the motor's stator receives three-phase AC power. where p is the number of magnetic poles, f is frequency (hertz (Hz)), and ns is synchronous speed (meter/second (m/s)). The rotor conductor is subjected to the revolving magnetic field. Therefore, using the equation e = 4,44 f n φ, the electromotive force (emf) on the rotor will be generated. where f is frequency (Hz), n is the number of windings, φ is flux (Wb), and e is electromotive force (joule/coulomb (j/c)). Current (i) results from the rotor winding's tight loop. Force (f) is produced on the rotor by the current within the magnetic field (Nurhayati, 2013).

2.2 PID Controller

To produce a stable output, a PID controller can repair errors. The PID system maintains objects (output) at the set value (SV), and the current value (PV) of the detected item is the value. In the same value, PID regulates both of them (Sumiati Ruzita, 2009).
Deviation E is then used to refer to the difference between SV and PV. It will then force the object to return to its set value (SV) by giving the actuator manipulates value (MV).

2.3. Mathematical Description of IMC

The IMC block diagram and its equivalent conventional feedback structure are shown in Figure 1, 2 respectively. According to IMC design procedure, the model of the plant can be factorized as shown in Eq. (1).

$$G^{*}(s) = G_{+}p^{*}(s)G_{-}p^{*}(s) \qquad (1)$$

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where $G_{+}p^{*}(s)$ is a portion of the model contains the non-minimum phase and right half poles, $G_{-}p^{*}(s)$contains the stable poles.

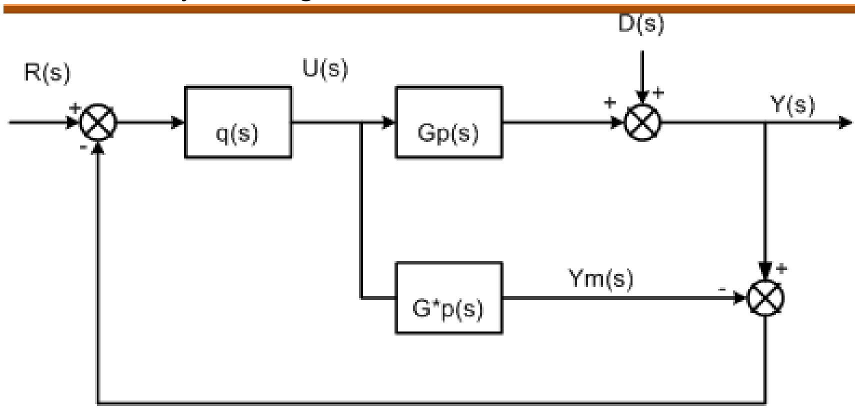

Figure 1: Schematic representation of IMC

Figure 2: Conventional feedback control scheme.

3. **Reviews**

The adaptive neural network technology was developed by Al-Mahasneh and colleagues in 2025 for the direct online speed regulation of a three-phase induction motor. We demonstrate the use of an online adaptive general regression neural network (OAGRNN) for a direct online speed controller for a three-phase induction motor. To keep the induction motor running at its rated speed throughout a range of load conditions and in real time, the speed error and its derivative are continuously recorded and returned to the OAGRNN controller. In order to instantly generate the proper frequency and voltage for the induction motor, the OAGRNN controller sends the control signal to the inverter. Interestingly, the OAGRNN controller displayed outstanding performance without requiring a learning mode; it was able to track the desired motor speed and begin operations from the beginning. A three-phase induction motor setup has been created to demonstrate OAGRNN's strong capacity for tracking the motor's target speed under a range of load torque conditions. The MATLAB simulation and the experimental setting are the two stages in which the performance of OAGRNN is investigated. Comparing the OAGRNN's performance to that of the proportional integral (PI) controller further reveals its exceptional capability and superiority for online changes pertaining to the speed regulation of the three-phase induction motor.

Ekim et al. (2024) designed and modelled a proportional derivative controller for controlling the speed of a three-phase induction motor. Motor speed control performance was examined using the scalar control methodology. Research was done on proportional-integral (PI) and proportional derivative (PD) controllers for the controller method. MATLAB (Simulink) software is used to present the simulation results. The presence of high peaks, overshoots, and rise time further indicates that the PI controller performed badly, according to an analysis of the PI and PD performance. Nonetheless, the results produced by the PD controller were satisfactory. In contrast to the unstable PI controller, which had an overshoot of almost 96% and a steady state error of 1.22, the PD controller demonstrated superior performance with a 1.01 s settling time and a steady state error of 1.0.

For close-loop speed control of an induction motor fed by a pulse width modulation voltage source inverter, Eko et al. (2020) used a constant v/f scalar control. MATLAB/SIMULINK software is used to simulate the machine. Speed, electromagnetic torque, and stator current responses are used to analyse the machine's transient performance. The findings of the simulation of a fuzzy logic controller are contrasted with those of a traditional PI controller. A fuzzy logic controller allows the machine to respond more quickly.

Six-phase drive control was compared by the authors of (Rinkeviciene et al., 2023) using a hybrid PID fuzzy controller. The parameters of this controller were established online and it is based on proportional, integral, and differential actions. The scientists removed oscillations and overshoot from the system using an adaptive fuzzy logic approach, however when compared to the fuzzy PID controller, the sliding mode controller was shown to have several advantages, including more resilience and a faster response (Rinkeviciene and Mitkiene, 2024).

An ant colony optimisation (ACO) algorithm was suggested by Mahfoud et al. (2022) as a way to optimise the PID controller's gains and efficiently control torque and speed in the doubly fed induction motor (DFIM). Through the use of MATLAB-Simulink, the intelligent ACO-direct torque control (DTC) control was implemented, outperforming traditional DTCs in terms of speed, stability, precision, and torque ripples.

The PID controller's parameters were optimised and fine-tuned by Mahfoud et al. (2021) using a genetic algorithm (GA). Speed overshoot mitigation, response time reduction, lowering the rate of total harmonic distortion (THD) in the stator and rotor currents, and minimising the speed rejection time as well as the amplitude of torque and flux ripples in the DFIM were among the several goals that this method sought to accomplish.

Brushless direct current (BLDC) motors are widely used in mechanical applications because of their small size, appropriate torque, and efficiency (Alias, 2020). It is difficult to achieve the best performance and adjust the parameters for the highest force output using a simple bespoke PID controller.

In order to handle non-linearity, parameter changes, and load fluctuations in the BLDC motor drive system, Mahmud et al. (2020) implemented an adaptive PID controller that makes use of an extra feedback signal. According to the findings, adaptive PID controllers can efficiently minimise parameter changes and are appropriate for dynamic movements.

For speed control, Premkumar et al. (2019) proposed a fuzzy-anti windup-PID (FAW-PID) controller that lessens the saturation effect on the motor's speed response. The PI controller, the FAW-PID controller, and the recommended controller are among the control system parameters for the induction motor that are measured and contrasted. Performance-wise, the FAW-PID controller outperforms the others.

Three hybrid approaches for DTC of the dual star induction motor (DSIM) drive were compared by Boukhalfa et al. (2019). The speed-regulated loop behaviour of the DSIM is enhanced by the use of fuzzy-PSO, GA-PSO, and proportional integral derivative-particle swarm optimisation (PID-PSO). Fuzzy-PSO is therefore the ideal option. Fuzzy-PSO's main goals are to enhance rising time, minimise high torque ripples, and prevent disruptions that affect drive performance.

For controlling the speed of an AC motor, an intelligent control algorithm based on a back-propagation neural network (BP-NN) and a PID controller is suggested. The outcomes show how versatile, resilient, and capable the system is of intelligently controlling the AC motor's speed (Liu and Bai, 2022). The smooth start of a three-phase induction motor could also be improved by using additional meta-heuristic control techniques (Izci et al., 2022; Ekinci et al., 2021).

In the references (Rinkevi ciene et al., 2023; Rinkeviciene et al., 2021; Rinkeviciene et al., 2020), two fuzzy controllers with distinct membership functions are compared. These controllers are based on per-unit membership functions as well as known input and output values. Robust systems are produced by both fuzzy controllers. Classical PI or PD controllers are typically used in conjunction with fuzzy controllers. Fuzzy logic controllers' benefits and well-thought-out design demonstrate how adaptable and resilient drive system control is to load fluctuations and parameter changes.

The first step of the study (Mohamed et al., 2019) involves gathering training data for the neural network (NN) using model-predictive control (MPC). After the NN has been trained, it is utilised as a controller to monitor the induction motor's voltage. The suggested method is still reliant on the MPC for data gathering, despite its positive outcomes in both dynamic and steady-state responses. Furthermore, the NN weights cannot be adjusted online.

Neutral networks (NN) are employed as a speed estimator in numerous other applications (Pimkumwong and Wang, 2018). In the industrial sector, the proportional integral derivative (PID) controller is widely used to control linear systems. However, it may not be as useful when dealing with nonlinear behaviour. Through optimisation methods, researchers have incorporated artificial intelligence to improve the performance of PID controllers, especially when it comes to doubly fed induction motors.

Even without knowing the plant transfer function, the authors of Gregor et al. (2008) created a PI fuzzy controller with gain scheduling and self-tuning based on the step response of a weight belt feeder.

For use in three-phase induction motor speed controllers, Idoko et al. (2017) designed a proportional integral derivative controller tuning mechanism. In-depth instructions on how to use the MatLab program to effectively search for the best PID controller parameters inside a mechanism system are provided. The suggested method has better qualities, such as less computing work, steady convergence characteristics, and ease of implementation. It is challenging to design the speed controller for three-phase induction motors due to their intricate mathematical modelling. Here, a software PID tuning mechanism was created that can be utilised to determine the ideal PID control parameters under fully loaded settings as well as the starting PID parameters under typical operating conditions. The parameters of the suggested PID controller tuning mechanism will be automatically adjusted within these ranges. The performance of the suggested tuning mechanism for the PID controller was demonstrated by modelling a three-phase asynchronous motor in MATLAB, obtaining the transfer function with the software, and designing a controller using PID. The results of the models and simulations demonstrate the suggested controller's potential for high efficiency.

Ansar et al. (2016) use INFOU SCADA to compare and establish the real-time effects of PID tuning on the three-phase induction motor and PQM II to track changes in frequency, current, voltage, and power. The curve was shown on INFOU SCADA and motor data was displayed from PQM II after the PID determination was adjusted using a trial-and-error method. The study's findings demonstrate the significant impact that PID controllers have on induction motors. Controlling P, I, and D together can enhance the offset level and time rise. When the SV value was set to 1500 rpm and the PID value was set to P = 1, I = 10, and D = 0, the motor response showed on the INFOU SCADA visual was good, and the PV time to obtain SV was sufficiently quick at 11 seconds. Motor data recorded on the PQM panel, however, indicated that the motor was operating at its optimal speed and did not surpass the motor capacity indicated on its name plate. The corresponding values for frequency, current, voltage, and active power were 50 Hz, 1

Ampere, 151 V, and 0.06 kW. The INFOU SCADA graphic displays the impact of PID tuning on the 3-phase induction motor's speed, while the PQM II panel with the three-phase induction motor and the INFOU SCADA display the other variables.

Ziegler and Nichols (1942) created closed-loop controller tuning guidelines in 1942. This method just needs a few process variables, such oscillation period and controller gain. According to Yuwana and Seborg (1982), this method is not the best for integrating and unstable systems since it forces the process into minimal stability.

In the 1950s, Cohen and Coon (1953) developed an open-loop reaction curve method for calculating PID variables, which has attracted a lot of interest from a range of industries. One drawback of this approach is that it requires the experimental test to be conducted in open-loop mode, and no control measures are implemented in the event of unforeseen disturbances (Yuwana and Seborg, 1982). The information gathered from these two approaches is used to compute the PID variables for First Order Process with Dead Time (FOPDT).
The first comprehensive IMC-based PID tuning guidelines were presented by Rivera et al. (1986). These guidelines use a single tuning parameter to provide the trade-off between the servo and regulatory responses. The IMC filter time constant, also known as the closed-loop time constant, offers a practical tuning method to strike a balance between the closed-loop system's resilience and speed (Lee et al., 1998).
By approximating the integrating process to a UFOPDT, Lee et al. (2000) initially presented the IMC-PID controller for integrating processes with dead time. An IMC-based approach for integrating processes with dead time has been developed by Lee et al. (2006) and Arbogast et al. (2007). This approach can be used to other types of processes as well. With this approach, a controller with a PID-like structure enhanced by a filter is produced. Based on an optimal IMC filter, Shamsuzzoha and Lee (2007) developed a PID controller and offered analytical recommendations for choosing tuning parameters.
The tuning criteria for an integrating process with dead time have been determined by Shamsuzzoha et al. (2008) utilising a lead/lag filter as an IMC filter and a pure PID controller. Higher-order IMC filters have been employed by a number of researchers to enhance regulatory performance (Shamsuzzoha and M. Lee, 2008; Rao et al., 2011; Rao and Sree, 2010).
Fractional-order process models have been controlled by integer-order controllers since the 1990s. Fractional-order controllers are being used by process engineers as process control technology aims for increased precision. There has been little prior work on fractional order controller design using IMC PID. Maamar and Rachid (2014) and Ranganayakulu et al. (2021, 2017; 2020) have created fractional order PID using the IMC technique for non-integer order systems and integer order processes, respectively.
These techniques use a fractional order filter as an IMC filter to derive fractional order PID. In general, the authors have attempted to improve the controller's performance by using various dead time estimations and IMC filters. Consequently, various types of PID controllers are produced, including traditional PID,

4. CONCLUSION

The IMC-PID design for three phase induction motors was thoroughly examined in the paper. Numerous options for estimating the kind and sequence of an IMC filter are examined. Researchers' different dead time approximation types are presented. Numerous examples from the body of current literature are taken into account and looked at. Performance has been discovered to be affected by a number of parameters, including the dead time approximation, the form of PID, the type of IMC filter, and the order of the IMC filter.

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