Position Control of DC Motor Using PID and LQR Methods: A Comparative Analysis

Ivan Nanda Septiandi [1], Salsabila Ika Yuniza [2]
[1,2] Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya
[1] ivanseptiandi@student.ppns.ac.id , [2] salsabilaika@student.ppns.ac.id

Abstract

The rapid technological advancements of this era have significantly influenced various fields, including engineering and innovation in electrical systems. Accessing and utilizing technological knowledge has become increasingly convenient, enabling researchers and engineers to push boundaries in innovation and development. In the field of electrical engineering, this ease of access has facilitated the study and implementation of advanced techniques for efficient energy utilization and control systems. For instance, the exploration of DC motor control methodologies, such as PID and LQR, highlights the potential for optimizing performance in industrial and robotic applications. Research and testing play a pivotal role in driving future innovations by ensuring that electrical systems meet the growing demands for power efficiency and technological sophistication. This study specifically addresses the development and analysis of DC motor position control using PID and LQR methods, providing a comparative evaluation of their performance metrics. These findings contribute to the advancement of robust and efficient control systems, aligning with the needs of modern engineering applications.

Keywords: rectifier, 3 phasa, half wave, generator

1. Introduction

In the era of rapid technological advancement, transformative changes have emerged across numerous fields, particularly in engineering and technology. Electrical engineering, as a cornerstone of modern innovation, continues to evolve in response to growing industrial and societal demands. Technology has become an integral part of daily life, with advancements in electrical systems playing a pivotal role in enhancing efficiency and sustainability (Arpin, 2020). The progressive development of electrical components and their diverse applications underpins the foundation of this study, which focuses on the critical aspects of DC motor position control using PID and LQR methods.

The importance of electrical engineering is evident in its vast array of components and systems, each tailored for specific functionalities and applications. Understanding and mastering the principles of electrical circuits, particularly in control systems, fosters innovations that address contemporary challenges. This study builds upon these principles by exploring the optimization of DC motor control, a crucial element in industrial machinery, robotics, and automation systems (Edminister, 1992). The application of advanced control techniques such as PID and LQR not only enhances precision and stability but also demonstrates significant improvements in system performance.

In industrial settings, where power demand is substantial, the development of efficient and reliable electrical systems is imperative. This study delves into the comparative analysis of PID and LQR methodologies in controlling DC motor positions, aiming to contribute to the advancement of control strategies in high-demand applications. By leveraging the potential of modern control theories, this research seeks to provide insights and practical solutions that align with the requirements of large-scale industrial systems (Hartono et al., 2014).

Through this study, the exploration of innovative approaches and their practical implementation in DC motor control can pave the way for more robust, efficient, and adaptive systems. The findings are expected to generate new ideas and applications, offering significant contributions to the field of electrical engineering and inspiring further advancements in control systems for industrial and technological applications.

2. Material and methods

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2.1. Generator

Generator is a tool that can convert mechanical energy into electrical energy (Zuhal, 1998). This mechanical energy is usually from water, heat, steam, and so on. In the process, mechanical energy comes from potential energy and also kinetics, then it can move the rotor by passing through the connecting shaft in the generator. The way it works is that the potential energy first pushes the impeller or blade in the turbine which results in generating kinetic energy (Mustofa, 2021). The result of the generator is in the form of electrical energy by passing through a rotor magnet and winding of the stator coil (Indriani, 2015). Usually the electrical energy derived from the generator results can be in the form of alternating electricity / AC electricity and also unidirectional electricity / DC electricity (Sunarlik, 2017). The use of AC electricity and DC electricity depends on each generator construction used in power plants. Generators consist of two groups, namely:

a. Asynchronous generator
b. Synchronous generator

Generators with alternating current are commonly referred to as synchronous generators and alternators. This synchronous generator occurs due to the construction in the generator which causes the direction of the current to reverse every half turn (Nugraha, As'ad, & Abdullayev, 2022). This synchronous generator can work when the frequency as well as the speed is constant. This gives an important role to the process of transforming energy towards a form that can be beneficial (Armansyah & Sudaryanto, 2016). Generators with alternating current have two types, namely:

a. AC current generator 3 Phase
b. AC current generator 1 Phase

The use of this generator based on its function is used when supplying power to other equipment, especially in the current industrial field that requires electricity for engine operations and of course as the main power source of engine drive and also as a backup power source (Pramono, n.d.). In general, the generator is divided into two parts, these two parts are the rotor and the stator. The way to distinguish it is that the rotor is the part that can move, while the Stator part is the part that cannot move (Asri et al., 2022). Synchronous Generator Construction here there are various stator components such as:

a. Slots
b. frame
c. Core
d. Tooth
e. roll.

The rotor components consist of: roll, pass, Axis

The last component is the prime mover. In the generator, there is a stator that has a function to receive magnetic induction through the rotor, the way it works is that AC current is channeled through the armature to the load (Sudirham, 2012). The shape of the stator itself has a shape like a cylindrical frame with the number of windings of a conductor wire with a large number. This stator is made with ferromagnetic material and then laminated to reduce current loss in the navel. If you want to have high resistivity and permeability of materials, it must have good ferromagnetic core quality as well (Demeianto et al., 2020).

In the three-phase synchronous generator there is a stator consisting of various layers of windings. The windings are double winding and single layer winding (Zuhal, 1998). The rotor has the function of generating voltage and this voltage is generated by the same magnetic field and then induced towards the stator. The rotor has various types of shapes such as the shape of the silenderis and also the shape of the poles of the shoe. The following is the shape of the rotor (Demeianto et al., 2020).

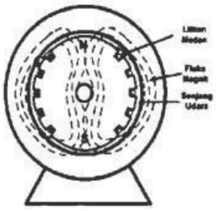

Figure 1. Rotor

The working principle of this synchronous generator is when the magnetic field has alternating properties then arises in the rotor coil when it is rotated through the prime mover (Nugraha et al., 2022a). whenever the stator

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coil is cut by a magnetic field so that it will give the result of an electric electromotive force in the area of the end of the stator coil accompanied by reciprocating motion together and also accompanied by the rotational speed of the rotor and also the electrical frequency must be the same. To find out the electrical frequency in the stator is by the formula below

$$f = \frac{NrP}{120}$$

Where:
f = electric frequency (Hz)
Nr = rotor rotational speed
P = number of magnetic poles

We can test this synchronous generator in two ways, namely testing by using load and testing without using load and by testing using load (Ivannuri & Nugraha, 2022). In a generator without using a load, the way to test it is by rotating the generator simultaneously and the rotor has been given a current, then the result is a voltage which in this test does not acquire the influence that comes from the anchor. We can find out the magnitude of the voltage, namely:

$$E_0 ¿ C . N . \phi$$

Where :
C = machine constant
N = synchronous rotation
ϕ = flux generated If

Synchronous generators that have loads, namely Ia, current Ra resistance E0, resistance ZL where if given a variable load, the terminal voltage VΦ will change. This is due to the presence of voltage drop due to anchor resistance (Ra), anchor leakage reactance (XL) and Anchor reaction (Indriani, 2015).

To generate electricity in a generator it is necessary to take advantage of the faraday law and also the lenz law following its understanding

1. Faraday's Law
According to experiments conducted by Faraday, the induction GGL arising between the ends of a coil is directly proportional to the rate of change in the magnetic flux surrounded by the coil. Faraday's law states that the electrical voltage impacted in a circuit is the same (except for its negative sign) as the flux velocity through the circuit (Apriadi, 2019).

$$\varepsilon = \frac{-d^{\phi} B}{dt}$$

Where:
ϕ B = Fluks Magnetik (weber)

If its application is used in a selenoide consisting of several N windings, then we can obtain the formula, which is:

$$\varepsilon = \frac{-d^{\phi} B}{dt} = \frac{d(N ¿¿ \phi B)}{dt} ¿$$

where:
$^{\phi}$B = Fluks Magnetik (weber) N = number of turns

2. Lenz's Law
Lenz's law was discovered by a physicist named Friederich Lenz in 1834. Lenz's law is a physical law that gives a statement about induction GGL (Electromotive Force). This law explains the direction of the induction current due to the existence of the induction GGL (Lenz's Law, 2014) (Apriadi, 2019).

2.2. Diode

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Diode is a semiconductor component for power electronics that has 2 sides of the terminals located on the left and right sides of the terminals named anode terminals (A) and cathode terminals (K) (Aswardi, 2020).

Figure 2. Diode [8]

The working principle of the diode component is that it can be described as a blockade of a one-lane highway, where the road is only allowed in one direction if there is a different direction that will be inhibited in existence, as with the diode, the diode will allow one direction of current, and the current in different directions will be inhibited, this will later change a current that was originally AC (alternating) turned into DC (unidirectional).

The way the diode works is when the diode is in ideal conditions when the diode is conducted or ON causes a voltage drop or anode-cathode voltage drop then has a value of zero while the amount of electric current flowing in the diode component also has a relatively large amount that is relatively the same as the electric current flowing in the load (Gancoli, 2001). If the diode is off, then the large voltage drop that occurs at the anode-cathode has the same magnitude as the voltage supplied and connected to the diode, if the amount of electric current flowing at the anode-cathode has a magnitude of zero (Merdeka et al., 2022).

2.3. Rectifier Circuit

A rectifier circuit is a way to change a circuit which initially moves back and forth or an AC circuit which then turns into a one-way circuit or DC circuit by means of an obstacle that can block current or voltage in only one direction. In this rectifier circuit is still divided into several parts (Hafid & Zakaria, 2020). Here is the division:

a. Uncontrolled rectifier circuit
b. Half-controlled rectifier circuit
c. Controlled rectifier circuit

In this report discusses the half-wave uncontrolled rectifier circuit, to make this rectifier circuit requires many components such as resistors, capacitors, transformers, diodes.

2.4. Methods

This study employs a participatory observation approach, a qualitative data collection method where the researcher actively engages as both an observer and an implementer in the research process. By taking on this dual role, the researcher can gain a comprehensive understanding of the system being studied. In this case, data is collected from experimental observations involving the measurement of current, voltage, and power output from a rectifier circuit derived from a three-phase generator. The primary goal of these measurements is to evaluate the efficiency and effectiveness of the rectifier circuit in delivering power to the load.

The data analysis technique used in this study involves systematically organizing, manipulating, and summarizing the collected data. By structuring the results in an accessible format, this method ensures clarity, facilitating both evaluation and interpretation. This structured approach not only aids in understanding the outcomes but also ensures that the findings are ready for rigorous analysis and presentation in engineering research contexts.

The research media and tools are critical components that significantly influence the success and reliability of experiments in engineering studies. In this research, the PSIM (PowerSim) software is utilized as a simulation platform. PSIM, a robust and user-friendly tool, is specifically designed for virtual simulations in power electronics and electric drive systems. The software enables detailed modeling, simulation, and analysis of electrical circuits, ensuring high accuracy in evaluating system performance. Its integration into the study facilitates data collection, analysis, and the generation of insights, while also making the experimental results more comprehensible to readers and practitioners in the field.

3. Results and discussion

3.1. Simulation

In taking data in this study, it was done well and also carefully in order to get perfect results, therefore the first step in the results this time was with a series of experimental pictures. The experimental circuit here uses a simulation circuit in the PSIM software. the following is a picture of the circuit:

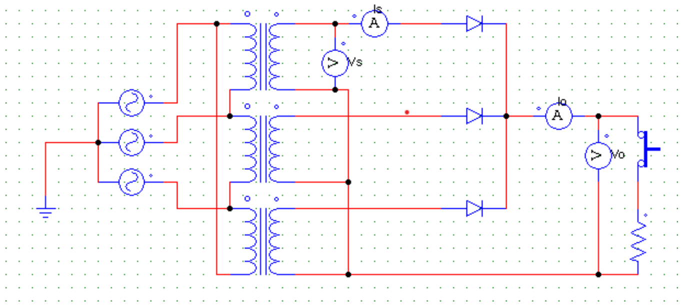

Figure 3. Circuit Simulation

In the series of experiments there is also a wave that has various forms. In this circuit there are waves resulting from current and voltage. Here's a picture of the waves:

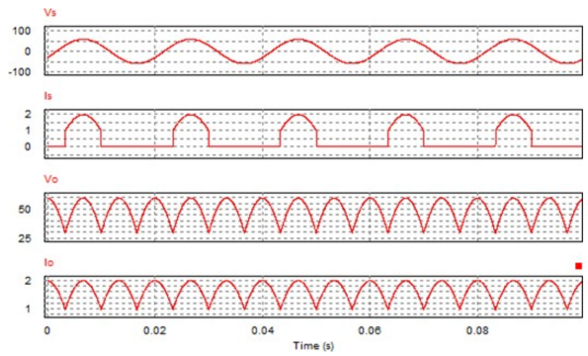

Figure 4. The Sinusoidal Wave Result

The circuit, of course, has a variety of components. The following are the components installed in this experiment such as: Alternator, Resistor, Diode, Voltmeter, Ammeter. These components are installed in such a way as to form an uncontrolled 3- phase rectifier circuit which is supplied by a 3-phase synchronous generator.

3.2. Data

To obtain the results of several experiments taken through an application or simulation software called PSIM. The results of this experiment in the form of data that has been tested and passed several changes that occur to several input voltages from the generator. Here the circuit uses a resistor of 10k ohm.

Table 1. Simulation calculation results

No	Vs (V)	Is (rms)	Is (A)	Vo (rms)	Vo (V)	Io (rms)	Io (A)
1	50	0,0024	0,0013	41,5	40,8	0,004	0,004
2	70	0,0038	0,0019	58,3	57,3	0,005	0,005
3	100	0,0048	0,0027	83,5	82,2	0,008	0,008
4	120	0,0058	0,0031	100	98,7	0,010	0,009
5	15	0,0072	0,0041	125,7	123,6	0,012	0,012

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0	

Based on the table above, we can find out the results of experiments conducted using a PSIM software. The results of the experiment can be seen that there is a change in each value of current or voltage, therefore the results of the experiment in the form of this table will be discussed in the discussion section so that it is more detailed.

3.3. Calculation

Based on the data obtained from the simulation results using PSIM, here we will also perform calculations manually using the following formulas.
To obtain a DC output voltage then:

$$Vo(dc) = \frac{3Vm.L-L}{\pi} = 0{,}8274\,Vm.L-N$$

To get the voltage from the RMS output then:

$$Vo(rms) = Vm.L-N\sqrt{\frac{3}{2}+\frac{9\sqrt{3}}{2\pi}} = 0{,}841\,x\,VmL-N$$

Based on the above formulas, we can determine manual calculations based on the formulas we get and can also be compared with calculations using simulations.

1. Vm = 50V
   Vo (rms) = $0{,}841\,x\,VmL-N = 0{,}841\,x\,50 = 42{,}05$
   Vo (dc) = $0{,}8274\,x\,VmL-N = 0{,}8274\,x\,50 = 41{,}37$
   Io (rms) = $\frac{V0}{R} = \frac{42{,}05}{10000} = 0{,}004\,A$

2. Vm = 70V
   Vo (rms) = $0{,}841\,x\,VmL-N = 0{,}841\,x\,70 = 58{,}87$
   Vo (dc) = $0{,}8274\,x\,VmL-N = 0{,}8274\,x\,70 = 57{,}91$
   Io (rms) = $\frac{V0}{R} = \frac{58{,}87}{10000} = 0{,}005\,A$

3. Vm = 100V
   Vo (rms) = $0{,}841\,x\,VmL-N = 0{,}841\,x\,100 = 84{,}10$
   Vo (dc) = $0{,}8274\,x\,VmL-N = 0{,}8274\,x\,100 = 82{,}74$
   Io (rms) = $\frac{V0}{R} = \frac{84{,}10}{10000} = 0{,}008\,A$

4. Vm = 120V
   Vo (rms) = $0{,}841\,x\,VmL-N = 0{,}841\,x\,120 = 100{,}92$
   Vo (dc) = $0{,}8274\,x\,VmL-N = 0{,}8274\,x\,100 = 99{,}28$
   Io (rms) = $\frac{V0}{R} = \frac{100{,}92}{10000} = 0{,}010\,A$

5. Vm = 150V
   Vo (rms) = $0{,}841\,x\,VmL-N = 0{,}841\,x\,150 = 126{,}15$
   Vo (dc) = $0{,}8274\,x\,VmL-N = 0{,}8274\,x\,150 = 124{,}11$
   Io (rms) = $\frac{V0}{R} = \frac{126{,}15}{10000} = 0{,}0015\,A$

Table 2. Results of manual and simulation calculations

Vs	Vo (dc) (P) (Volt)	Vo (dc) (T) (Volt)	Vo (rms) (P) (Volt)	Vo (rms) (T) (Volt)	Io (rms) (A)	Io (T) (A)
50	40,8	41,37	41,5	42,05	0,004	0,004
70	57,3	57,91	58,3	58,87	0,005	0,005
100	82,2	82,74	83,5	84,1	0,008	0,008
120	98,7	99,28	100	100,92	0,010	0,010
150	123,6	124,11	125,7	126,15	0,012	0,012

From the table above, it can be seen that the results of manual calculations (T) with calculations using simulations (P) are close to the same even though there are differences in errors that are not too large, from these results conclusions can then be drawn in the discussion section

3.4. Discussion

So in the discussion section this time based on the data that has been obtained by the researcher. In manual calculations and calculations with simulations, the difference is the average voltage or Vo(dc) in theory and practice, the results are slightly different, even though they are close to the percentage of error that is calculated, which is still relatively small. For manual calculations and simulations the rms output voltage is also the same as before, there are still differences but not too significant, while in manual calculations and simulations in rms currents it can be seen that the results are the same, there is no difference between calculations, it can be said that the calculations do not have errors. In the image of the first wave, the results of the experiment show that the wave was originally an AC wave into a DC wave, but the wave was still not perfect or in other words without ripples. Based on the theory, the waves in DC electric current are only half waves and it can be said that the waves only reach the peak because in DC electric waves only positive waves pass.

4. Conclusion

Based on the experiments that have been carried out, the results can be obtained which can then be concluded and also given suggestions that:

1. In the rectifier circuit, it functions to convert AC electric current into DC electric current
2. To make the electric current direct, we need a diode component whose function is to block one direction of electric current
3. In this study, it still needs to be tested again in detail so that it is more precise in obtaining results and also researchers must understand the existing material.

Credit authorship contribution statement

Author Name: Conceptualization, Writing – review & editing. **Author Name**: Supervision, Writing – review & editing. **Author Name**: Conceptualization, Supervision, Writing – review & editing.

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