Conference of Electrical, Marine and Its Application
Vol. xx, No xx, Month-Year ISSN:

Development of a Single-Phase Fully Controlled Rectifier for 2 HP DC Motor Applications

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ABSTRACT

Speed control of DC motors is among the simplest compared to other motor types. However, traditional control methods, such as using an autotransformer, are still widely employed today. As is well known, autotransformer configurations have significant drawbacks. Chief among these are economic issues: damaged autotransformers are costly, difficult to repair, and expensive to replace. To address this challenge, a controlled rectifier utilizing the TCA 785 IC is employed to regulate the firing angle of thyristors driving the DC motor. The TCA 785 IC offers ease of control and simplified repair processes if the device malfunctions. This system is designed to regulate the voltage on the armature winding using a fully controlled rectifier with a maximum output voltage of 190 VDC. The device employs the TCA 785 IC to set the thyristor firing angle and deliver the resulting voltage to the motor's armature winding. As a result, the DC motor operates without current surges during voltage increments. Furthermore, the motor is coupled to a three-phase synchronous generator, which achieves the desired rotation speed (1000 rpm). By connecting incandescent lamps to the three-phase generator output, a load simulation is performed for the DC motor. This project aligns with community empowerment goals, particularly in advancing technical education and practical skills development. By offering an innovative yet cost-effective alternative to traditional motor control systems, the device contributes to increasing accessibility for small industries and vocational training centers. These benefits relevant for community service programs aimed at fostering local technical expertise and economic resilience.

Key Word: *controlled rectifier, DC Motor, TCA 785*

I.INTRODUCTION

A rectifier circuit is a system designed to convert AC voltage into DC voltage. A controlled rectifier circuit utilizes thyristors as rectifying components to manage the output DC voltage[1]. Controlled rectifiers are categorized into fully controlled rectifiers and half-controlled rectifiers, both of which can be employed for regulating the speed of DC motors. Speed control of a DC motor can be achieved through various methods, including adjusting the terminal voltage (Vt) of the armature winding[2]. By controlling the terminal voltage, the motor's speed can be regulated both during startup and operational phases. Power electronics simplify and enhance the efficiency of Vt adjustments[3].

In this design, a 2 HP DC motor is utilized with individual excitation as part of the control system. The speed control of the DC motor is achieved using a rectifier[4]. The primary objective of this design is to develop a single-phase thyristor-controlled rectifier capable of driving a 2 HP DC motor by regulating the armature voltage. This regulation is achieved through a fully controlled thyristor rectifier while the magnetic flux from the field winding remains semi-controlled. The magnetic flux is increased to a nominal value and kept constant, while speed variations are managed by adjusting the armature voltage until the desired motor speed is attained[3].

The construction of the thyristor-controlled rectifier includes both fully controlled and semi-controlled rectifiers, facilitating smooth operation during startup and normal running conditions[4]. The thyristor control circuit employs analog control using the TCA 785 IC. The motor field voltage reaches a maximum of 198 VDC, while the armature voltage is regulated to a maximum of 190 VDC with a current capacity of 13.5 A. The input AC voltage operates at a frequency of 50 Hz. Speed regulation is accomplished solely by adjusting the armature voltage through the fully controlled rectifier, while the field voltage remains constant[5].

Simulation testing is conducted using a 2 HP DC motor coupled with a three-phase induction generator supplying voltage to incandescent lamps, simulating the load conditions. However, the simulation does not represent the harmonics generated within the circuit nor the operation of a two-phase induction generator. Additionally, the electronic circuitry employed in the design is elaborated upon from an operational functionality perspective, emphasizing its role in achieving precise motor control[6].

II.METHODOLOGY

1. Direct Current Motor

The general formula for a direct current (DC) motor is used to determine the point at which speed regulation can be effectively carried out, allowing the motor to operate according to the desired operational requirements[7][8].

$$E_b = C \,.\, N \,.\, \varnothing \qquad (1)$$

Where:

$E_b = opposing\ electromotive\ force\,(V)$

$C = Constant$

$N = Anchor\ rotation\ speed\,(rps)$

$\varnothing = fluks\ magnet\,(Wb)$

$$E_b = V_t - I_a \,.\, R_a \qquad (2)$$

Where:

$V_t = Voltage\ Maximum\,(V)$

$I_a = Anchor\ Current\,(A)$

$R_a = Anchor\ Resistance\,(\Omega)$

From both equation before, combine to this formula:

$$N = \frac{V_t - I_a \,.\, R_a}{C\,\varnothing} \qquad (3)$$

From the equation above, it can be concluded that the rotational speed of the armature can be regulated by adjusting the value of φ (by changing the voltage or current of the field winding), Ra (by adding a series resistor to Ra), and Vt (by altering the terminal voltage of the armature winding)[9]. The torque generated is determined using the following equation:

$$T = \frac{E_b \,.\, I_a}{2\pi \,.\, N} \qquad (4)$$

When a direct current (DC) motor is started, the starting current can reach 20 to 30 times higher than the nominal current under full load conditions[10]. This phenomenon can be demonstrated using Equation as follows:

$$V_t = E_b - I_a \,.\, R_a$$

$$I_d = \frac{V_t \,.\, E_b}{R_a}$$

At the time of starting Eb = 0 so:

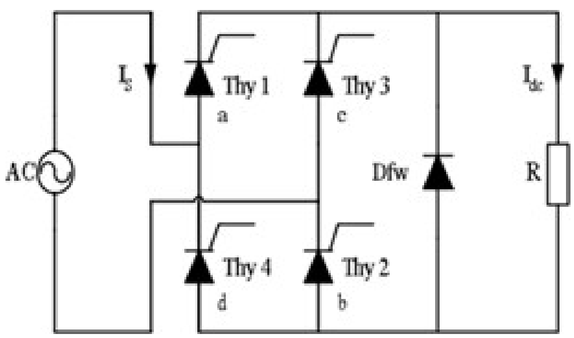
$$I_d = \frac{V_t}{R_a} = I_{st} \qquad (5)$$

2. Single Phase Fully Controlled Rectifier

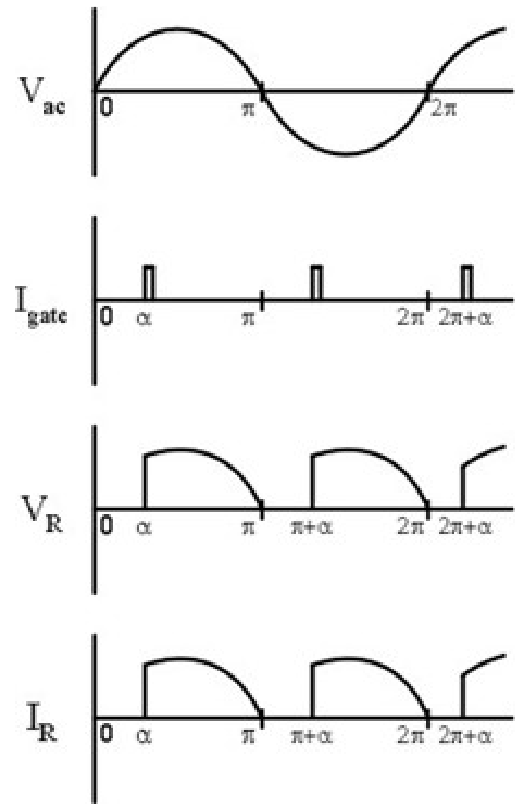
As demonstrated, a single-phase fully controlled rectifier, consisting of four thyristors and a freewheeling diode, is utilized to supply electrical energy to the armature winding and regulate the armature voltage[11]. This configuration is employed to control the speed of the DC motor effectively. The operation of the rectifier is executed in an open-loop system, facilitating the initial startup and ongoing operation of the motor[12].

The DC output voltage (Vdc) or output voltage (Vo) of the rectifier is determined using the following equation:

$$V_o = V_{dc} = \frac{2}{2\pi} \int_{a}^{\pi} V_m . \sin \omega t \, d(\omega t)$$



(a)

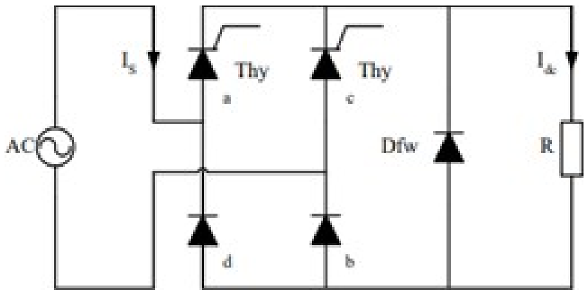


(b)

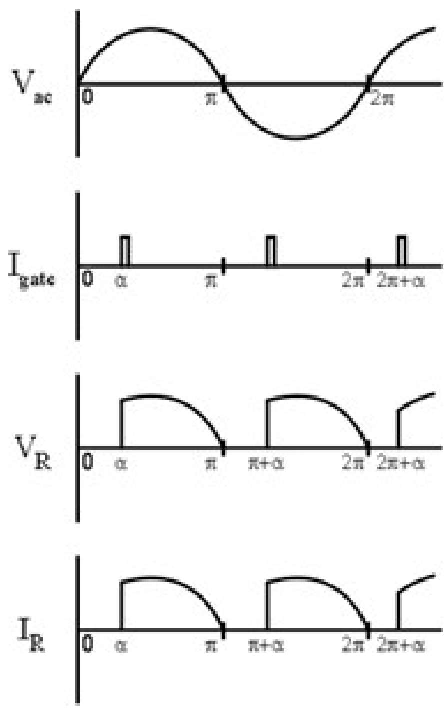
Figure 1. (a) fully controlled full wave rectifier (b) Vac, Igate, VR, and IR waveforms

3. Single Phase Half Controlled Rectifier

To convert the described system into a half-controlled circuit, we would typically replace two of the thyristors with diodes, while keeping the other two thyristors to allow for partial control of the output voltage[13]. In a half-controlled rectifier, the thyristors control the positive half-cycle of the AC input, while the diodes conduct during the negative half-cycle, providing a form of unidirectional current flow with partial control over the output[14].



(a)



(b)

Figure 1. (a) half controlled full wave rectifier (b) Vin, Iin, Iout, and Vout waveforms

4. Thyristor

A thyristor is a semiconductor component with a gate, operating similarly to a diode but with the ability to be controlled and adjusted during its conduction phase[15]. Unlike a standard diode, which conducts current only when forward biased, a thyristor can be turned on and off by controlling the gate signal[16]. This unique feature makes it highly suitable for applications that require precise control of electrical power, such as in the regulation of DC motor speed through a fully controlled rectifier.

In the context of community service and vocational training, the integration of thyristors into power electronics provides a valuable learning opportunity. By understanding and applying thyristor-based circuits, individuals in underprivileged areas can gain technical skills that are essential for modern industries. Furthermore, these systems offer a more affordable and sustainable solution for small-scale energy projects in rural areas, promoting local economic development and energy independence.

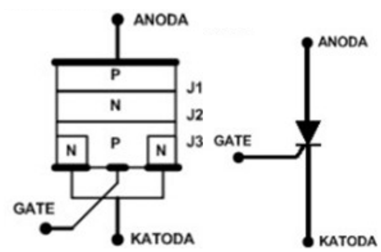


Figure 3. Structure and symbol Thyristor

5. TCA785

The working principle of the IC TCA 785 is centered around its ability to control the firing angle of the thyristors in a fully controlled rectifier circuit[17]. This integrated circuit (IC) provides precise control over the operation of the rectifier, allowing for the regulation of the DC output voltage supplied to the armature of a DC motor[18]. By adjusting the firing angle, the IC ensures smooth and efficient speed control of the motor, offering significant advantages over traditional methods, such as autotransformer-based controls.

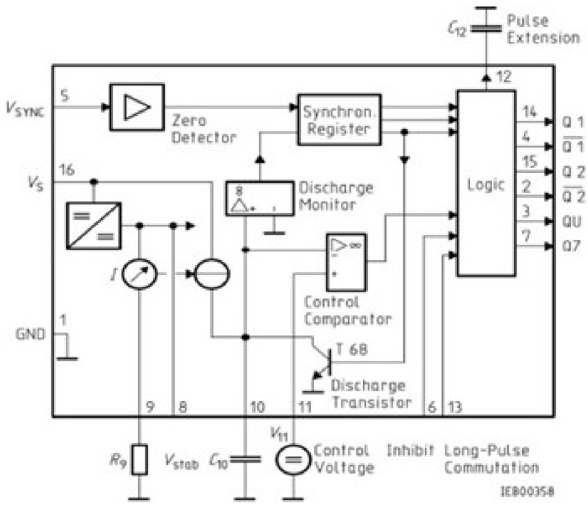


Figure 4. Diagram IC TCA785

In the context, the IC TCA 785 is a valuable tool for developing low-cost, energy-efficient systems for local industries or educational programs. Its simplicity in implementation and ease of control make it ideal for use in rural or underserved communities where technical training and affordable solutions are essential for fostering economic development and technological empowerment. Waveform data from the TCA785 IC can be seen in the image below

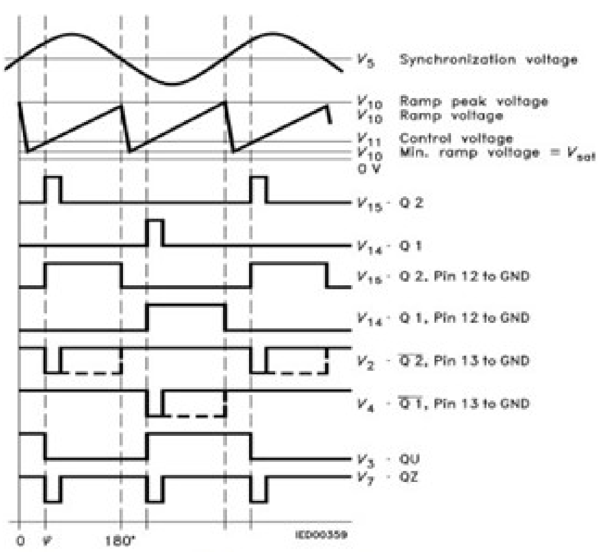


Figure 5. Pulse Diagram

6. Optocoupler

An optocoupler circuit is employed to protect the control circuit in the event of a failure or malfunction within the power circuit[19]. The optocoupler isolates the control components from the high-power components, ensuring that any electrical surges or faults in the power circuit do not damage the sensitive control electronics[20]. This protection mechanism is essential for maintaining the reliability and longevity of the system, especially in critical applications such as the operation of a DC motor.

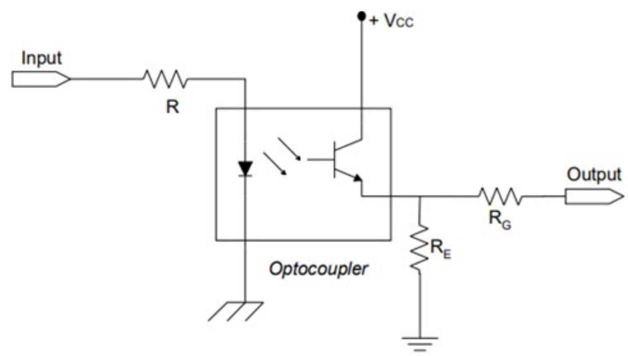


Figure 6. Optocoupler circuit

III.RESULT & DISCUSION

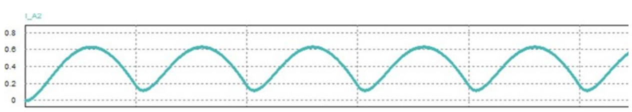
1.Testing

a. Power source

There are three primary voltage sources in the system: the power supply (220VAC), the triggering source (15VDC), and the optocoupler (12VDC). These sources are essential for the proper functioning of the fully controlled rectifier and DC motor control system. The power supply provides the necessary alternating current (AC) to drive the rectifier, while the triggering source and optocoupler provide the necessary DC voltages for controlling the thyristors and ensuring the isolation between the high-power and control circuits.

Testing these voltage sources using PSIM simulation software resulted in the following waveforms and data, which are integral in analyzing the performance and reliability of the system.

From a community service perspective, understanding the behavior and interactions of these voltage sources can be a crucial part of technical education programs aimed at improving local energy solutions. By utilizing such simulations and practical circuit designs, communities can enhance their understanding of power electronics and improve the efficiency and safety of locally deployed motor control systems.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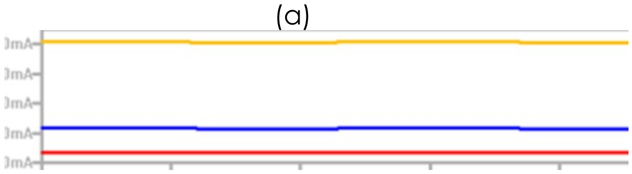
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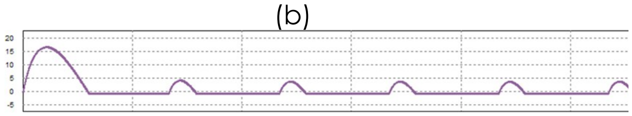
(c)

Figure 7. (a) Power Waveform
(b)Voltage Source waveform
(c)Optocoupler circuit waveform

b. Pulse

The output of the triggering circuit plays a crucial role in supplying the necessary voltage to the thyristor, ensuring that it operates at the correct times during the AC cycle. This voltage passes through the pulse isolator circuit to provide electrical isolation between the triggering circuit and the power components, preventing any potential damage due to voltage spikes or fluctuations. In this design, three types of triggers are employed to optimize the operation of the thyristors, each with specific characteristics suited for different operational conditions. These trigger types include a phase control trigger, which adjusts the timing of the thyristor firing, a current limit trigger to prevent overcurrent conditions, and a pulse-width modulation (PWM) trigger that helps regulate the output voltage by varying the duty cycle. By using these three types of triggers, the system ensures precise and reliable control over the thyristor's switching behavior, leading to efficient regulation of the DC motor's speed and performance.

- Saw pulse waveform

The testing of the sawtooth wave generator was conducted at pin 10 of the IC TCA 785, relative to ground, using the PSIM simulation software. This test is crucial for analyzing the waveform characteristics and performance of the circuit, particularly in controlling the firing angle of the thyristors within the single-phase fully controlled rectifier. By simulating the circuit in PSIM, the system's behavior and response to different input parameters can be accurately observed, allowing for optimization of the motor control system.

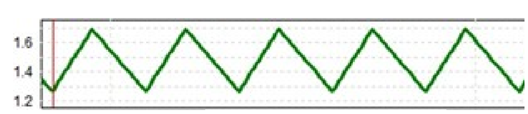

Figure 8. Saw Pulse

- Voltage Control

This voltage control test was conducted with pin 11 of the TCA785 connected to ground. The purpose of this test was to determine the minimum and maximum limits of the control voltage while adjusting the variable resistor. The waveforms generated during the testing, as observed through the PSIM simulation software, are shown below.

Figure 8. Maximum and minimum voltage control

- Output Pulse

The output voltage measurement of the trigger was recorded at 1.7V. Figure 20 illustrates the output waveform generated by PSIM. Since the results are consistent, both the measurement and the waveform from PSIM correspond to output 1 and output 2.

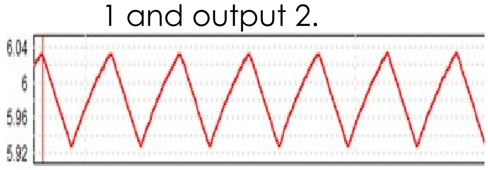

Figure 9. Output puse waveform

c. Optocoupler

The output from the Optocoupler is used to trigger the thyristor in the power circuit. The output waveform from the Optocoupler can be observed on the oscilloscope, as shown in the figure below.

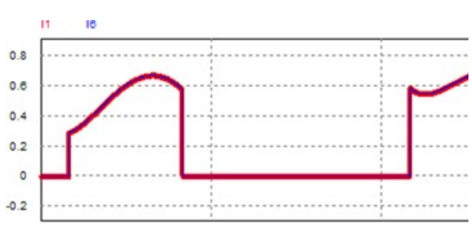

Figure 10. Optpcoupler waveform

d. Power Circuit waveform

The circuit was tested using a light bulb load, with the phase angle (α) set to 120°, producing a as shown in Figure 11. Similarly, the circuit was tested with a DC motor load, also set to a phase angle (α) of 120°, yielding a waveform as shown in Figure 12.

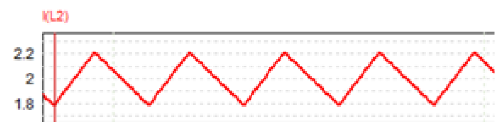

Figure 11. Bulb Load

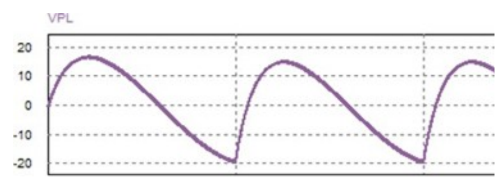

Figure 12. Motor DC Load

These tests demonstrate the practical applications of a single-phase fully controlled rectifier in various scenarios, including both resistive and inductive loads, such as light bulbs and DC motors. Such technology holds significant potential in community-based projects, where reliable and efficient power control is critical for local infrastructure. By providing a low-cost solution to regulate motor speeds and manage electrical loads, this system can enhance the sustainability of small-scale power generation, especially in off-grid communities.

2.Discussion

a. Without Load

This experiment was carried out without placing a load on the generator. After obtaining the experimental data, the following graph is obtained:

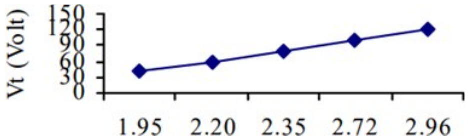

Figure 13. Comparison graph of Vt against Ia

In Figure 13 above, it can be seen that with every increase in Vt (voltage on the motor armature) there is no high surge in Ia current.

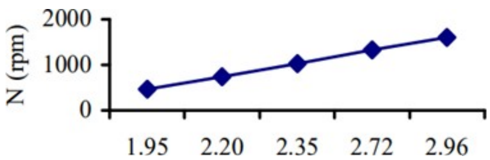

Figure 14. Comparison graph of N against Ia

Figure 14 shows the comparison of N with Ia, under the condition that Vt is increased, and it can be seen that the increase in Ia is followed by an increase in N.

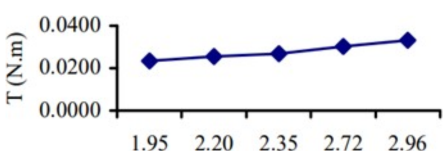

Figure 15. Comparison graph of T against Ia

Figure 15 shows the ratio of T to Ia, under the condition that Vt is increased, and it can be seen that the change in Ia to T is directly proportional

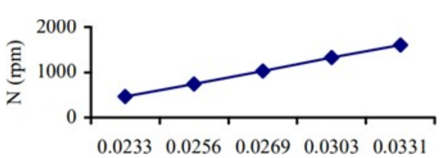

Figure 16. Comparison graph of T against N

b. With Load

The data acquisition method consists of initial conditions without load, rotating the regulator until the DC motor speed reaches 1500 rpm, then determining the load in the form of a generator bulb according to Table 4.2. Without changing the knob position. After obtaining the experimental data, the following graph was obtained: To examine the changes in armature voltage (Vt) that occurred, the graph in Figure 28 clearly shows the changes in armature current (Ia).

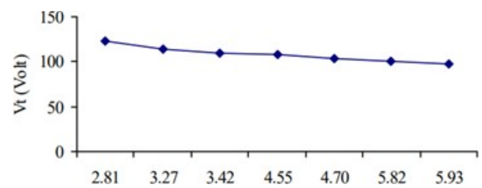

Figure 17. Comparison graph of Vt against Ia

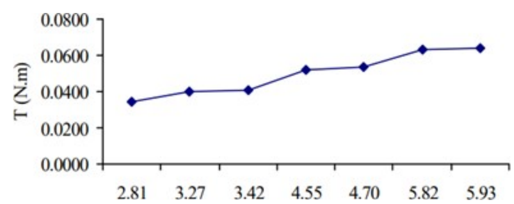

Figure 18. Comparison graph of T against Ia

Figure 18 shows the comparison of T with Ia, in conditions where Vt is decreasing, it can be seen that the change in Ia versus T is directly proportional.

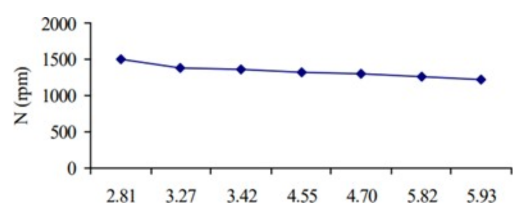

Figure 19. Comparison graph of N against Ia

Figure 19 shows the comparison of N and Ia. Adding a load reduces the voltage Vt by, but increases the current Ia, followed by a rotation of N.

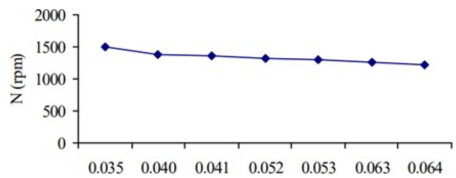

Figure 20. Comparison graph of N against T

Table 1. Resul table

No	Type of Converter	Load	Value PI	Voltage (V)	Current (A)	Power (W)	%
Half-waveform Rectifier							
1	Feedback	R	29	219,99	18,33	1120,37	
			91	219,99	18,33	1120,37	
Full-waveform Rectifier							
1	Without Feedbaack	R	31	219,99	24,44	2501,61	
			91	219,99	24,44	2.765,27	
2	Feedback	R	20	153,39	76,69	2.407,74	
			100	219,99	109,99	8.800,73	
			226	219,99	109,99	12,48	
		RL	15	133,91	22,38	675,19	
			85	219,69	36,75	2.592,77	
			240	219,99	36,66	4.161,13	
		RC	12	121,46	30,37	902,27	
			115	219,99	54,99	4.589,89	
			230	219,99	54,99	6.216,74	
		RLC	17	218,66	55,65	3.558,74	
			120	219,99	54,99	5.434,53	
			220	219,99	54,99	6.091,47	
3	Connected Series	RL	8	105,43	21,18	1.169,81	
			24	105,43	21,18	1.169,81	

IV.CONCLUSION

The results can be summarized as follows:

1. Make a fully controlled single phase rectifier by regulating the voltage output on the motor armature (up to 190 VDC) and excitation on the motor field (up to 198 VDC) to make a 2hp DC motor work properly
2. Adjustment of the motor dynamo voltage is carried out after increasing the field excitation until the desired rated voltage is reached. The excitation voltage value does not change, no. The only change that was adjusted was the motor armature tension to achieve maximum motor rotation at 1750 rpm.
3. The variable DC output of the fully controlled rectifier can be adjusted by thyristor phase angle control of the TCA 785 phase control IC trigger circuit.
4. DC motor loading is carried out with the alternator output connected to a 15 watt incandescent lamp after the motor reaches a minimum rotation of 1,500 rpm, loading the lamp gradually until the load reaches 75. Will be added. To slow down the motor speed.
5. The trigger output waveform produced by changes after being passed through the isolator circuit, depending on the rise and fall times of the optocoupler.

V.REFERENCE

[1] Coutinho, H. V., Toledo, J. A., Silva, L. A., & Maia, T. A. (2023). Design and implementation of a low-cost and low-power converter to drive a single-phase motor. Machines, 11(7), 673.

[2] Swamy, M. M., & Guddanti, C. (2014). An improved single-phase active-front-end rectifier system for use with three-phase variable-frequency drives. IEEE Transactions on Industry Applications, 51(2), 1732-1742.

[3] Nugraha, Anggara Trisna, and Rachma Prilian Eviningsih. Konsep Dasar Elektronika Daya. Deepublish, 2022.

[4] Nugraha, Anggara Trisna, and Rachma Prilian Eviningsih. Penerapan Sistem Elektronika Daya: AC Regulator, DC Chopper, dan Inverter. Deepublish, 2022.

[5] Ivannuri, Fahmi, Anggara Trisna Nugraha, and Lilik Subiyanto. "Prototype Turbin Ventilator Sebagai Pembangkit Listrik

Tenaga Angin." Journal of Computer, Electronic, and Telecommunication (COMPLETE) 3.2 (2022).

[6] Zhu, W., Zhou, K., Cheng, M., & Peng, F. (2014). A high-frequency-link single-phase PWM rectifier. IEEE Transactions on Industrial Electronics, 62(1), 289-298.

[7] Ghosh, R., & Narayanan, G. (2007). A single-phase boost rectifier system for wide range of load variations. IEEE transactions on power electronics, 22(2), 470-479.

[8] Rahayu, E. S., Ma'arif, A., & Cakan, A. (2022). Particle swarm optimization (PSO) tuning of PID control on DC motor. International Journal of Robotics and Control Systems, 2(2), 435-447.

[9] Aliasand, A. E., & Josh, F. T. (2020). Selection of motor foran electric vehicle: A review. Materials Today: Proceedings, 24, 1804-1815.

[10] Giraneza, M., & Kahn, M. T. E. (2020). Broad band opto-capacitive power line communication coupler for DC nanogrids. Journal of King Saud University-Engineering Sciences, 32(4), 246-254.

[11] Mehar, H. (2013). The case study of simulation of power converter circuits using Psim software in teaching. American Journal of Educational Research, 1(4), 137-142.

[12] Mu'in, Misbakhul, et al. "ANALISIS ALIRAN DAYA DAN CAPASITOR PLACEMENT PADA SISTEM KELISTRIKAN PT BLAMBANGAN BAHARI SHIPYARD DENGAN SOFTWARE ETAP." Jurnal 7 Samudra 8.1 (2023).

[13] Amrullah, Muhammad'Ubaid, et al. "RANCANG BANGUN MONITORING KUALITAS AIR TAMBAK UDANG VANAME DENGAN KONTROL PADDLE WHEEL BERBASIS MIKROKONTROLLER." Jurnal 7 Samudra 8.2 (2023): 117-122.

[14] Pangestu, Nanda Dwi, et al. "PERANCANGAN SMART PROTECTION PADA MOTOR KINCIR AERATOR TAMBAK UDANG MENGGUNAKAN LOGIKA FUZZY." Jurnal 7 Samudra 9.1 (2024): 1-8.

[15] Hidayana, Elmi, et al. "UTILIZATION OF BAGASSE WASTE FOR BIO-OIL EXTRACTION FROM SUGARCANE JUICE VENDORS IN BANYUWANGI REGENCY." Jurnal Cakrawala Maritim 7.1 (2024): 43-51.

[16] Rahman, Farhan Wahyu Nur, et al. "ASSESSING THE MARKETING APPROACH OF PT PAL INDONESIA COMPANY THROUGH A SWOT ANALYSIS." Jurnal Cakrawala Maritim 6.1 (2023): 20-24.

[17] Handandi, Zukhruf Zidane, et al. "HOW THE PERFORMANCE OF A DC MOTOR SYSTEM IS IMPACTED BY NOISE." Jurnal Teknologi Maritim 6.1 (2023): 11-16.

[18] Kurniawan, Rizky Fitra, et al. "HOW THE PERFORMANCE OF A DC MOTOR SYSTEM IS IMPACTED BY NOISE." Jurnal Teknologi Maritim 6.1 (2023): 23-32.

[19] Asadi, F., & Eguchi, K. (2021). Power electronics circuit analysis with PSIM®. Walter de Gruyter GmbH & Co KG.

[20] Sun, H. (2020, May). PSIM simulation and experimental analysis of power transformation and control principle and its failure. In AIP Conference Proceedings (Vol. 2238, No. 1). AIP Publishing.