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Community Empowerment Through DC Motor Speed Control Using PSIM-Based Full Wave Rectifiers

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ABSTRACT

The use of an autotransformer for motor control has various drawbacks, particularly in terms of cost-effectiveness. When an autotransformer malfunctions, it necessitates a more practical and economical alternative for controlling the speed of series-wound DC motors. Utilizing PSIM simulation software facilitates system design in the field, significantly saving time, effort, cost, and reducing risks associated with failure. Once the system design aligns with specifications, a full-wave controlled rectifier is incorporated into the DC motor, followed by the adjustment of the firing angle. However, sourcing new components for such systems poses challenges due to high costs. The system employs a single-phase 220V AC supply, which is rectified by the full-wave controlled rectifier circuit. It was observed that the firing angle inversely affects the rotational speed of the series-wound DC motor under torque loads of 0 Nm, 1 Nm, and 2 Nm. The rectifier circuit simultaneously functions as both the DC power supply and the speed controller for the motor. Using PSIM simulation software minimizes potential losses caused by failures during the system design process. The speed control of series-wound DC motors is achieved by adjusting the firing angle of the thyristor. Increasing the firing angle reduces the motor's speed, thereby optimizing operational control. Compared to previous studies, this approach demonstrates advancements in the use of a full-wave controlled rectifier within the system, emphasizing enhanced practicality and efficiency for community-focused applications.

Key Word: *Speed controller, DC motor, Fully controlled rectifier, PSIM.*

I.INTRODUCTION

Implementing electrical systems in practical applications requires more than just analyzing electrical circuits; it often involves integrating knowledge from mechanical, thermal, and control systems[1]. This interdisciplinary approach is crucial for addressing complex challenges and ensuring optimal system performance. During the planning phase, research across multiple disciplines becomes essential to discover innovative solutions and refine existing systems to meet specific needs[2]. Such an approach is particularly relevant in community empowerment programs, where practical and cost-effective solutions are critical for addressing local challenges.

Simulation plays a pivotal role as the final step in the planning process. By using simulation tools, designers and engineers can save significant amounts of time, effort, and financial resources while minimizing risks associated with implementation failures. Among the many simulation software options available today, PSIM stands out for its efficiency and user-friendliness[3]. Its SIMVIEW feature, in particular, simplifies system visualization, allowing for rapid and accurate analysis of design parameters. These advantages make PSIM an excellent choice for applications requiring precise control and optimization, such as in community-based energy or skill development projects[4].

This paper presents a detailed simulation of DC motor speed control using a full-wave controlled rectifier, conducted with PSIM 9.1. By adjusting the armature voltage through a full-wave controlled rectifier, the DC motor's speed can be precisely managed to accommodate varying load conditions. This study evaluates how load changes impact motor speed, providing valuable insights into system dynamics and performance. The findings of this simulation are not only relevant for advancing technical understanding but also hold significant potential for application in community empowerment initiatives, particularly those aimed at promoting energy efficiency and sustainable development[5].

II.METHODOLOGY

Research on DC motor controllers using fully controlled rectifiers has been extensively conducted in the past. Journals and studies discussing similar theories and research subjects have been referenced as foundational materials for this study. Below are examples of prior research that explore DC motor controllers with fully controlled rectifiers, offering valuable insights into the development of this work.

While studies provide a foundation for the present research, this work differs in its focus and methodology. The similarity lies in the facilitation of system design for fully controlled rectifiers applied to DC motors using simulation software. However, the current research employs a different software platform, PSIM, and targets a different type of DC motor, emphasizing the unique contributions and expanded scope of this study. This distinction is particularly relevant for practical community applications, such as improving technical skills and promoting efficient energy solutions in underserved areas.

1. Method

a. PSIM

PSIM is a specialized simulation software designed for power electronics, motor drives, and power conversion systems[6]. It offers rapid simulation processes, making it a powerful tool for meeting the demands of simulation and development in these fields[7]. PSIM's efficiency and precision are crucial in various applications, from industrial motor control to renewable energy systems, and it provides an essential platform for designing and testing power electronics solutions[8].

The software consists of three main components: the PSIM Schematic program, the PSIM Simulator, and the SIMVIEW waveform processing program. The PSIM Schematic allows users to create detailed circuit diagrams and simulations, enabling them to model complex systems with ease[9]. The PSIM Simulator performs the actual simulations, calculating system behavior and generating results that reflect real-world performance. SIMVIEW then processes the simulation data, offering visualizations such as waveforms and graphs that help users understand the system's response to various conditions[10].

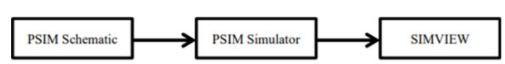

Figure 1.Work of PSIM

community empowerment projects, especially in the context of rural or underserved areas, PSIM provides a valuable tool for developing and testing energy-efficient solutions. By simulating motor control systems and power conversion technologies, communities can improve local infrastructure and create sustainable, cost-effective solutions. Using PSIM in such initiatives can help reduce energy costs, improve reliability, and enhance the technical skills of local engineers and technicians, contributing to long-term community development and self-sufficiency.

b. DC MOTOR

A DC motor is powered by a direct current (DC) voltage applied to the field winding, which is then converted into mechanical energy. The DC motor consists of two primary windings: the field winding, which generates a magnetic field, and the armature winding, which serves as the location for the induced electromotive force (emf)[11]. When the current in the armature winding interacts with the magnetic field, a torque (T) is generated, causing the motor to rotate[12].

This fundamental principle of electromagnetic induction is at the heart of DC motor operation. The armature winding, placed within the magnetic field created by the field winding, experiences a force due to the interaction between the magnetic field and the electric current. This force generates a torque, which leads to the rotation of the motor shaft. The speed of the motor is directly related to the voltage applied to the armature and the field winding, while the torque is determined by the current flowing through the armature[13].

In the context of community empowerment, particularly for rural or underserved areas, the understanding and application of DC motor technology can have significant benefits. The ability to control and optimize the speed and torque of DC motors allows for more efficient use of energy in applications such as water pumping, milling, and small-scale manufacturing. By utilizing tools like PSIM for simulation and control, communities can develop locally suitable solutions for power generation and motor-driven systems, leading to improved infrastructure and greater self-sufficiency.

c. Self-amplified Direct Current Motor

A self-excited DC motor is a type of DC motor in which the field winding is supplied by the same DC current source that powers the armature winding[14]. This configuration allows for the motor to operate with a feedback loop where the field current is derived from the armature current, making it self-regulating. The self-excited DC motor is highly versatile and commonly used in various applications due to its ability to adjust to different load conditions without requiring an external field current supply.

Based on the way the field winding and armature winding are connected, DC motors are generally classified into three main types: 1) Shunt-wound DC motor, where the field winding is connected in parallel with the armature winding. 2) Series-wound DC motor, where the field winding is connected in series with the armature winding[15]. 3) Compound-wound DC motor, which combines both series and shunt winding configurations to provide a balance of characteristics, offering a more stable performance across varying load conditions.

In the context of community empowerment, these various types of DC motors can play a crucial role in local development projects. For instance, in rural or off-grid areas, self-excited DC motors can be used for a variety of mechanical tasks such as water pumping, milling, and even powering small local industries[16]. The ability to control and regulate the motor's speed and performance through modern tools such as PSIM-based full-wave rectifiers enhances the efficiency and sustainability of these motors, making them more adaptable for community-driven energy solutions. The use of simulation software can aid in the design and optimization of these systems, ensuring that the motors operate efficiently while minimizing costs and risks associated with failure. This contributes to greater self-sufficiency and economic empowerment for communities.

d. Series Amplified Direct Current Motor

A series-wound self-excited DC motor is a type of DC motor where the field winding and armature winding are connected in series. This configuration is known for its characteristic performance, where the motor's speed is not constant and is directly affected by the load. When a large load is applied, the rotational speed of the motor decreases, while a smaller load causes the speed to increase[17]. This behavior makes series-wound DC motors particularly suitable for applications where the motor needs to adapt to varying loads, such as in certain industrial machines or energy systems in community-based projects.

In practical applications, such as in community empowerment initiatives, the series-wound self-excited DC motor can be utilized in situations where load variability is frequent. For instance, small-scale power generation systems in rural areas could benefit from these motors. With the ability to adjust to load changes, series-wound motors can drive machinery like water pumps or small grinders, providing a crucial service for local agricultural or water management projects. However, to optimize their performance and ensure the sustainability of these solutions, speed control and regulation techniques are essential.

One approach to managing the speed and performance of these motors is through the use of modern tools such as PSIM-based full-wave rectifiers. These rectifiers provide a reliable means of controlling the voltage and current fed into the motor, thus allowing for better management of its speed and efficiency. By integrating simulation software like PSIM, engineers can design and test motor control systems to ensure that they are suitable for the specific needs of the community[15]. This integration of technology not only enhances the performance of DC motors in practical applications but also contributes to more efficient and sustainable energy solutions for community development projects.

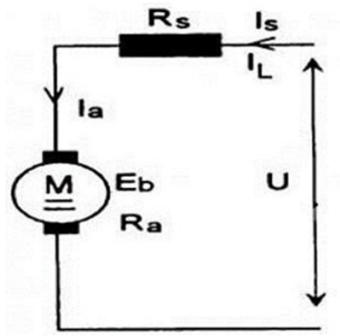

Figure 2. Equivalent circuit of DC motor

e. Rectifier

A rectifier is a device used to convert an alternating current (AC) source into a direct current (DC) signal. AC, typically represented as a sinusoidal waveform, is transformed into a steady-state DC waveform through the rectification process. This conversion is essential for many applications, as DC power is required for various electrical systems, such as motor control and power supplies. The output DC signal, which is more stable, can be observed using measuring instruments like an Oscilloscope (CRO)[11].

Rectifiers often utilize a step-down transformer, which reduces the voltage to the desired level based on the transformer's turn ratio[19]. This is particularly important in applications where voltage regulation is necessary for optimal system performance. In the context of community empowerment, this is crucial for designing systems that efficiently provide energy solutions to rural or underserved areas. For example, in small-scale renewable energy projects, such as solar power systems, rectifiers play a pivotal role in converting the generated AC into usable DC power for local communities[.

The use of rectifiers in DC motor speed control systems, particularly with full-wave controlled rectifiers, allows for more precise regulation of motor speed. This is an essential component in empowering local communities, especially in rural areas, by providing reliable, controllable power for various machines, from water pumps to agricultural equipment. Integrating rectification systems with motor control technologies like PSIM-based simulations not only ensures the efficiency of these systems but also fosters sustainable development and enhances the economic and social wellbeing of communities.

f. Single Phase Rectifier Circuit Design

A single-phase full-controlled rectifier is used as both the DC power supply and the speed controller for a DC motor[18]. In the design of the single-phase full-controlled rectifier, SCR (Silicon Controlled Rectifier) components are utilized. To activate the rectifier circuit, a triggering voltage is required between the gate and cathode terminals of the SCR. Triggering must be applied to pairs of SCRs (T1, T2 and T3, T4) simultaneously, allowing the full-controlled single-phase rectifier to operate effectively. Figure 4 illustrates the circuit diagram of the full-controlled single-phase rectifier.

To protect the rectifier circuit from residual current in inductive loads, a freewheeling diode is often installed in parallel with the rectifier circuit[19]. This diode serves as a safeguard, preventing damage caused by residual current from the inductive load. When the power supply to the circuit is switched off, the inductive load may still generate a voltage across the inductor, represented as L di/dt. As a result, residual current will flow back into the rectifier circuit. If the rectifier components are not designed to withstand this current, they could be damaged. The installation of the freewheeling diode ensures that the residual current only flows through the diode, preventing it from reaching the rectifier circuit and thus protecting the system from potential damage[20].

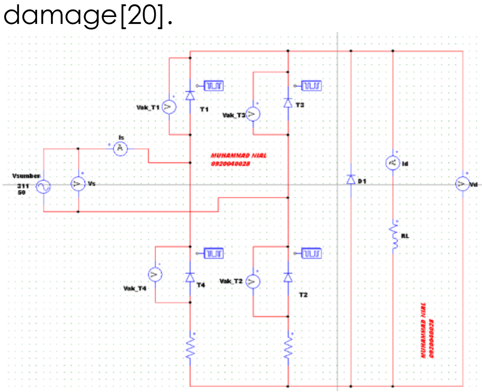

Figure 3. Single Phase Rectifier Circuit

In the context of community empowerment, especially in areas where reliable and controlled power is necessary, such as in rural or off-grid regions, the application of such rectifiers can provide an efficient and sustainable solution. The ability to control DC motor speeds through a PSIM-based simulation of full-wave rectifiers empowers local communities by offering more precise control over machinery, which is essential for agricultural processes, water pumping, and small-scale industry. Moreover, the implementation of safety measures like freewheeling diodes ensures the longevity and reliability of the power supply systems, which is critical for sustainable development in community-focused energy projects.

III.RESULT & DISCUSION

1.Result

After conducting measurements using the PSIM software, the observed data include the armature voltage (Va), armature current (Ia), and the rotational speed (N) of the self-excited series DC motor. Subsequently, the DC motor was loaded with torque values of 0 Nm, 1 Nm, and 2 Nm. The measurement results can be seen in the table below.

These measurements are essential in understanding the behavior of the DC motor under varying load conditions. By simulating different torque loads, the system's response in terms of voltage, current, and motor speed can be accurately assessed. Such data not only helps in fine-tuning the motor control system but also aids in the optimization of energy usage and motor performance. The insights gained through this simulation can contribute to the design and implementation of more efficient and reliable DC motor control systems, particularly in community-driven projects where energy efficiency and control are paramount.

In the context of community empowerment, this type of research plays a critical role in advancing local energy solutions. By using PSIM-based simulations to optimize DC motor speed control, communities can harness the power of renewable energy sources, such as solar or wind, to drive local industries, agricultural activities, and other community-based services. This approach ensures sustainable energy use and provides opportunities for economic development, particularly in rural or underserved areas.

Table 1. Measurement results using Torque = 0 Nm

ignition angle (°)	Anchor Voltage (Va) (Volt)	Anchor Current (Ia) (Ampere)	Rotation (RPM)
0	184.64	0.65	2927.94
30	172.14	0,61	2895.25
60	137.64	0.52	2701.85
90	90.48	0.41	2271.98
120	43.5	0.29	1597.77
150	9.8	0.16	700.38
180	5.79E-18	4E-14	0

Table 2. Measurement results using Torque = 1 Nm

ignition angle (°)	Anchor Voltage (Va) (Volt)	Anchor Current (Ia) (Ampere)	Rotation (RPM)
0	177.2	1.01	1517.92
30	165.06	0.95	1493.72
60	131.32	0.83	1353.75
90	84.9	0.68	1047.42
120	38.62	0.53	588.54
150	3.52	0.47	51.09
180	3.35E-17	8.8E-15	0

Table 3. Measurement results using Torque = 2 Nm

ignition angle (°)	Anchor Voltage (Va) (Volt)	Anchor Current (Ia) (Ampere)	Rotation (RPM)
0	174.7	1.13	1103.95
30	162.65	1.07	1083.02
60	128.93	0.95	965.7
90	82.4	0.81	717.06
120	35.62	0.67	363.95
150	0.32	0.63	0.0739
180	6.8E-18	4.2E-14	0

a. Function Characteristics of Ignition Angle on Motor Rotation Speed

The speed of a self-excited series DC motor is controlled using thyristors by adjusting the firing angle (α) of the thyristors. In this study, the following firing angles (α) were used: 0°, 30°, 60°, 90°, 120°, 150°, and 180°. The relationship between the firing angle (α) of the thyristor and the rotational speed (N) of the DC motor is shown in the characteristic graph below.

By controlling the firing angle of the thyristor, the motor speed can be precisely adjusted to meet various operational needs. This approach allows for efficient speed regulation, which is crucial in applications where energy optimization and control are of the utmost importance. The firing angle adjustments directly influence the amount of power supplied to the motor, thereby controlling the motor's torque and speed, making it a vital tool in industrial and community-level applications that require reliable and adaptable motor control.

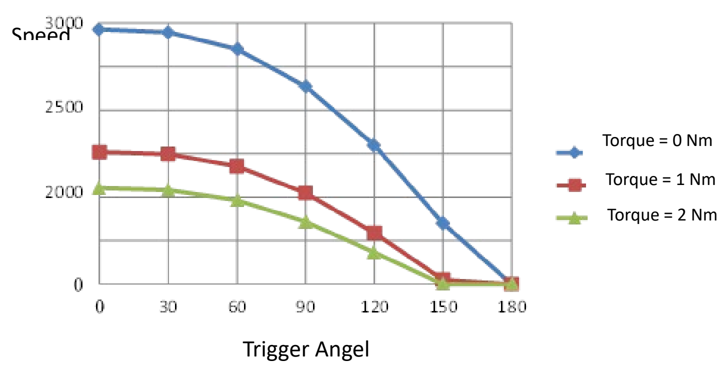

Figure 4. Graph of the function of the ignition angle against the rotation speed of the DC motor

b. Function Characteristics of Armature Voltage on Motor Rotation Speed

As the armature voltage (Va) applied to a DC motor increases, the rotational speed of the self-excited series DC motor also rises proportionally. This relationship is fundamental to the motor's operation and is crucial for controlling the speed in various

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applications. By adjusting the armature voltage, the motor's performance can be optimized for different tasks, which is especially valuable in both industrial and community-driven projects. The higher the voltage supplied to the armature, the greater the potential for increased speed, offering greater flexibility in motor-driven systems.

This characteristic is particularly beneficial in community empowerment initiatives where reliable and efficient motor control is essential. For example, in rural areas or communities where electrical infrastructure may be limited, understanding and utilizing the control of DC motor speed can enhance productivity in local enterprises, such as small workshops, agricultural processes, or water pumping stations. By managing motor speeds effectively through voltage regulation, these communities can optimize the use of their available power sources, ensuring better energy efficiency and sustainability in their operations.

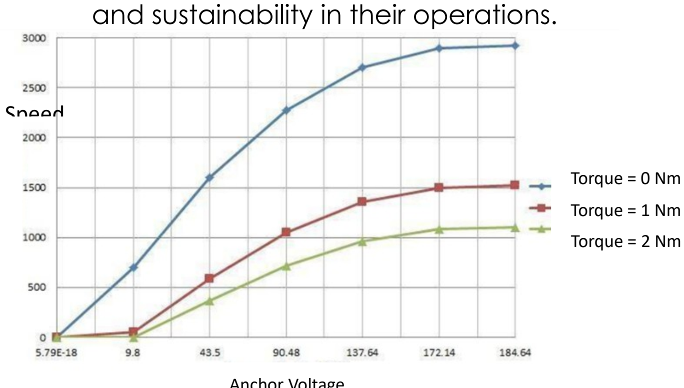

Figure 5. Graph of the function of the Anchor Voltge against the rotation speed of the DC motor

The graph illustrates the function of armature voltage (Va) against the rotational speed (N) of the DC motor. By carefully monitoring and adjusting the armature voltage, it is possible to fine-tune the performance of the motor in real-time, allowing for a more responsive and adaptable system. This capability supports community development by providing a reliable means to control various electric motor-based systems, which can contribute to improving local infrastructure, reducing energy waste, and enhancing the overall quality of life in underserved areas.

c. Function Characteristics of Armature Current on Motor Rotation Speed

As the armature current (Ia) in a DC motor increases, the rotational speed of the self-excited series DC motor also increases accordingly. This relationship between armature current and motor speed is a fundamental principle in the operation of DC motors and is critical in achieving precise control over motor performance. The higher the armature current, the more torque is generated, leading to an increase in the motor's speed. This principle can be effectively utilized in various practical applications, particularly in energy-intensive tasks where speed control is essential.

In the context of community empowerment, understanding the relationship between armature current and motor speed becomes a powerful tool for improving local industries and community-based projects. For example, in rural or underserved areas, small-scale industries such as water pumping stations, agricultural machinery, or local workshops can benefit from efficient motor speed control systems. By adjusting the armature current, these systems can be finetuned to optimize performance, enhance productivity, and reduce energy consumption, directly contributing to more sustainable and economically viable community operations.

The graph below illustrates the function of armature current (Ia) against the rotational speed (N) of the DC motor. By monitoring and controlling the armature current, it is possible to achieve a desired motor speed, providing more flexibility and efficiency in motor-driven applications. This control method not only supports community development by improving local infrastructure but also helps mitigate the challenges associated with limited power supply and energy efficiency, empowering communities to use their resources more effectively for better livelihoods.

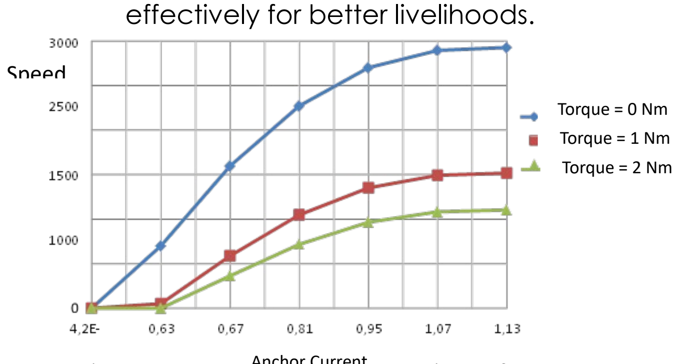

Figure 6. Grc ction of the Anchor Current against the rotation speed of the DC motor

2.Discussion

The measurement data observed in this study includes armature voltage (Va), armature current (Ia), and the rotational speed (N) of the self-excited series DC motor. The DC motor was subjected to different torque loads, specifically 0 Nm, 1 Nm, and 2 Nm. The results from the measurements reveal that the firing angle (α) has an inverse relationship with the motor speed. As the firing angle (α) applied to the thyristor increases, the rotational speed of the self-excited series DC motor decreases. This indicates that adjusting the firing angle directly influences the motor's speed, which is critical in applications requiring precise speed control.

Furthermore, the armature voltage has a direct proportional relationship with the motor's speed. As the armature voltage increases, the rotational speed of the motor also increases. Similarly, the armature current follows the same trend, where a higher current leads to an increase in motor speed. This relationship between armature voltage, current, and motor speed is essential for fine-tuning the performance of the DC motor, particularly in applications where stable and adjustable motor speed is required. These findings demonstrate that controlling voltage and current can be an effective way to manage the speed and efficiency of a motor in practical settings.

From the measurements, we also found that the rotational speed of the self-excited series DC motor was affected by both the firing angle (α) and the applied torque. It was observed that as the torque load increased, the rotational speed of the motor decreased. This relationship highlights the importance of managing torque and speed together, especially in community-based applications where resources are often limited. For instance, in small-scale industries or rural electrification projects, understanding these relationships helps optimize motor performance, contributing to more sustainable energy usage and enhanced productivity.

In conclusion, the findings support the idea that motor speed can be controlled effectively through voltage, current, and firing angle adjustments. These insights can be applied to a wide range of community empowerment initiatives, especially where motor-driven equipment is used for local development and resource management.

IV.CONCLUSION

- PSIM simulation software plays a crucial role in system design, helping to prevent potential losses during development, particularly in controlling motor speed in systems like DC motors.

- This research uses a fully controlled rectifier system to regulate the speed of a DC motor by adjusting the firing angle of a thyristor, offering a precise way to control motor speed, especially for motors requiring speeds below their nominal rating.

- The study demonstrates that adjusting the firing angle can effectively fine-tune the speed of a DC motor. For example, applying a 1 Nm torque with a 0° firing angle resulted in a motor speed close to the nominal speed of 1500 RPM, with higher firing angles reducing the speed.
- The research emphasizes the importance of speed control in DC motors for applications in rural electrification and small-scale industries. Using controlled rectifiers for motor speed regulation offers a cost-effective, scalable solution for improving energy efficiency, productivity, and local economic growth.

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