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IMPLEMENTATION OF VVVF DRIVE FOR THREE PHASE INDUCTION MOTOR USING HYBRID RENEWABLE SOURCES

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Abstract
This paper presents a stepby stepmatlab/simulink implementation of VVVF Drive to improve the performance of the Three Phase Induction Machine using hybrid renewable sources. Within this VVVF drive scheme SPWM technique is used to generate the varying voltage waveform. Both the frequency and voltage of an induction motor is controlled, and this is achieved by the modulation of width of the pulse in the generated waveform. The adjustment of both voltage and frequency permits a responsive working of the induction motor. The VVVF technology is used widely because of its capability to give a better torque and speed control of the motor. The voltage and frequency of the induction motor are adjusted in such a way there is maximum optimization of energy consumption. This will increase the efficiency and hence making it economical. The complex challenges like improving efficiency are addressed and is achieved by this VVVF drive scheme. And the analysis is presented in this paper. The practical testing of this VVVF drive scheme, applied for simplified slip estimation, is conducted, and the presentation of experimental results is outlined below.
Keywords: VVVF Drives, Induction machine (IM), SPWM, Speed control, Frequency.

Introduction
Electric machines and transformers, which are the backbone of the power assiduity, are electromagnetic systems[1]. Induction machines, also referred to as asynchronous motors, operate based on Michael Faraday's discovery of electromagnetic induction. They boast essential characteristics such as soft starting, reliability, and high efficiency. Hence IMs are used extensively in electric drives for numerous operations. Combining induction motor with an electric drive will help us to have a better control of the speed of an induction motors. In many operations, an external speed loop is closed to regulate speed. However, induction motors (IMs) used in fluid cargo applications have a disadvantage compared to others because they typically have a larger air gap, which makes it challenging to maintain a consistent vacuum state. Different types of speed control styles are present for an induction motor, while variable voltage variable frequence VVVF is one of utmost generally used speed control system. With this system proper position control and high speed control delicacy can be attained [2]. The speed of an induction motor can be adjusted by manipulating the frequency of the power supply, as there is a direct correlation between frequency and speed. But as the frequence increases flux will be reduced as it's equally commensurable to frequence due to this the necklace of the induction motor is reduced. Hence, to balance the speed on an induction machine a VVVF drive is used. As the name suggests the VVVF drives work on a principle of varying voltage and frequence in such a way the speed of the machine is controlled. VVVF drives are used in numerous operations similar as elevators, induction machines etc. exemplifications of these operations include heating, air exertion, suckers and boasters [2]. This project aims to explore the utilization of hybrid renewable energy sources to power VVVF drive systems for three-phase induction motors. By combining multiple renewable sources such as solar, wind, and possibly energy storage systems, we seek to create a reliable and environmentally friendly power supply for industrial motor applications [3].

Literature

- A literature survey on VVVF drive for three phase induction motor would involve gathering and reviewing existing research studies, and publications related to the speed control of motors using matlabSimulink.. Here's a structured approach to conducting a literature survey on this topic:
- Implementing a VVVF (Variable Voltage Variable Frequency) drive for three-phase induction motors using hybrid renewable sources involves a combination of electrical engineering principles, control systems, and renewable energy integration.
- Leverage academic databases containing resources such as peer-reviewed journal articles, research papers, and textbooks in disciplines including electrical engineering, power electronics, renewable energy systems, and control theory.. Look for keywords such as "VVVF drive," "induction motor control," "hybrid renewable energy," and "power system integration." Websites like IEEE Xplore, ScienceDirect, and Google Scholar are good places to search.

Methodology

Methodology for Implementation of VVVF Drive for Three Phase Induction Motor Using Hybrid Renewable Sources:

3.1 System requirements analysis:

Defines the operational requirements and performance criteria of the VVVF drive system. Determine the power rating, speed control range, and efficiency targets for the induction motor. Identify the available renewable energy sources and their characteristics (solar, wind, etc.).

3.2 Hybrid renewable energy system design:

Conduct a feasibility study to assess the suitability of combining different renewable energy sources. Design the hybrid renewable energy system considering factors such as location, available resources, and energy demand profile.Select appropriate components such as solar panels, wind turbines, batteries, and power converters based on the system requirements.

3.3 Power electronics design:

Design the VVVF drive system for the three-phase induction motor. Select suitable power electronic converters (such as inverters) capable of handling variable voltage and frequency operation. Design the control algorithms for the converters to achieve precise speed control and maximize energy efficiency.

3.4 Integration and control strategy:

Develop an integrated control strategy to manage power flow between the renewable energy sources, energy storage system, and the VVVF drive. Implement control algorithms for optimal energy management, including maximum power point tracking (MPPT) for renewable sources and battery charging/discharging control. Ensure seamless transition between grid-supplied power and renewable energy sources to maintain system stability.

3.5 Simulation and validation:

Utilize simulation tools such as MATLAB/Simulink to model the hybrid renewable energy system and VVVF drive.Perform extensive simulations to verify the performance, stability, and efficiency of the integrated system under various operating conditions. Validate the simulation results through experimental testing using a scaled-down prototype or hardware-in-the-loop (HIL) simulation.

3.6 Deployment and optimization:

Install the VVVF drive system and hybrid renewable energy setup in the target application environment. Fine-tune the control parameters and operating strategies based on real-world performance data.Continuously monitor and optimize the system to maximize energy harvesting from renewable sources, minimize grid dependence, and ensure reliable operation of the induction motor.

Related work

4.1 Various methods for Speed Control of an Induction Motor:

- Varying the frequency of the power supply
- Adjusting the number of poles in the motor
- Using variable frequency drives(VFDs)
- Employing soft starters
- Implementing rotor resistance control
- Utilizing stator voltage control
- Applying field-oriented control(FOC)
- Utilizing sensor less vector control techniques
- Employing direct torque control(DTC)
- Using pulse-width modulation(PWM) techniques

4.2 V/F method for speed control

The V/F (Voltage to Frequency) method is a common Approaches employed for regulating the speed of induction motors can vary depending on the specific application and requirements. In this method, the frequency of the applied voltage to the motor is varied while maintaining a constant ratio between voltage and frequency (V/F ratio). The basic principle is to keep the magnetic flux in the motor constant, allowing for stable operation across different speeds.

The relationship between voltage (V), frequency (F), and motor speed (N) is given by the equation:

$$V/F = \frac{V\ \text{rated}}{F\ \text{rated}} = \frac{\text{constant}}{\text{rated speed}}$$

The constant is typically selected to correspond with the rated speed of the motor, where V rated represents the rated voltage and F_{rated} represents the F_{rated}. To control the motor speed, the frequency of the input voltage is adjusted according to the desired speed using the equation:

$$F_{\text{output}} = \frac{N\ \text{desired}}{N\ \text{rated}} = \frac{\text{constant}}{\text{rated speed}}$$

Where, F_{output} is the output frequency applied to the motor, N_{desired} is the desired speed, and N_{rated} is the rated speed of the motor.

By adjusting the frequency of the input voltage while maintaining the V/F ratio, the motor speed can be controlled efficiently using the V/F method.

Three-phase induction motors

Induction motors find widespread use across diverse industrial and commercial applications owing to their simplicity, reliability, and cost-effectiveness. These motors function based on the principle of electromagnetic induction, generating a rotating magnetic field within the motor. This magnetic field induces currents in the rotor windings, thereby initiating rotation.A key advantage of induction motors is their sturdy construction, consisting of a stationary stator and a rotating rotor. The stator generally comprises a series of unevenly spaced windings connected to an interspersing current(AC) power source, while the rotor consists of conductive bars or coils placed within the stator's glamorous field.When an AC voltage is applied to the stator windings, it generates a rotating magnetic field that interacts with the rotor, inducing currents in the rotor conductors. These induced currents, in turn, generate their own magnetic field, which interacts with the stator's magnetic field, resulting in a torque that drives the rotor to rotate. This process continues as long as the stator is supplied with AC power, allowing the motor to operate continuously. Induction motors are classified into two main types squirrel pen and crack rotor. Squirrel pen motors are characterized by their simple and rugged construction, with rotor bars suggesting a squirrel pen. These motors are generally used in operations taking high starting necklace and minimum conservation. On the other hand, crack rotor motors feature a rotor with windings connected to slip rings, allowing external resistance to be added to the rotor circuit for enhanced control over speed and necklace. Overall, induction motors play a vital part in powering a wide range of ministry and outfit in diligence similar as manufacturing, transportation, and

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HVAC systems. Their effective operation, combined with their versatility and continuity, makes them necessary factors in ultramodern- day engineering and technology.

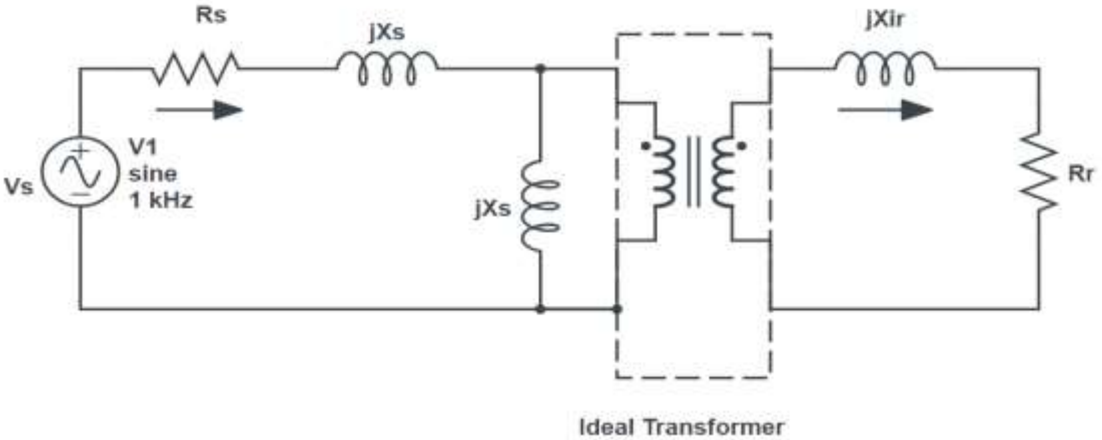

Figure 1:Equivalent circuit of three phase induction motors

In the derivation of the general expression for the torque of a three-phase induction motor using the equivalent circuit shown in Fig. 1, the influence of magnetizing impedance (Zm = Rc/Xm) will be disregarded.

The per-phase torque developed can be expressed as in (1)

$$T= \frac{\text{power developed}}{\text{rotor speed}} = \frac{i_2^2 R_L}{W_r} \quad (1)$$

The equivalent mechanical load resistance R_l :

$$R_L = R_s.(\frac{1-s}{s}) \quad (2)$$

Where S represents the slip of the induction motor, which is determined by the following formula:

$$S= W_s - W_r / W_r \quad (3)$$

$$W_s = \frac{2\pi N_s}{60} \textit{ in rad/sec}$$

$$W_r = \frac{2\pi N_r}{60} \text{ in rad/sec}$$

$W_r = W_s(1-S)$ (4)

Substituting (2) (4) into(1), we get

$$T=\frac{i_s^2 R_s \frac{1-s}{s}}{W_s(1-s)} \quad (5)$$

$$T=\frac{i_2^2 R_2}{W_s S} \quad \text{N.m/ phase} \quad (6)$$

From the equivalent circuit, the magnitude of current i_2 can be determined.

$$i_2 = |\frac{v}{z}| \frac{v}{(R_1+R_2/s)+(X_1+X_2)^2} \quad (7)$$

The torque developed can be expressed in terms of the motor's parameters based on the information provided above.

$$T = \frac{v^2}{\left[R_1 + \frac{R_2}{s}\right]+[^2X_1+X_2]^2} \quad \text{N.m/phase} \quad (8)$$

So, the torque for three phase induction motor can be calculated according to the general expression as follows:

$$T=\frac{\frac{3v^2R_2}{s}}{W_s\left[R_1 + \frac{R_2}{s}\right]+[^2X_1+X_2]^2} \quad \text{N.m} \quad (9)$$

The torque can expressedas below:

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$$T=\frac{KSR_2E_2^2}{R_2^2+s^2X^2} \quad (10)$$

Where ,k is a function of the physical parameters of motor.

PWM voltage source inverter

Pulse width modulation is one of the popular technique to produce a sine wave. This technique involves generating a digital waveform and modulating the pulse width in such a way that the average output waveform closely resembles a pure sine wave.PWM inverter work with a DC link and this is essential to reduce fluctuations in voltage and maintain a better performance of the inverter's output.PWM combines both voltage and frequency control, this allows correct regulation of output voltage and frequency.

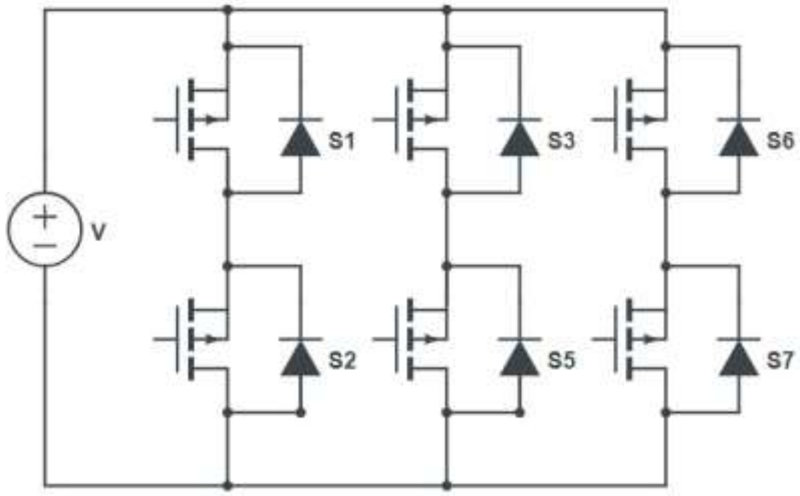

Figure2:Voltage source inverter

Generally, the source of a PWM inverter is a fixed DC voltage supplied either by an uncontrolled diode rectifier or a battery system or a combination of both. Broadly speaking modulation techniques can be classified into two classes: operating at a fixed switching ratio (block or picket fence modulation) and operating at a sinusoidally varying switching ratio (SPWM).

Sinusoidal PWM

Fashion used in power electronics to induce sinusoidal waveforms for controlling AC motors or other bias. It involves modulating the range of beats in a PWM signal according to a sinusoidal reference waveform, performing in an affair waveform that nearly resembles a sine surge. This helps reduce harmonious deformation and ameliorate effectiveness in motor control operations. The main aim of an SPWM scheme is to convert the waveform that is close to a sine wave. Here modulation index and normalized carrier frequency plays a major role.

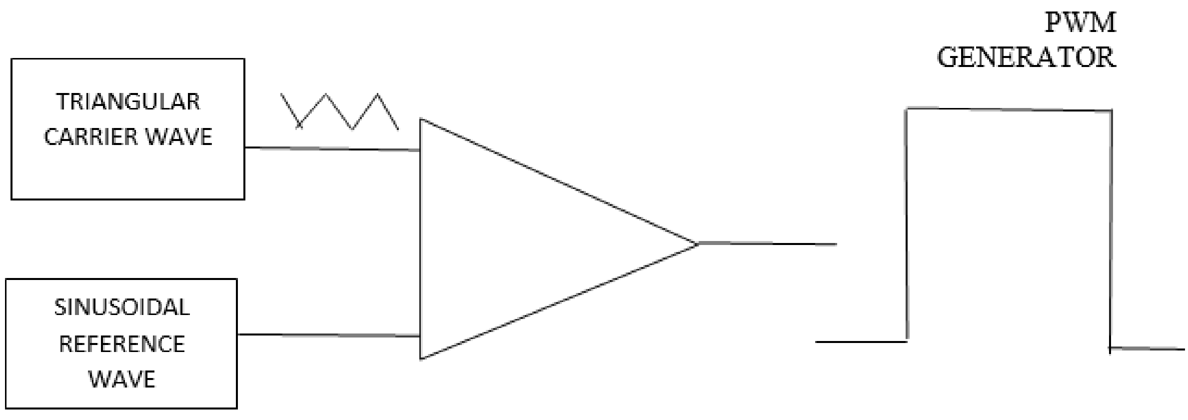

Figure 3:Sinusoidal pulse width modulation

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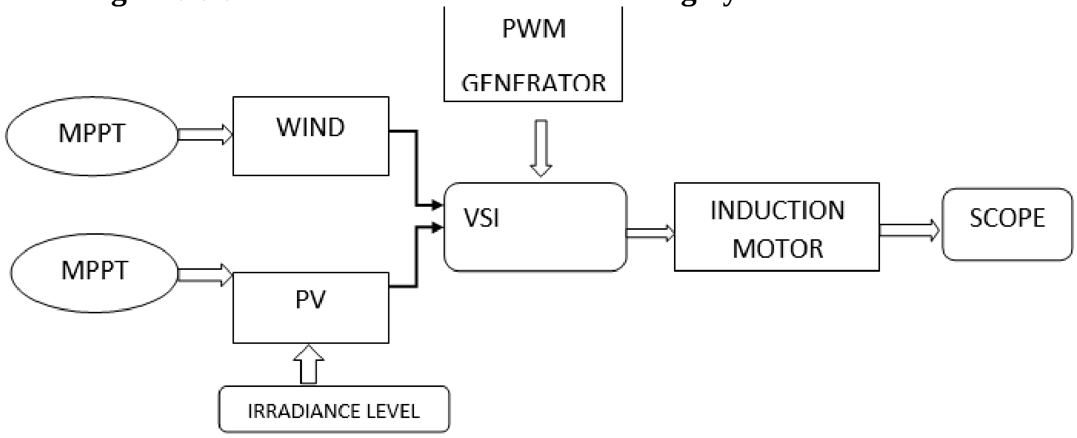

Figure 4:Flow chart of simulink model

Simulation model

Here the simulation model of implementation of VVVF drives for three phase induction motor using hybrid renewable source of energy is shown in fig 5.

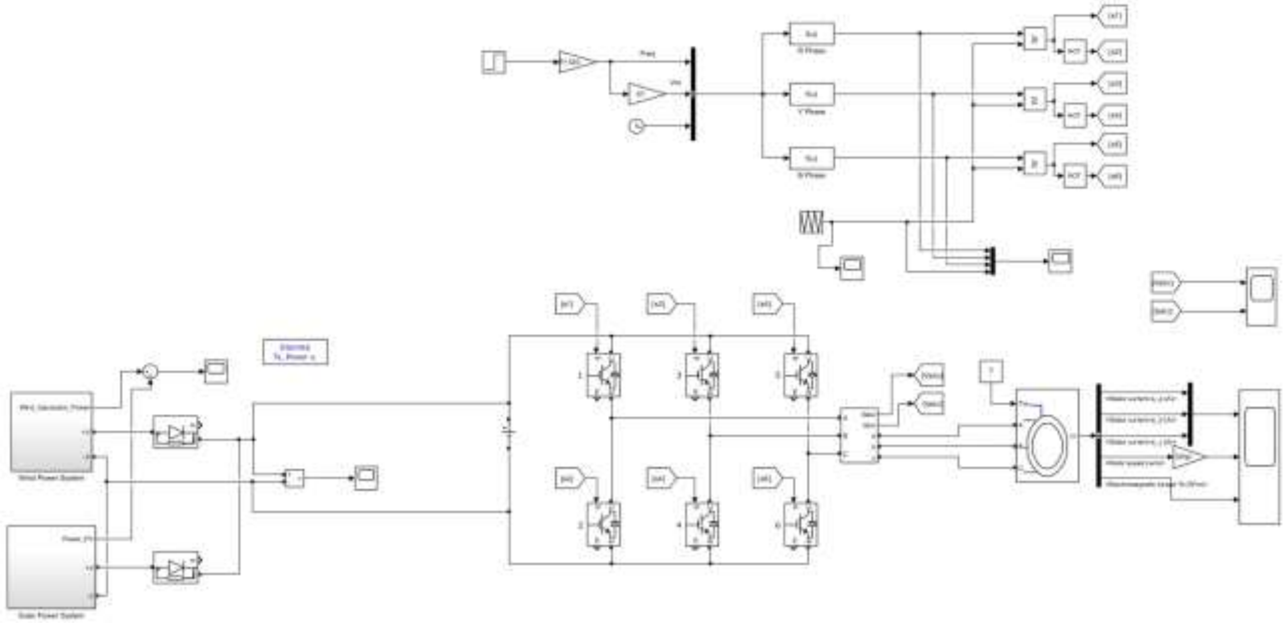

Figure 5: simulation model of implementation of VVVF drives for three phase induction motor using hybrid renewable source

Developing a simulation model for the implementation of Variable Voltage Variable Frequency (VVVF) drives for a three-phase induction machine powered by a hybrid renewable energy source presents a multifaceted engineering challenge with vast potential for sustainable energy utilization. VVVF drives employ sophisticated algorithms to adjust both voltage and frequency supplied to the motor, optimizing performance across a wide range of operating conditions. By dynamically altering these parameters, VVVF drives enable smooth acceleration and deceleration, eliminating the jolts associated with traditional fixed-speed motors. This enhanced control not only improves efficiency but also extends the lifespan of equipment by minimizing mechanical stress. Additionally, VVVF drives facilitate energy savings through better matching of motor speed to load requirements, reducing overall power consumption and operational costs. Moreover, these drives enhance safety by allowing for quick and precise emergency stops and facilitating integration with advanced control systems for predictive maintenance and remote monitoring. Overall, the implementation of VVVF drives represents a

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significant advancement in motor control technology, offering unparalleled flexibility, efficiency, and reliability for industrial applications.

Simulation results

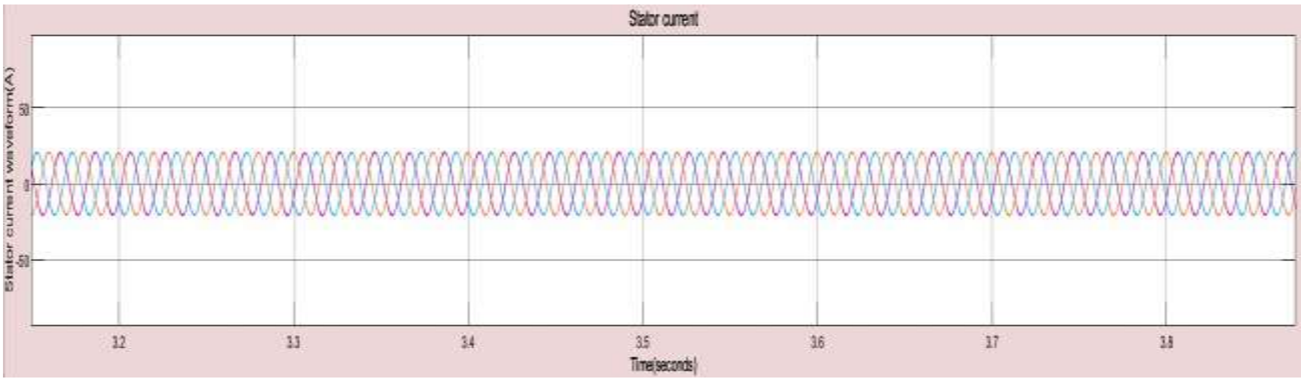

Figure 6: Three-phase stator current

Control of the stator current enables the VVVF drive to deliver the required torque and speed with high accuracy. By adjusting the voltage and frequency supplied to the induction machine, VVVF drives regulate the stator current to maintain optimal performance under varying load conditions.

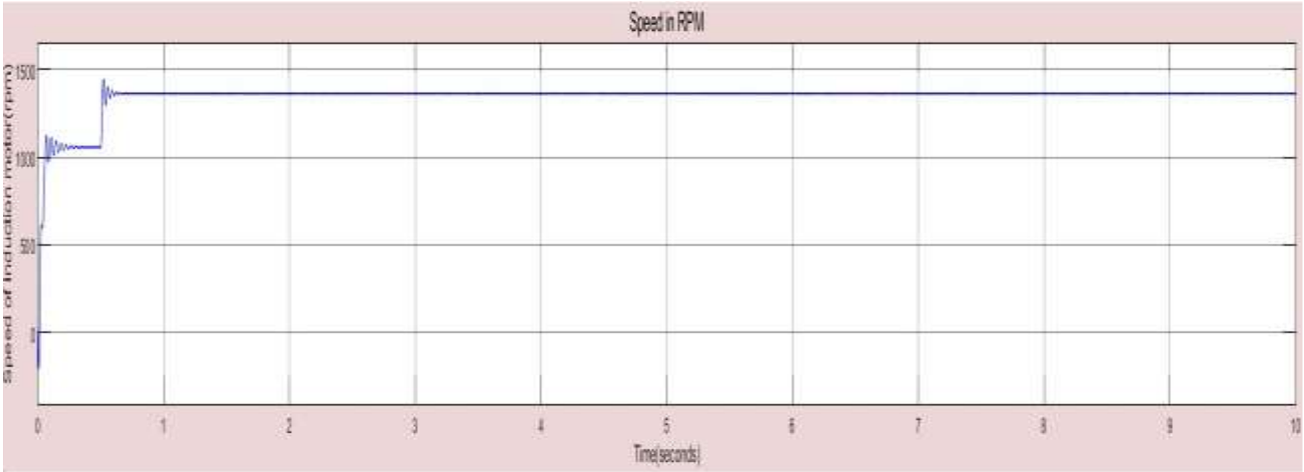

Figure 7: Induction motor speed in RPM

Speed of the induction motor by adjusting both the voltage and frequency of the supplied electrical power. Speed control enables energy savings by adjusting the motor speed to match the required load.

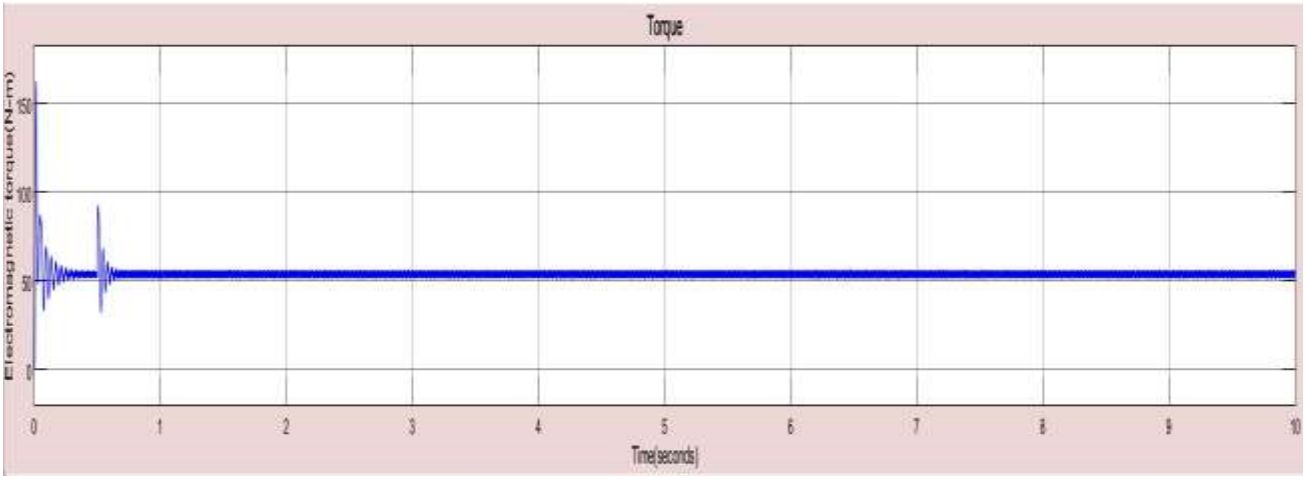

Figure 8:Torque of three-phase induction motor

The torque produced by the motor is typically proportional to the square of the applied voltage divided by the frequency (V/f). This means that as the speed decreases, the torque increases, following a roughly linear relationship.

Applications
- Industrial Fans and Blowers
- Pumps
- Conveyor Systems
- Compressors
- Machine Tools
- Machine Handling Equipment
- Centrifuges
- HVAC Systems
- Energy Saving Retrofit Projects

Advantages
- VVVF drive is energy efficient where control of voltage and frequency optimizes motor speed to match load requirements, reducing energy consumption.
- It has improved performance.
- It is flexible and adaptable
- It reduces the noise by controlling the motor speed and reduces mechanical stress, resulting in quieter operation and reduced noise and vibration levels.
- It reduces starting current limits starting current drawn by the motor, minimizing voltage sags and stress on the electrical distribution system.
- It has precise control and enables optimization of system performance, fault diagnosis, and implementation of predictive maintenance strategies.

Comparison with existing system

Aspect	Existing Speed Control Methods	V/F Control Method
Control Principle	Methods such as pole changing, variable resistance, and cascade control are used.	Control is based on adjusting the voltage and frequency supplied to the motor in proportion to each other to maintain a constant V/F ratio.
Efficiency	Efficiency may vary depending on the method used, with some methods leading to energy losses and reduced efficiency.	V/F control can be highly efficient, especially when properly tuned to match the motor's characteristics.
Speed Range	Limited speed range may be achievable depending on the method used.	Limited speed range may be achievable depending on the method used.
Complexity	Some existing methods may be complex to implement and require additional components or systems.	V/F control is relatively straightforward to implement and can be integrated into modern motor drive systems with ease.
Maintenance	Maintenance requirements may vary depending on the complexity of the control method used.	V/F control typically requires minimal maintenance once properly configured.

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Cost	Costs associated with existing methods may include additional components or systems.	V/F control systems can be cost-effective, especially when considering the benefits of improved efficiency and performance.
Compatibility	Compatibility with different motor types and applications may vary depending on the method used.	V/F control is compatible with most standard three-phase induction motors and can be applied to a wide range of applications.

Speed torque characteristics of induction motor

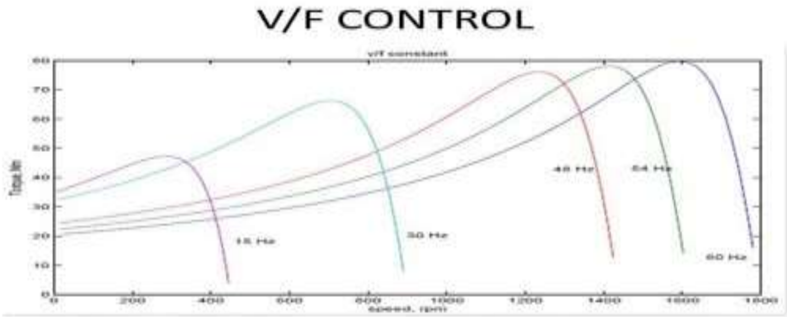

Fig 9: Characteristics of induction motor

Conclusion

In this study, the simulation model for implementing Variable Voltage Variable Frequency (VVVF) drives for three-phase induction motors utilizing hybrid renewable sources shows promising outcomes in improving energy efficiency and diminishing reliance on non-renewable energy sources.. By integrating VVVF drives with Renewable energy sources like solar and wind power, The system becomes more sustainable and environmentally friendly. The simulation demonstrates the feasibility and effectiveness of such a setup in optimizing energy utilization and minimizing carbon footprint. Additionally, the flexibility of VVVF drives allows for better control and adjustment of motor speed, leading to improved performance and reliability. Overall, this simulation model presents a viable solution for achieving greater energy efficiency and sustainability in industrial applications.

References

[1] Introduction to Electric Machines and Drives by Paul C. Krause , Thomas C. Krause ,2002.
[2] Gordon R.Slemon ,Electric Machines and Drives, Addison-Wesley,1992.
[3] "Power Electronics: Converters, Applications, and Design" authored by Ned Mohan, Tore M. Undeland, and William P. Robbins. It was published in the year 2003.
[4] Variable Frequency Drives: principles and applications for energy savings" by William E.Drury Jr.(2003)
[5] "Power electronics and Variable Frequency Drives: Technology and applications" by Bimal K .Bose(2006)
[6] "Variable Frequency Drives: Installation & troubleshooting" by Glen A. Mazur (2004)
[7] "Induction Motor Drives: Principles, Control, and Implementation" by Bin Wu and Mehdi Narimani(2015)
[8] M. Beck and D. Naunin , "Slip frequency and sensorless control of induction motors," Proc. Of 4th Ann. Mtg. PPL Conf., pp. 179-181, 1985.
[9] C.Schauder, "Adaptive speed identification for vector control of induction motor without rotational transcuders ," IEEE Trans. Ind. Applicat., vol.28, pp.1054-1061. Sep/Oct. 1992.