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Comparison of Simulation Results for Two Types of Induction Motors Using Conventional and Variable Speed Drives

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Abstract

This paper comprehensively compares simulation results for two distinct types of induction motors: wound rotor motors and squirrel cage motors. Both motor types are assessed under identical operating conditions, rated explicitly at 2750 kW, 6.6 kV, and 50 Hz. The study aims to evaluate and analyse two different control methodologies. The first control method employs a conventional approach involving fixed-speed operation and standard control techniques. The second method used an advanced variable-frequency drive system. It removed all the direct online equipment, allowing dynamic motor speed adjustment and improved performance for the second proposed control method. The torque improvement by the second method is more than 20%, and the starting current is very low (there is no inrush current), which saves money. Through detailed simulations, this research highlights the differences in efficiency, torque characteristics, and overall operational effectiveness between these two motor types and their respective control strategies.

Keywords: Comparison of Induction Motors, Variable Speed Drives, Slip Ring, Squirrel Cage, Numerical Simulation.

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1. Introduction

A wound-rotor motor, also known as a slip-ring motor, is an induction motor in which the rotor windings are connected via slip rings to external resistances. Adjusting these resistances can control the motor's speed and torque characteristics. Sliding rotor motors can be started with low starting currents by introducing high resistance into the rotor circuit. This resistance can be gradually reduced as the engine accelerates. Asynchronous machines work in asynchronous mode, providing electrical power to the moving part of the machine through an electrical induction circuit, similar to the operation of a transformer. These electrical machines are classified into two major classifications: squirrel cage induction machines (SCIM) and wound rotor induction machines (WRIM). A squirrel cage induction motor (SCIM) consists of a fixed coil of heavy bars (usually aluminium or copper) coupled with rings at the ends of the rotor. This shape resembles a rotating cage, which is true to the name.

On the other hand, a wound induction machine (WRIM) has a rotor winding made of several insulated wires coupled to slip rings on the motor shaft. This shape allows for better motor power control by coupling external resistors and other control devices to the rotor circuit. Although resistors can control motor speed, external resistors burn up and waste much energy [1].

This technology originated from Faraday's electrical experiments in 1821 [2]. One of the earliest electric machines was a simple electric device invented by Scottish engineer Andrew Gordon in the 1740s [3]. The fundamental truth that explains the mechanical force produced by the exchange of an electric current and a magnetic field is called Ampere's law. It was discovered in 1820 by André-Marie Ampère 1820. British scientist Michael Faraday demonstrated the conversion of electrical energy into mechanical energy through electromagnetic means in 1821. In his experiment, a free-hanging wire was immersed in mercury with a permanent magnet placed on top. When an electric current passes through the wire, the current produces a circular magnetic field around the wire [4]. Jedlik's "electromagnetic self-rotor," 1827 (Museum of Applied Arts, Budapest). The historic motor still works perfectly today [5].

In 1827, Hungarian physicist Ányos Jedlik began experimenting with electromagnetic coils. After overcoming the technical challenges of achieving continuous rotation by inventing the commutator, he referred to his early devices as "electromagnetic self-rotors." Although these devices were primarily used for instructional purposes, in 1828, Jedlik demonstrated the first device comprising the three main components of practical DC motors: the stator, rotor, and commutator. Notably, his device did not utilise any permanent magnets; instead, the magnetic fields for the stationary and rotating components were generated solely by the currents flowing through their windings [6-12]. A variable-frequency drive (VFD), also known as an adjustable-frequency drive, variable-speed drive, AC drive, micro drive, or inverter drive, is an adjustable-speed system used in electro-mechanical drive applications. VFDs control AC motor speed and torque by varying input frequency and voltage. VFDs control AC motor speed and torque by changing the motor's input frequency and voltage [13-16]. A VFD system consists of three main subsystems: the AC motor, the main drive controller assembly, and the drive operator interface [16-17]. The foundation of this technology can be traced back to Faraday's electromagnetic experiments in 1821. One of the earliest electric motors was a simple electrostatic device created by the Scottish monk Andrew Gordon in the 1740s. The theoretical principles explaining mechanical force generation through the interaction of electric current and a magnetic field, known as Ampère's force law, were discovered by André-Marie Ampère in 1820.

British scientist Michael Faraday demonstrated the conversion of electrical energy into mechanical energy through electromagnetic means in 1821. In his experiment, a free-hanging wire was immersed in mercury with a permanent magnet placed on top. When an electric current passed through the wire, it rotated around the magnet, illustrating that the current produced a circular magnetic field around the wire. In 1827, Hungarian physicist Ányos Jedlik began experimenting with electromagnetic coils. After overcoming the technical challenges of achieving continuous rotation by inventing the commutator, he referred to his early devices as "electromagnetic self-rotors." Although these devices were primarily used for instructional purposes, in 1828, Jedlik demonstrated the first device comprising the three main components of practical DC motors: the stator, rotor, and commutator. Notably, his device did not utilise any permanent magnets; instead, the magnetic fields for the stationary and rotating components were generated solely by the currents flowing through their windings. A variable-frequency drive (VFD), also known as an adjustable-frequency drive, variable-speed drive, AC drive, micro drive, or inverter drive, is an adjustable-speed system used in electro-mechanical drive applications.

VFDs control AC motor speed and torque by varying input frequency and voltage. A VFD system consists of three main subsystems: the AC motor, the main drive controller assembly, and the drive operator interface. The VFD controller is a solid-state power electronics system with three distinct subsystems: a rectifier bridge converter, a direct current (DC) link, and an inverter. Voltage-source inverter (VSI) drives are the most common among various drives. Most drives are considered AC-AC since they convert AC line input into AC inverter output. However, in specific applications, such as standard DC buses or solar energy systems, drives may also be configured as DC-AC drives. The simplest rectifier converter for a Voltage Source Inverter (VSI) drive is a three-phase, six-pulse, full-wave diode bridge. The drive controller can be configured as a phase converter, featuring a single-phase converter input and a three-phase inverter output [18]. Over the past sixty years, advancements in controller technology have taken advantage of significant increases in the voltage and current ratings, as well as the switching frequency of solid-state power devices.

2. Technical Features of Slip Ring Motor and Squirrel Cage Motor

The rotor prototype is the major constructional distinction between wound-rotor machines and squirrel-cage machines, vital for the motor's functioning and operation. Wound rotor machines are conceived in detail as a "phase rotor." This kind of rotor is well known for the fact that it contains slip rings. Brushes that are purposely coordinated into the rotor body. These elements carry out vital tasks: The potential to yield exterior command of the reluctance to accept and to permit variable speed functioning. As a result, wound rotor machines can perform a higher degree of pliability and accuracy in functioning. This makes it the best for approaches that demand the best control, such as large machines or conveyors.

However, these additional qualities have the disadvantage of increasing difficulties. Including slip rings and brushes can generate maintenance issues as these components are liable to wear and shatter; regular monitoring is highly needed. The main structural variation between the slip machine and the squirrel cage machine is included in the rotor design. This is extremely important for engine work and production. The inclusion of slip rings classifies this type of rotor. Brushes are deliberately combined into the rotor assembly. These components perform the critical function of controlling external resistance and allowing variable speed operation.

In contrast, squirrel-cage motors use a squirrel-cage rotor, a more straightforward, more adaptable, and sustainable design. As the name suggests, the rotor has a cage with short-circuit conductors. Arranging the inside and the absence of rings and brushes clarifies the rotor design and makes the machine high-powered and trustworthy, which is acceptable for many applications. Application areas include fans, pumps, and household appliances. Squirrel cage motors have a simple design, which means they need less maintenance and are less likely to fail. However, these compliant designs reduce speed control and friction, making them unsuitable for applications where good repairability is essential.

In summary, wound rotor motors offer superior control and flexibility due to their advanced rotor design. In contrast, squirrel-cage motors are known for their durability and low maintenance, making them a popular choice for many industrial and domestic applications. As shown in Figure 1, the starting torque of a wound rotor motor (Slip Ring Motor) is 2.5 times the rated torque, compared to 1.6 times that of a squirrel-cage motor (SCM). As speed increases to the rated speed, torque decreases gradually with conventional control methods. Figure 1 shows motor torque versus rotational speed for slip ring and squirrel cage induction motors.

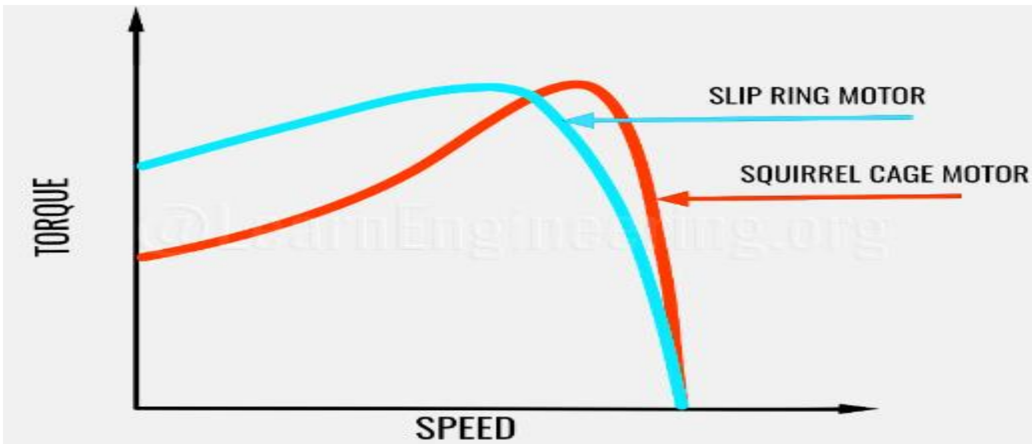

Figure 1. Torque versus Speed for Slip Ring and Squirrel Cage Induction Motors [19].

Direct-on-line (DOL) starters, slip ring motors, and squirrel cage motors are standard methods of connecting electric motors directly to the electrical supply source. This simple method is popular because it is straightforward to install. However, it is essential to understand a DOL starter's impact on engine performance and life. Starting a motor using a DOL starter results in high starting currents, which can be several times higher than the motor's full-load current. The interruption in the current can cause severe mechanical problems and thermal stress in the motor, leading to premature failure. DOL starters are suitable for small pumps, fans, and other applications that can be controlled by the motor and are in increasing demand. In practice, it is essential to consider other starting methods to increase longevity and performance. Star-delta starting is the more common method, especially for larger motors. In this method, the motors are connected in a star at startup, which reduces the voltage across each motor winding, thus starting the current.

When the motor reaches a certain speed, it becomes a delta. Configuration that provides full voltage and normal running power. These two stages of the process are critical. It minimises the inrush current during starting and saves motor power and the electrical system. Therefore, the star-delta configuration is suitable for large-scale applications. Motors for industrial or industrial applications with low starting voltage are as crucial as heavy equipment. However, complex switching processes (usually involving contactors), Timers, and hardware (including external devices) can cause performance problems and limit their use in simple systems. Variable speed drives (VSDS) represent a new development in motor control. They are VSDS, which allows the operator to adjust the motor performance according to the actual load needs. This feature optimises energy efficiency during operation, achieving Significant energy savings and reduced operating costs. For example, load conditions vary significantly in applications such as conveyor belt systems or HVAC units, and VSDS provides flexibility. Efficient operations and reduced waste are required. However, it is also important to note that VSDS can exhibit various power variations due to nonlinearity.

The operation of the drive will harm the overall energy efficiency and can lead to equipment failure or reduce the efficiency of sensitive systems. Therefore, harmonic reduction techniques such as proper water filtration or electrical design are required in applications where power quality is essential. By addressing the harmonic distortion issue, companies can maximise the benefits of VSD technology while ensuring a stable and efficient power supply. The insulated-gate bipolar transistor (IGBT), introduced in 1983, has dominated variable frequency drives (VFDs) as the primary inverter switching device over the last two decades [19-20]. Figure 2 illustrates this clearly. As the engine accelerates, the starting current decreases very slowly. It only decreases significantly after the engine reaches 80% of its maximum speed. Asynchronous motors operate efficiently by generating torque due to the interaction of magnetic fields in the stator and rotor. These magnetic fields are generated by currents that contain resistive (in-phase) and reactive (anti-phase) components. Starting efficiency is defined as:

$$\text{Starting Efficiency\%} = \frac{\text{Locked Rotor Torque}}{\text{Locked Rotor Current}} = \frac{\text{Full Load Torque\%}}{\text{Full Load Curren\%t}} \quad (1)$$

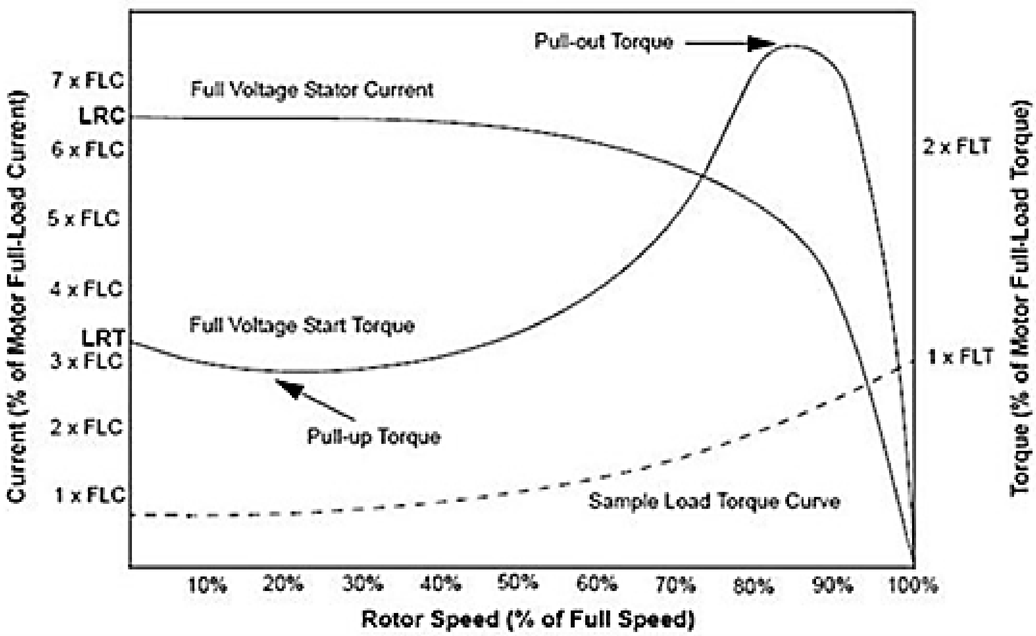

Figure 2. Current /Torque versus Rotor Speed to Full Speed Ratio.

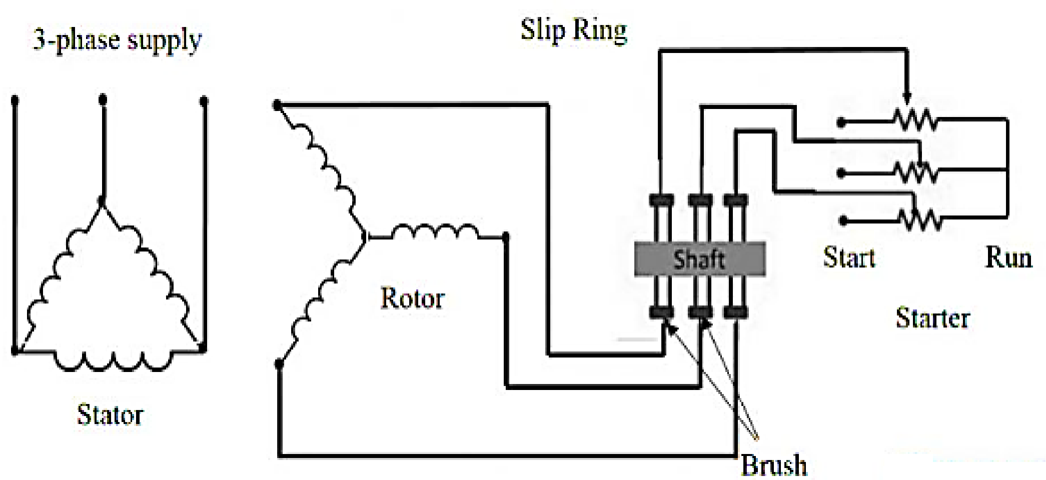

Figure 3. Circuit Diagram of Slip Ring Motor.

3. Simulation Results for the Two Methods

Variable speed is required; frequency control is effective. It is necessary not only to increase profitability but also to achieve optimum performance. To achieve this, it is essential to maintain the following: Voltage and frequency are proportional. This relationship is necessary to ensure that the stator flux remains constant, especially when the stator resistance is assumed constant. It is not essential, so the analysis is simplified. A detailed study of the open-loop voltage/hertz control method. Here is a comprehensive block diagram highlighting the power chain's robust architecture. The circuit starts with a diode rectifier connected to a three-phase AC supply, followed by a filter. It is designed to smooth out the output signal, and finally, there is a voltage inverter with pulse width modulation (PWM) capability. This control scheme works effectively without the need for a feedback signal. This independence from the feedback mechanism increases the engine control system's reliability and simplifies the overall design. In this system, the frequency acts as the primary control variable. It is directly related to the motor rotor speed. In ideal conditions, the sliding speed is the difference between the synchronous speed and the speed. The torque provided by the VSD significantly exceeds the maximum starting torque requirements typically expected from induction motors. This capability allows the system to handle demanding applications while maintaining optimum performance and reliability in various operating scenarios.

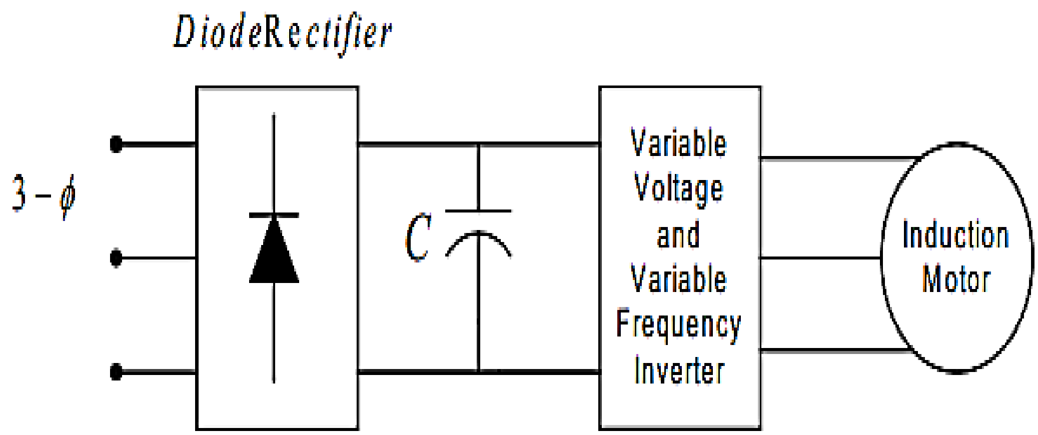

Figure 4. Open-loop control method of the block diagram for Volts/Hz.

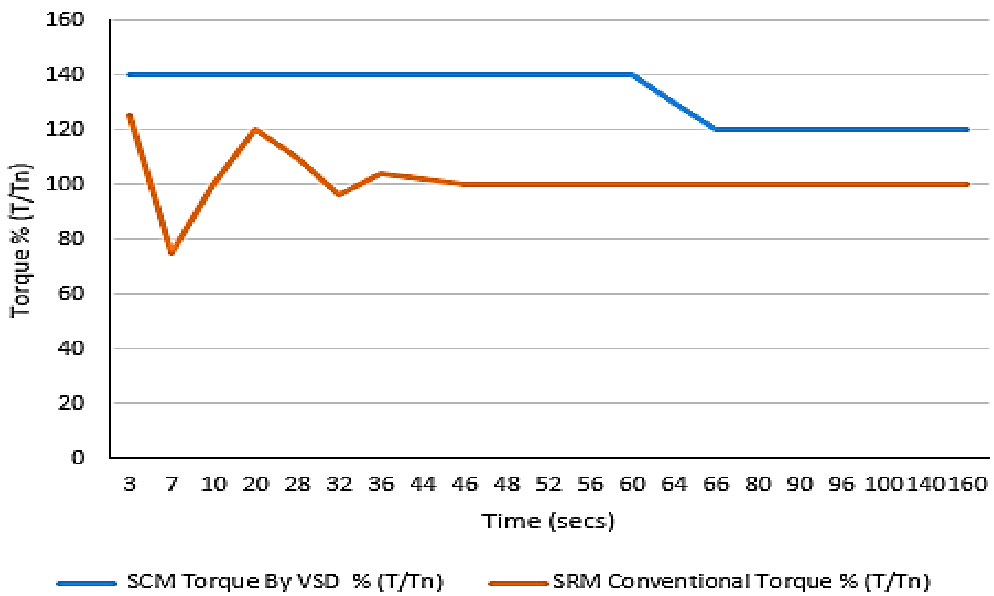

Figure 5. Two Proposed Controllers Trends for Torque versus Time Response.

Torque is the fundamental concept of rotation in the field of rotational dynamics. It is the same as linear force. Linear force can be thought of as a push or pull that moves an object. When driving in a straight line, torque represents the rotational effect produced by a specific applied force. It is located at a certain distance from the axis of rotation. This distance is often called the arm span. This is a significant value in determining the amount of torque produced. Here are some essential things to remember when talking about torque: Let's look at the concept of speed. The distance an object travels over time. This is very important. The relationship between torque and speed is inversely proportional. As torque increases, the rotational speed applied to the object generally decreases. Conversely, as torque decreases, the rotational speed tends to increase.

This relationship is essential for engineers and designers who must consider these changes when designing and evaluating various technologies to ensure performance and full functionality in multiple applications. Mathematically, torque can be thought of as the ratio of force (i.e., the amount of work done) to angular velocity (i.e., a measure of rotational speed, usually expressed in radians per second). Understanding this relationship is crucial because it shows the interaction between power output and RPM and how this affects the performance and efficiency of many machines. For example, a machine operating at high power may have difficulty reaching high RPMS if the load requires a lot of power. In the real world, especially in the power sector, variable frequency drives (VFDs) are essential in controlling motor power. This handy device is designed to provide voltage measurements to a motor when operating at frequencies above 50 Hz or close to the maximum operating voltage of the drive. The ability to provide a constant voltage is crucial because it ensures the motor has stable power under various conditions. These products are used in multiple applications, from industrial processes to heavy equipment transportation. However, it is also worth noting that the torque the motor provides increases as the operating time increases.

Decrease. Understanding this balance is critical to effective management. People give a lot of spee d, power, and strength. This is subject to specific needs and limitations. For engineers and technicians, the torque/speed curve is an essential tool for understanding these changes. This diagram shows the torque required by the load and the relationship between torque and the speed of the process. In a typical torque-speed curve, torque is plotted on the vertical axis and speed on the horizontal axis.

This arrangement makes it easy to visualise how torque should vary with the difference. Speed gives you an idea of how well the system is performing. The torque-speed curve shows the torque required. The shape and characteristics of the torque-speed curve will vary greatly depending on the type. Equipment and loads may have specific torque values and operating patterns. Experts can carefully analyse and interpret these curves. Optimise mechanical system performance to meet operational requirements. Respond to energy usage patterns. This optimisation can reduce operating costs. Let's look at power and speed characteristics to minimise environmental impact and better explain this concept. The two management methods are different.

The data shows that during the initial phase of rotor acceleration, motors using the control model experience a 14% reduction in torque compared to motors controlled by a variable speed drive (VSD). Because the rotor is faster and more efficient, the VSD controller provides 18% more output torque than a traditional drive. The superior power generation capability of VSD during acceleration differentiates it from efficiency. The advantages of the application require high-performance motors and efficiency. Such a thought is considered appropriate as the industry continues to search for solutions. Maximise productivity while minimising energy consumption.

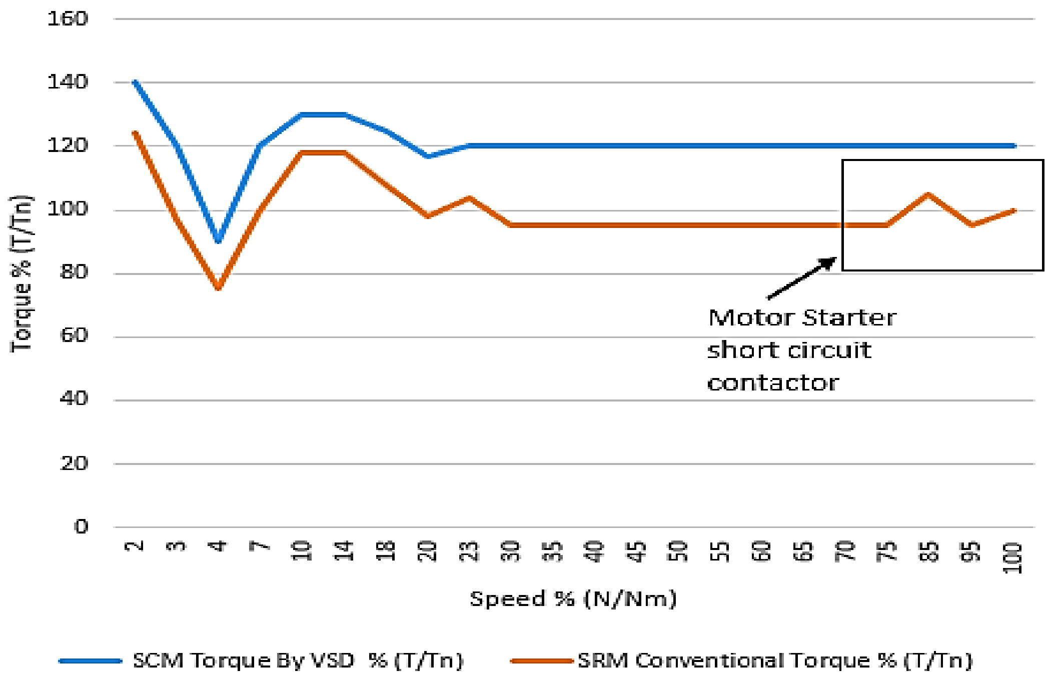

Figure 6. Two Proposed Controllers Trends for Motor Torque versus Rotated Speed.

Variable speed drive (VSD) is an advanced device that controls the speed and power of a generator. One of the characteristics of VSD is that it changes the input frequency and voltage. Non-linear currents in electrical devices cause harmonic distortion in electrical circuits. Harmonic distortion can affect the operation of other equipment, reducing the system's efficiency. This causes electronic components to overheat. However, we must understand the following facts: The benefits of using VSD far outweigh these difficulties. VSD has many advantages.

These include improved power, engine and torque management, and reduced emissions. It reduces the mechanical load on the engine and extends the life of the equipment. Good results are achieved when necessary. Solutions and countermeasures, such as active and passive filters, can be used to reduce interference. It offers high performance and efficiency in a variety of applications. Figure 7 compares the starting current and shifting characteristics of the drive controller (VSD) and gas starter (LRS). One of the most critical features of the VSD is its ability to reduce high starting currents. In previous models, starting currents often exceeded 145% of the motor's rated current. VSD technology employs a soft start to gradually increase the engine's power and frequency, thereby accelerating the engine's operation. Gradually increasing power prevents maximum performance and reduces the effects of electrical components that can cause alternator voltage surges and engine wear. This soft start feature also ensures that the required starting power is available reliably, essential for high-speed applications without stressing the chassis. VSD enables companies to improve energy efficiency and physical productivity while addressing social issues and establishing sustainable, long-term business strategies.

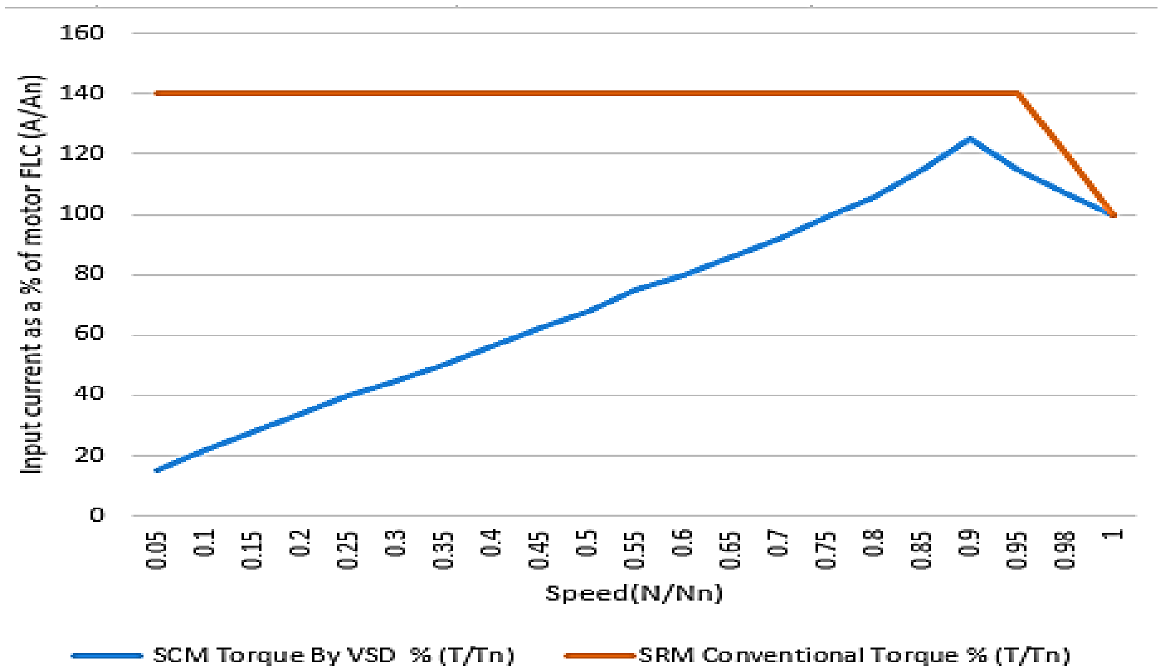

Figure 7. Two Proposed Controller Trends for Starting Currents versus Rotor Speeds.

4. Understanding Total Harmonic Distortion

Total harmonic distortion (THD) is a key metric to evaluate harmonic distortion in an electrical signal, especially concerning the fundamental frequency. Harmonic distortion occurs when the waveform of an electrical signal deviates from an ideal sine wave due to the presence of additional frequencies. THD is particularly significant in various fields, such as audio engineering, power systems, and any application where periodic signals are scrutinised for quality and reliability. According to the IEEE standard 399, often called the Brown Book, “Harmonics are voltages and/or currents present in an electrical system at some multiple of the fundamental frequency.”

This definition means that harmonics comprise frequencies generated by a system that are integer multiples of the fundamental frequency, which is the central frequency of interest, excluding the fundamental itself. For instance, if the fundamental frequency is 50 Hz, the harmonics would be 100 Hz (2nd order harmonic), 150 Hz (3rd harmonic), and so on. In inverter applications, THD is a crucial characteristic of the inverter's output waveform. The performance and efficiency of an inverter are directly related to its THD level. Excessive distortion can cause unwanted effects on connected devices, degrade performance, and increase energy loss. The THD of the output waveform can vary depending on several factors:

1. How fast the inverter switches between low and high states is very important. Frequency modulation can improve the waveform, increase distortion, and strain the components.
2. The design of the PWM waveform plays a significant role in the occurrence of harmonic distortion. The modulation effect varies due to different PWM concepts, such as carrier-based PWM, space vector modulation, etc.
3. THD varies significantly depending on whether the load connected to the inverter is resistive, inductive, or capacitive. For example, nonlinear loads can introduce additional harmonics interfering with the ideal output. It is essential to keep the inverter output THD as low as possible to ensure optimal performance and minimise the effects of electromagnetic interference (EMI). This not only improves the performance of connected devices but also improves energy efficiency. THD is typically measured using equipment such as a distortion or spectrum analyser. The THD percentage is calculated by dividing the total harmonic power by the fundamental power, indicating the level of distortion. A low THD value (typically less than 5% for most applications) indicates a higher-quality output waveform. A high THD value indicates a waveform that may harm the connected load.

4.1 Performance of Quality Improvement

1. The latest pulse width modulation (PWM) technology is essential. It improves the quality of the signal shape. Methods such as sinusoidal pulse width modulation can work more smoothly. While approximating the desired output waveform, the third harmonic injection PWM targets and minimises specific harmonic distortions. Space vector pulse width modulation PWM is another advanced method. Performance is improved by optimally utilising the inverter output state
2. Integrating filters into the inverter output stage is an efficient method for reducing harmonic distortion. In particular, low-pass filters can attenuate high-frequency harmonics by passing only the fundamental frequency and its components. These filters can be passive (using inductors and capacitors) or active, depending on application requirements.
3. Ensuring proper load matching for the output is imperative. This is the characteristic of the inverter. This may include selecting load components designed to work with the inverter output to reduce the potential for additional harmonic distortion. A closed-loop control system can also be implemented to adjust the inverter output dynamically as load conditions change.

4. High-quality components, such as capacitors and inductors with low ESR (equivalent series resistance) and high ratings, are essential to minimising losses. Improves the overall performance of the inverter system. High-quality components reduce the potential for additional harmonic distortion due to parasitic effects and ensure more stable operation. By incorporating these detailed strategies, it is possible to significantly reduce the total harmonic distortion of the inverter output waveform. This integrated approach provides a cleaner output signal and obviously reduces electromagnetic interference, ultimately improving the performance and reliability of the entire electrical system.

4.2 Advantages of VSD Controller Over Conventional Controllers

1. Significantly lower starting current
2. Exceptionally smooth startup
3. Precise variable speed control
4. High power factor exceeding 90%, making it exceptionally motor-friendly
5. Elimination of brush maintenance
6. Substantial increase in process availability.

The simulation of an A5-level inverter reveals promising results, showing a reduction in losses by 58% at rated load. This significant improvement highlights the efficiency potential of utilising more inverter levels, as it contributes to a decrease in Total Harmonic Distortion (THD) in the output. Figure 8 demonstrates a complex distorted signal composed of the 50 Hz fundamental frequency and its 3rd, 5th, and 7th harmonics (150 Hz, 250 Hz, and 350 Hz, respectively). Notably, only "odd" harmonics-specifically the 3rd, 5th, and 7th multiples of the fundamental frequency tend to appear for symmetrical waveforms, as illustrated in Figure 8. These findings underscore the advantages of advanced inverter configurations in enhancing output quality and efficiency.

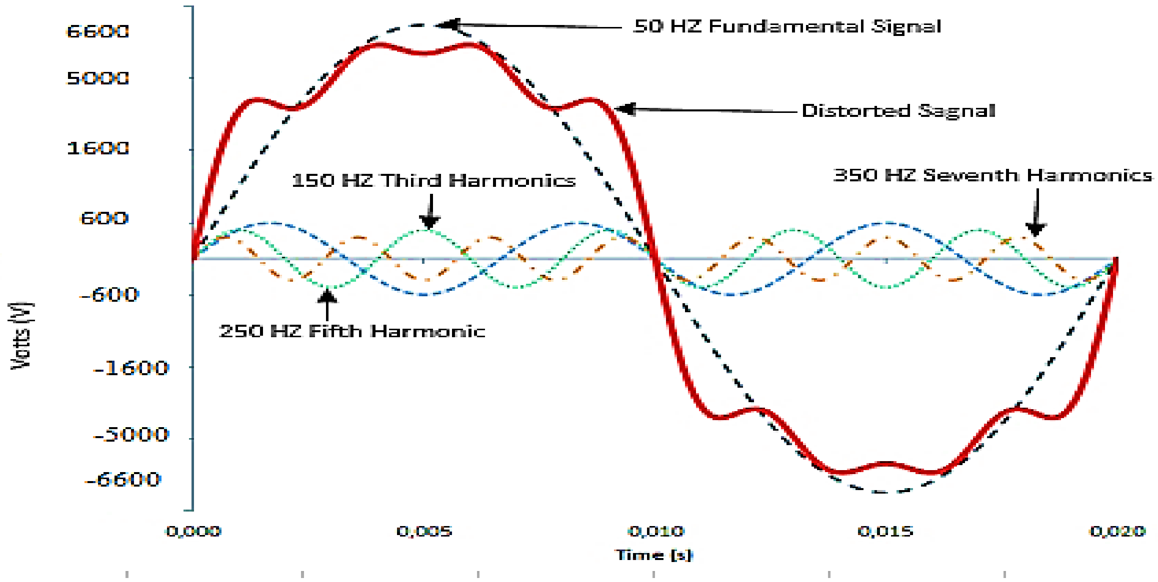

Figure 8. 6.6 kV: Distorted Signal Contains Fundamental and Harmonics for the VSD Output.

THD is a crucial electrical engineering metric quantifying harmonic components' cumulative influence in a voltage or current waveform relative to its fundamental frequency. Harmonics are voltage or current waveforms that are integer multiples of the fundamental frequency, and they can occur due to non-linear loads in the system, such as certain types of lighting, computers, and industrial machinery. Understanding THD is essential for the following reasons: First, it provides critical insight into the overall quality of a signal. High THD values indicate poor signal quality, resulting in poor power consumption and poor performance of electronic devices. High THD levels can also lead to overheating, equipment failure, and increased operating costs. THD analysis also helps identify potential problems in power systems, such as resonant conditions and voltage fluctuations, by accurately measuring and monitoring total harmonic distortion. Engineers and technicians can implement solutions that reduce the effects of THD, improve reliability, enhance performance, and meet business standards. Regularly monitoring and analysing THD ultimately improves the efficiency and extends the life of electronic equipment.

$$\text{THD} = \frac{\sqrt{(V2^2)+(V3^2)+(V4^2)+\cdots+(Vn^2)}}{\text{V1}} \tag{2}$$

This formula calculates a high-frequency electrical signal's THD. THD is a metric used in electrical engineering to evaluate and represent signal distortion. The degree to which harmonics deviate from the fundamental frequency. Calculated results: Percentage values can define relationships between consistent elements. This is one of several frequency types; the key point is the essential signal frequency. The higher the THD ratio, the more critical it is. Significant distortion of network signals can affect the performance and efficiency of the electrical system. To secure power stability and prevent problems, it is necessary to control the total harmonic distortion, including electrical appliances. The amplitude (or root mean square) value of harmonics is expressed as the fundamental current I1 or the root mean square value. The total current in r.m.s is:

$$I_n\,(\%) = 100\,\frac{In}{I1}\,,\ I_n = 100\,\frac{In}{Irms} \quad (3)$$

This formula efficiently calculates a voltage signal's THD and displays the result as a percentage. This percentage serves as a valuable tool for comparison. It is the sum of the fundamental and harmonic components of the signal. By understanding this result, the user can identify areas that need improvement, as a higher percentage indicates a higher level of distortion in network signals.

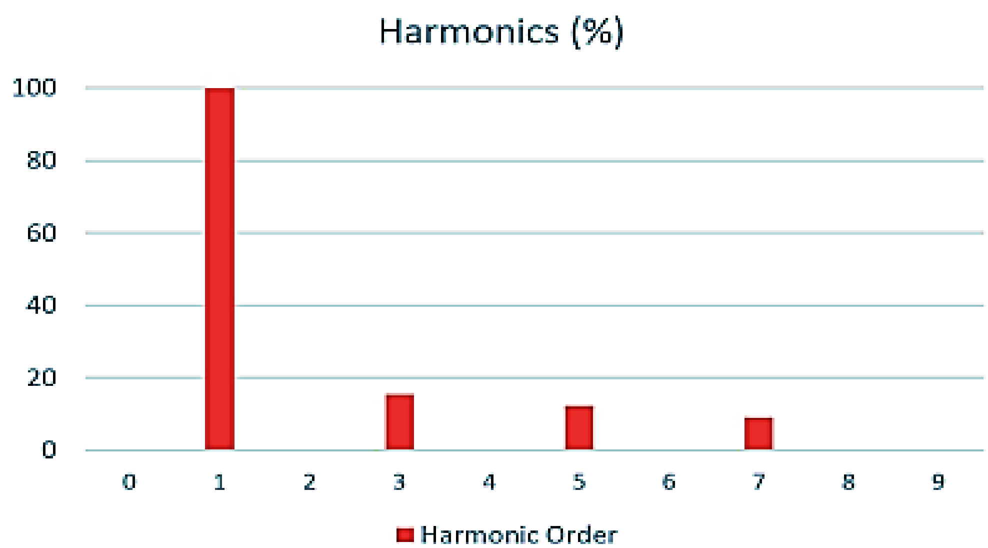

Figure 9. The simulated THD for VSD.

5. Conclusion and Remarks

The comprehensive data presented through the illustrations and simulation results offers in-depth insights into the performance and efficiency of the simulated system, which is the using the VSD controller over conventional controllers, as shown in figures 5, 6, 7, and 9 and the following conclusions are derivative from the above study:

1. Significantly lower starting current, as shown in Figure 7 (the blue line), and save money.

2. Exceptionally smooth startup, as shown in Figure 7 (the blue line)
3. Precise variable speed control as shown in Figure 7 (the blue line)
4. High power factor exceeding 90%, making it exceptionally motor-friendly, as shown in Figure 9.
5. Elimination of brush maintenance
6. Substantial increase in process availability

Below are the key findings that have emerged from our analysis:

- A single variable speed drive (VSD) can start and control two motors. In a coordinated manner.
- The process begins with the VSD initiating the start sequence of the first engine. After this engine has accelerated to the specified operating speed,
- The VSD seamlessly transfers control to the national grid to operate the engine. It operates independently while contributing to the overall system. After the first engine has been successfully operated, it is integrated into the national grid.
- The VSD takes complete control of the second engine at this stage, ensuring it operates at optimal performance levels.
- During the shutdown, the system was shut down in reverse order for safety and efficiency. First, the VSD stops the second engine to avoid abrupt changes. After the second engine had been completely stopped,
- The first engine currently in operation on the national grid is switched off. This systematic approach minimises interruptions and ensures a smooth transition during the startup and completion shutdown phase.

According to our careful evaluation, an effective liquid resistance starter is unnecessary. The operation of our system. This discovery simplifies the overall architecture of the design, making it simpler and easier to use. Eliminating the need for this component also significantly reduces initial capital costs and ongoing maintenance costs over time. Ultimately, this increases the economic viability of the system.

- The system's innovative design allows for complete and easy removal. Brushes and slip rings are eliminated. This improvement dramatically increases the system's reliability and significantly reduces the mechanical wear of the conventional systems. As a result, the frequency of replacement parts and required maintenance is minimised dramatically, allowing more work to be done.

- More compact and energy efficient. This reduces energy consumption and operating costs, allocating resources more effectively to other essential activities. Overall, the VSD controller has proven to be very reliable. This system plays a crucial role in extending the life cycle of various processes. This belief directly helps to improve the productivity level of different enterprises and industries.
- Total harmonic distortion values obtained through simulations are within acceptable and reasonable limits. This indicates that the system is working well. Convert negative impacts into positive energy. In summary, by combining these ideas, the significant improvements provided by our method are efficiency, effectiveness, and overall performance in current use and torque, which increase as shown by 20%, then the conventional method, as shown in Figures 5 and 6 as well as considering using high-quality VFD to minimize the THD.

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مقارنة نتائج المحاكاة لنوعين من المحركات الحثية باستخدام محركات السرعة التقليدية والمتغيرة

الخلاصة: يُقارن هذا البحث بشكل شامل نتائج محاكاة نوعين مختلفين من المحركات الحثية: محركات الدوار الملفوف ومحركات القفص السنجابي. قُيّم كلا النوعين من المحركات في ظل ظروف تشغيل متطابقة، مُصنَّفة بوضوح عند 2750 كيلوواط، و6.6 كيلوفولت، و50 هرتز. تهدف الدراسة إلى تقييم وتحليل منهجيتي تحكم مختلفتين. تعتمد طريقة التحكم الأولى على نهج تقليدي يتضمن تشغيلًا بسرعة ثابتة وتقنيات تحكم قياسية. أما الطريقة الثانية، فتستخدم نظام قيادة متطورًا بتردد متغير، وقد أزالت جميع المعدات المتصلة مباشرة، مما يسمح بضبط سرعة المحرك ديناميكيًا وتحسين الأداء لطريقة التحكم الثانية المقترحة. يزيد تحسين عزم الدوران باستخدام الطريقة الثانية عن 20%، كما أن تيار البدء منخفض جدًا (لا يوجد تيار اندفاع)، مما يوفر المال. من خلال عمليات محاكاة مُفصَّلة، يُسلِّط هذا البحث الضوء على الاختلافات في الكفاءة، وخصائص عزم الدوران، والفعالية التشغيلية الإجمالية بين هذين النوعين من المحركات واستراتيجيات التحكم الخاصة بكل منهما.

الكلمات المفتاحية: مقارنة بين المحركات الحثية،محركات السرعة المتغيرة،حلقة الانزلاق، القفص السنجابي، المحاكاة العددية.