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Optimisation of Energy Efficiency of Three-Phase Induction Motor Drives for Industrial Applications

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Abstract— Electric motors are used in nearly 60% of the global electrical power generated. Due to the greater energy consumption, there has been a considerable rise in production costs and environmental degradation, increasing general operating expenses. Therefore, the efficiency of three-phase squirrel cage induction motors (SCIMs) may be improved to save a large amount of electricity. The thesis aims to investigate increasing the efficiency of three-phase (SCIM). The proposed method improves the efficiency of (SCIMs) using PID controller Simulink design in Simulink/MATLAB. To successfully determine the motor characteristics and simulate a three-phase (SCIM) under various loads. The effects of lowering the voltage and using PID controller on motor characteristics such as generated torque, power factor, reactive power, apparent power, output power, rotor speed, and magnetising current are also discussed. The simulation result found that the proposed motor efficiency and power factor method is improved by using a PID controller. At motor torque of 12 N-m, the efficiency is 80%, which rises to 92 % at higher motor torques. After applying the proposed method, the power factor becomes 0.64%, which is an improvement of 0.2%.

Keywords: *SCIMs, Induction motors*

1. INTRODUCTION

The three-phase induction motors are most employed or used in what is known as industrial settings since mechanical energy is derived from electrical energy. Today, electric industries such as automotive factories use approximately 69% of electric power. And these electric drives are primarily alternating current (AC) and direct current (DC). In the last forty years, the popularity of the AC drives grew significantly, particularly the three-phase induction motor drives, which offered more robustness, efficiency, performance, and an incredible sustainable structure that is utilised mainly in industrial applications—for instance, powering elevators, refrigeration systems, robotics, and so on.

Since the development of the first induction motor by Nikola Tesla in the nineteenth century, the universal property of motors, regardless of their purpose, is that a large amount of electricity is needed to operate. The structure and performance of induction motors have since significantly improved. Specifically, this has been executed via motor power losses decrease by adopting high conductivity materials. For example, this may include using copper instead of criterion steel in the squirrel cage rotor. The stator core is also shaped using silicon steel sheets, which minimises the hysteresis losses and the eddy currents. [1]

The process control techniques in the industrial field have witnessed significant advances in the last few decades. Various control systems and methods, such as Neural and Fuzzy logic control, have been under study and investigation. In relation to these, the most well-find is the Proportional Integral Derivative (PID) controller because it is extensively employed and utilised due to the fact that its structure is quite simple and its performance is very robust and durable under a wide area of operating situations. However, it has been considered hard in terms of tuning PID controllers' gains because numerous industrial plants had to face several issues such as large orders, time delays, and nonlinearities. [2]

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2. RESEARCH METHODOLOGY

Based on Essensa and Christian [4], electric motors are used in almost sixty per cent of the global electrical power generated. Because of greater energy consumption, there has been a significant rise in production costs and environmental degradation, increasing general operating expenses. Induction motor driving systems that are more efficient and dependable are critically required for current and future applications. This study aims to develop an induction motor with low manufacturing and operating costs and with significant operational efficiency.

The investigated project aims to achieve a method to obtain high efficiency for a three-phase induction motor using PID controller Simulink design in Simulink Matlab. Therefore, the project's methodology is to compare three-phase induction motors under various loads in normal operation (at rated voltage) without using PID controller and Simulink various loads using PID controller to find the highest efficiency.

2.1 Simulink Model of Three Phase Induction Motor by without Using PID controller under Different Loads

A Simulink model was constructed to compare the standard operating procedure to the three-phase SCIM technique (see Figure 1). To connect the three-phase SCIM stator coils, spliced Y connections are employed. The excitation of the DC generator is used to provide the AC generator loads (rotor-shaft-rotor-shaft-rotor-shaft). Simulink represents a generator as an adverse torque signal in a DC or AC machine. As a result, the applied load torque must be positive, implying a one-ton increase in the dc generator's torque. It's wired into a dc generator with a variable resistive load. The standard practice is to adjust the resistive load while maintaining the motor's rated voltage. As a result, the engine is always under stress. To guarantee optimal efficiency at rising speeds, the voltage supplied to the motor may be varied in a predetermined way (rated voltage). Voltage and current, power factor, apparent power, rotor speed, and active and reactive power are all measured using the model's various blocks.

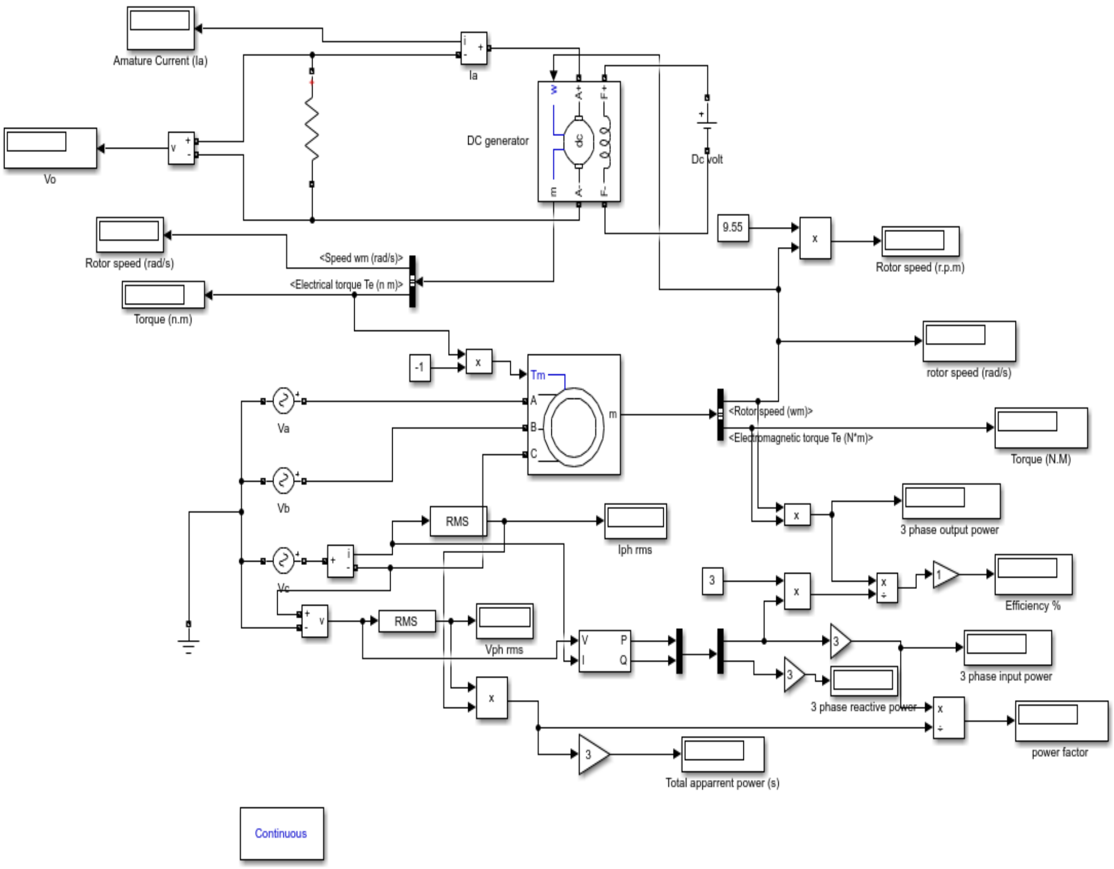

Fig 1 Simulink model of three-phase induction motor without PID controller [3]

2.2 Proposed Model of Three Phase Induction Motor by Using PID controller under Different Loads:

For example, in the industrial sector, DC generators may be used in servo systems and speed control. Due to the PID controller's simplicity, robustness, and ability to be tuned. The PID controller-based Simulink model in Fig. 2 compares the SCIM technique with normal operation. The stator windings are connected in a Y-connection using a three-phase SCIM concept. There is an ac generator attached to the motor's shaft, and the ac generator itself is linked to the dc generator using a direct connection. It is possible to use a PID controller in Simulink to regulate the output voltage serving as a generator. This results in a model where the applied load torque to the motor exceeds the dc generator torque. A changing resistive load charges the dc generator. By setting the applied voltage to the motor's rating, the load on the motor may be adjusted by varying resistance in the load. Using the suggested approach, the PID controller applied on speed is changed to operate at maximum efficiency more significantly than regular operation. There are various blocks in the Simulink for measuring various variables such as stator current, the voltage (V), active power (W) and reactive power (W), efficiency(%), as well as output power, apparent power and rotor speed.

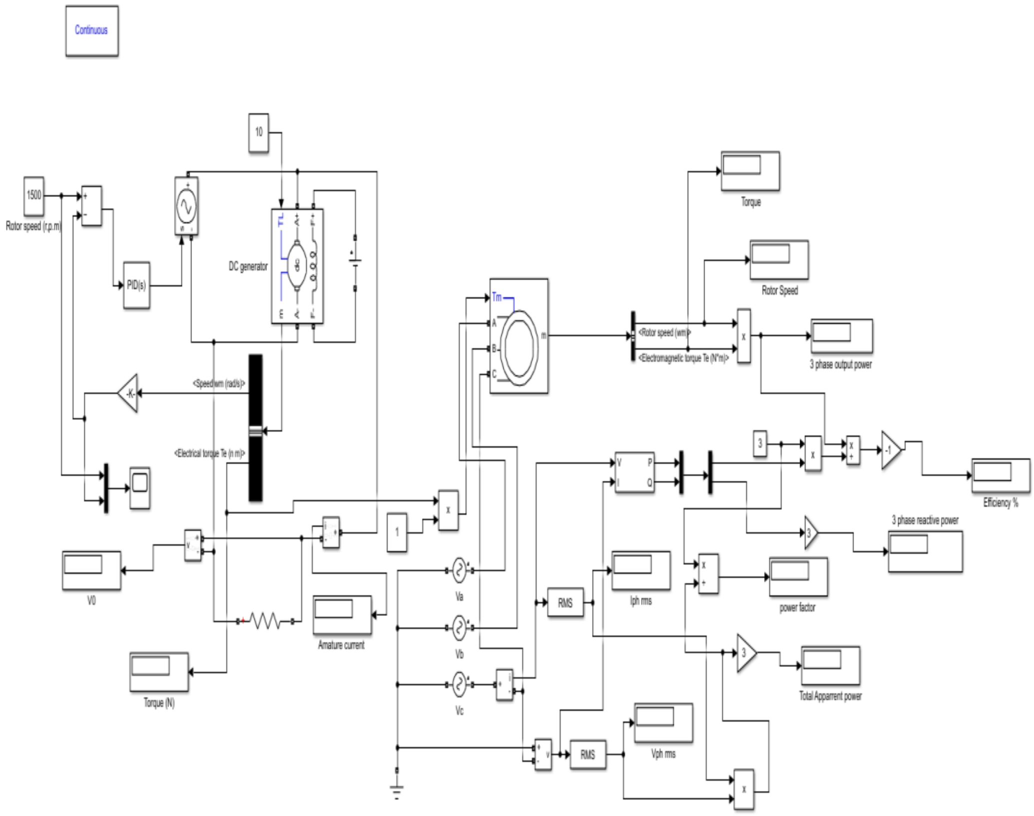

Figure 2 Simulink model of three phase by using PID Controller

2.3 The result of Simulink of a three-phase induction motor under various loads with using PID controller

After switching the MATLAB/Simulink with the PID controller, various characteristics are provided to illustrate their change with motor torque in normal operation and the suggested technique. As a result, the motor's applied voltage is maintained at its rated value. PID controllers are extremely effective and powerful controllers with a superior control strategy for maintaining motor speed. PID controller parameter values are set using tuning procedures and shown in Figures 3 and 4. Motor efficiency, power factor, output power, perceived power, stator current, and rotor speed are several parameters. Simulations of the suggested speed control model were carried out using Matlab's Simulink platform. This section shows the simulation outcome of a DC generator with motor speed control against the impact of load with speed – Torque characteristic curve. On the Simulink platform, a block scheme of a system model, whether without or with a PID regulator, is generated. To begin, the step response of the system model with a PID regulator is calculated and shown in figure 4. The rising time is 1.2 seconds, with a 2-second settling period. The steady-state error accounts for around 90% of the final result. We can see that when the motor is operating at optimum efficiency, the stator phase current is lower than when the motor is operating at light loads. The applied voltage is lower than the rated voltage. Reduced voltage boosts stator current and reduces motor effectiveness when the motor torque exceeds typical operating torque.

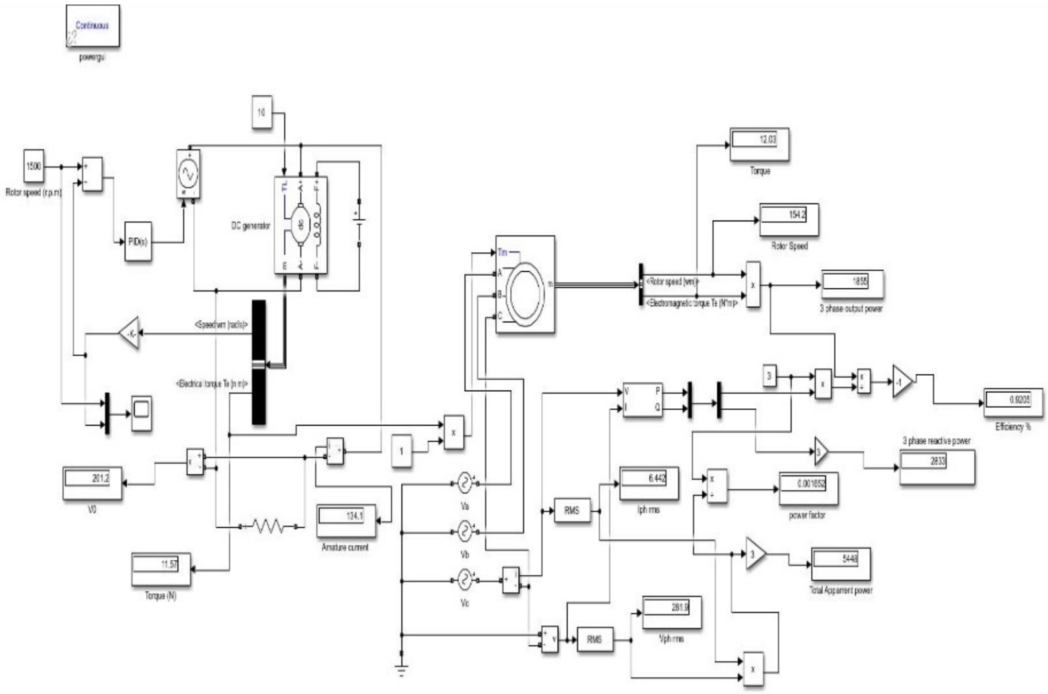

Figure 3 Simulink outcome of three phase by using PID Controller

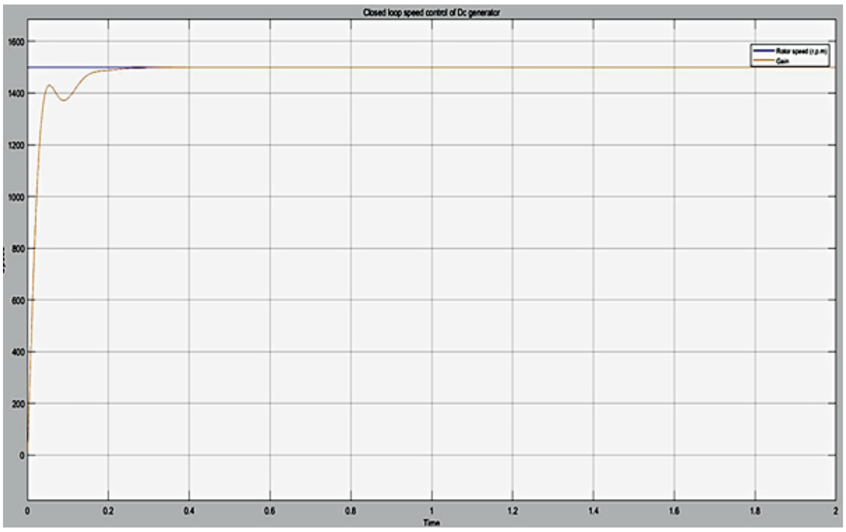

Figure 4 Result of controlling Rotor Speed by using PID Controller.

2.4. Data Collection for Results Simulation under Different Loads

Industrial variable speed implementation, which has the most requesting speed-torque characteristics, is straightforward to control. It is essential to apply PID controllers when the loads vary. A PID controller was used to regulate the speed of the motor while it was under load. As the motor speed remains constant, the load torque may be changed. The approach that was proposed was well thought out and thoroughly tried. For a motor's open-loop speed regulation, the PID controller proved to be very effective and powerful, as shown by the experiment results. PID controller parameter values were set using the Custom Tuning process. Based on simulation findings, the PID controller is a better choice for regulating and maintaining the speed of a motor under a variety of load circumstances. Researchers found that a PID-based closed loop speed control system was effective even with load disruptions. The motor's efficiency and power factor may be enhanced and maintained by lowering the applied voltage while running at a speed that can be controlled. The applied voltage may be reduced if the stator current and perceived power are low. As a result, the engine's lifespan is extended, and power is saved.

Figure 5 shows that the stator phase current fluctuates with motor torque. The stator phase current is lower when the motor runs at optimum efficiency than when a PID controller controls the motor. The voltage applied is lower than the rated voltage. It is possible to improve motor efficiency by applying voltage for increasing the stator current while the motor is operating at a higher motor torque than typical. Therefore, the motor's rated voltage is maintained.

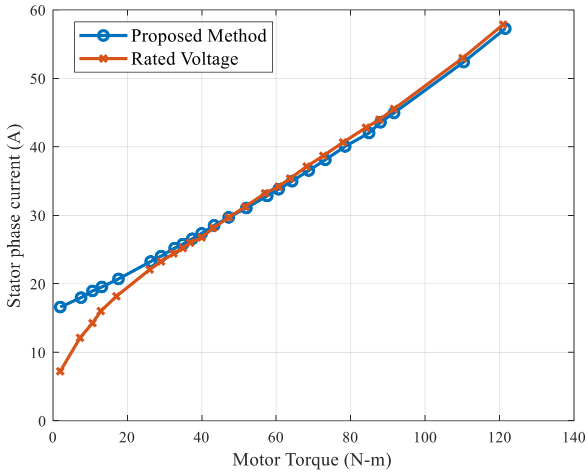

Figure 5 Outcome Simulink of stator phase verse motor torque

Figure 6 depicts the variation in motor efficiency as a function of motor torque. In normal operation, the applied voltage fluctuates at various rates below the rated value in order to hold the motor's efficiency at optimal efficiency at all loads (rated voltage). The efficiency of motors with more significant torques than the motor torque at optimum efficiency in the normal process is reduced when the applicated voltage is decreased, as can be shown. This necessitates that the rated voltage be maintained.

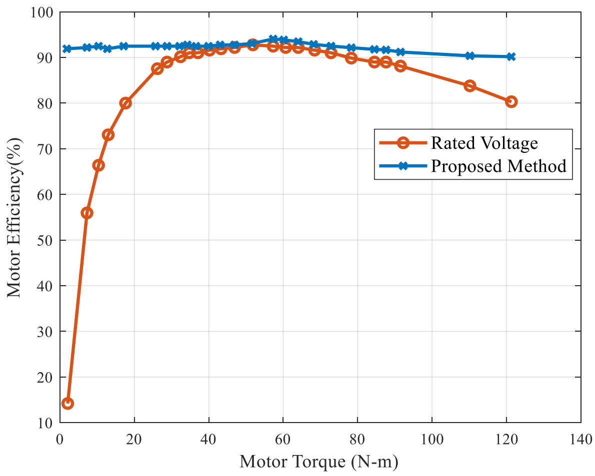

Figure 6 Outcome Simulink of Efficiency verse motor torque

The link between managing the rotor speed using a PID controller and motor torque is seen in Figure 7. With loads, the motor is operated at a steady speed, with the applied voltage reduced to maximise efficiency. As can be seen in this graph, the rotor speed is set to switch the motor at optimal performance. Consequently, the rotor speed is still controlled appropriately for the driving load. When a centrifugal pump is working at maximum efficiency, it's vital to make sure that reducing the speed doesn't result in inadequate fluid flow.

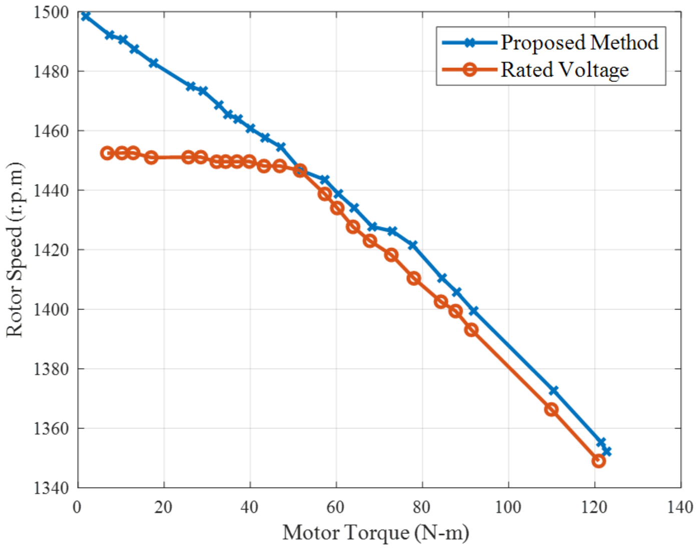

Figure 7 Outcome Simulink of Rotor speed (r.p.m) verse motor torque

The fluctuation of apparent and reactive power as a function of motor torque is shown in Figures 8 and 9. As can be seen, the proposed strategy of apparent and reactive power is less than normal operation by regulating speeds. When the current is increased, it is evident that the apparent and reactive power at loads drops. The magnitude of the voltage drop is larger than the magnitude of the current increase, resulting in an apparent power loss. To prevent outflow current more than the rated current and a drop in apparent and reactive power at the load, the applied voltage must be improved at the same rate as the current increases.

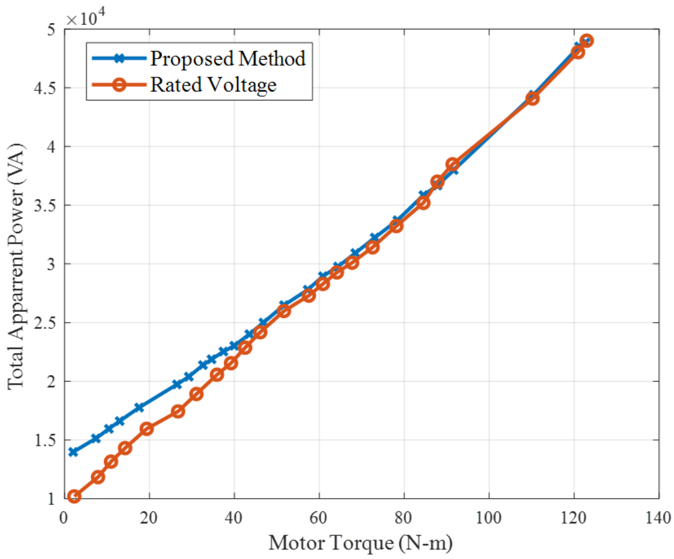

Figure 8 Outcome Simulink of Total Apparent power verse motor torque

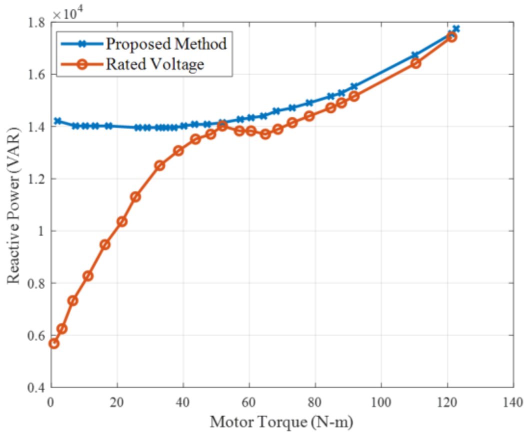

Figure 9 Outcome Simulink of Reactive power verse motor torque

Figure 10 depicts the variation in output power and motor torque. The output power of the suggested approach for managing speeds with varying loads is lower than the rated voltage, as can be shown. In light and heavy load operation, the rotor speed is controlled because the applied voltage is reduced below its rated value

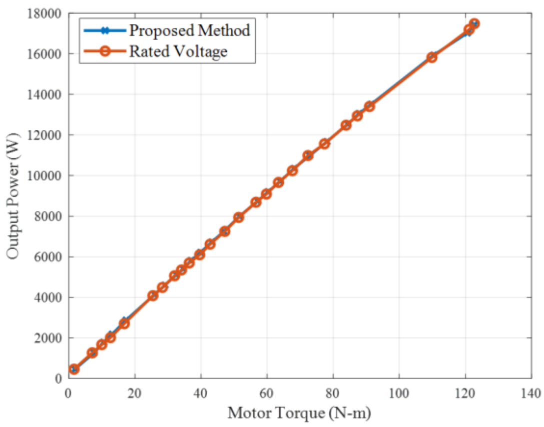

Figure 10 Outcome Simulink of Output power versus motor torque

In order to achieve the required speed, the PID controller was used in the existing block diagram of the system model in this experiment. After that, the system model was evaluated under full load without using a PID controller. Figure 7 depicts the speed-torque step response. The pace isn't up to par with the expected benchmark. The graph also shows that the load torque changes from 1000 to again. A PID controller is utilised to solve the existing challenge of speed control under load. Figure 4 illustrates the simulation graph of the system model. The system's responsiveness improves in terms of target speed sustainability with zero load torque when the same PID controller parameter values are used. However, when the load torque increases from 1000 to 1500Nm, the speed sustainability decreases dramatically. As seen in this graph, the speed is considerably reduced using closed loop speed control under full-load conditions, and the efficiency is over 90%.

3. CONCLUSION

A STANDARD method of converting electric power into mechanical energy is USING three-phase induction motors. Three-phase induction motors consume most of the electricity utilised in the sector. Motors with these specifications have a low-efficiency rating and power factor while running at typical loads. To preserve energy, high power factors and efficient motors are required. By improving efficiency under various loads, it is possible to test the influence of the suggested technique on motor properties such as stator current, output power, reactive power, rotor speed, and others.

To increase motor efficiency, a simple and inexpensive solution has been presented. The SCIM efficiency stays constant at its maximum value while the motor runs at a higher speed than usual. In both conditional situations, the stator current is inversely proportional to the rotor speed. Its highest value is at the beginning of the cycle (when slip equals one) and its lowest value is after the cycle. To put it simply, the stator's value is equivalent to zero load current. When the motor's constant losses are equal to its variable losses, it operates at its optimum efficiency. Any load rise leads to a rise in power losses, so the efficiency declines beyond the maximum efficiency threshold. Because there is no output power, the efficiency decreases indefinitely. Motor efficiency and power factor are improved by using Fig. 4.4; at motor torque of 12 N-m, the efficiency is 80%, which rises to 92 % at higher motor torques. After applying the proposed method, the power factor becomes 0.64%, which is an improvement of 0.2%.

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