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PERFORMANCE EVALUATION OF FOUR PHASE 8/6 SWITCHED RELUCTANCE MOTOR FOR SHIP PROPULSION SYSTEM

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Abstract

Nowadays, the use of electric propulsion in navy ships is not a unique idea in the field of marine industry. Because of the high demand for power generation in naval as well as in commercial ships, various generation of electrical motors must be used, and reformation in high power electronics aids in adjusting and driving the system. Due to its low reliability and simple design, the switched reluctance motor is receiving greater attention. However, torque ripple has become a significant issue, particularly at low speeds, limiting the SRM's applicability as a servo drive. Torque ripple also causes acoustic noise and vibrations which affects the motor's efficiency. Many control solutions have been presented to cope with torque ripples. The control strategy for torque ripple suppression is presented and discussed in this study, based on a Hysteresis controller to create a superior PWM and Cascaded Artificial Neural network (CANN). When compared to other approaches, CANN has been regarded as a promising method due to its generality, reduced complexity, stability, and accuracy. This study also introduces motors that could be used in vessel propulsion systems, as well as the significance of increasing the (8/6) type switched reluctance motors phases and by means of control strategies to address the major drawback in the motors. To demonstrate our technique, simulation results for torque ripple elimination at various speeds are examined. Finally, the pertinent findings are presented. Matlab/Simulink is used to create the simulation platform.

Keywords: All electrified ships (AES), Cascaded artificial neural network (CANN), Hysteresis current control, Ship/vessel propulsion motor, Switched reluctance motor (SRM), Speed and torque control.

1. Introduction

All Electrified Ships is an innovative shipbuilding trend that allows the vessel capacity to be powered from the same source of electric power that operates the propeller, removing the need for a separate generation system for various propulsion and vessel loads [1]. Because worldwide rules addressing NOx and SOx emissions have become increasingly rigorous, shipbuilders have begun to incorporate power-driven propulsion by way of a method to increase fuel cost then minimize emissions. Fuel price fluctuations have also compelled the marine industry and the owner of the ships in general to familiarize and hybrid power propulsion systems as well as employ quite electrified [2].

Because all electric ship propulsion motors vary according to the category of ship and its function, various types of electric motors are employed in the ship propulsion systems. Commutated DC motors doubly fed induction motor, synchronous motor, Commutator-less DC motor, induction motors, switched reluctance motors are the various motors used in ship for propulsion function. Other motor types have been suggested, such as synchronous reluctance motors, which will compete for usage in ship propulsion with traditional motors, notably permanent magnet synchronous motors, since various benefits of switching reluctance motors will be described later, and a suggestion to increase its performance will be presented [3, 4]. However, benefits of employing a motor as a propeller differ on the ship's weight and the type of engine used. Electric propulsion interacts effectively with the ship's integrated system, is easy to change in terms of torque and speed, which produces less noise, is quick to fit and remove due to the need of an aligned shaft or gearbox and is ecologically friendly.

Torque-sharing features, as reported by Mönch et al. [5] are recommended in this paper to achieve the SRM instantaneous torque and to reduce torque ripple during fixed or within-limits operation. The author's goal was to have a bearingless rotor magnetically hover in air without a mechanical support given by a single layer winding. In this work, the number of windings was lowered from 8 to 6, as it able to minimise the cost converter topologies, as reported by Sharma et al [6]. The speed limitation approach was proposed in conjunction with the driving philosophy. The main disadvantage is only fit for medium and low-speed applications.

Moron et al. [7] presented the findings of the instantaneous torque control technique, whereby the critical angle, or switching angle, of two adjacent phases has the same torque and current state or flow connection. The enhanced current reference switching was then designed to reduce torque loss [8]. This article torque ripple minimization may be used to optimize the current profile. A simple approach and the evolutionary algorithm are used to regulate the current waveform with a reasonably small number of optimization factors. The new modified method was designed to reduce the maximum value of the current phase through inexpensive solution quality and a shorter time frame [9]. The current expression of reference was chosen with only a few variables to establish the maximum STO range. It tests the universal SRM mathematical model's ability to represent the specified mathematical formula. The energy efficiency of SRMs investigated in this research utilizing a zero-voltage switching mechanism, as reported by Zaky et al. [10]. By lowering the flow connection peaks, null voltage loop switching can considerably increase SRM performance. The harmonic magnitudes are minimized by the magnetic flux densities within the SRM core.

2. Electric Propulsion System

Each propeller in an electric propulsion system (EP) system has more than one electrical drive. Propulsion motors may be replacing from geared gas turbines or traditional diesel propulsion engines that run slowly are the major prime movers which are fed by power electronics converter. As illustrated in Fig. 1, in modern naval vessels, two motors are required as a main propeller to drive the main propulsion and electrical distribution design, each motor rated 5MW, and the total of 20 MW provided by four of the diesel generators [11]. The motor rate of cruise ships is roughly 20-35 Mega Watt per single propeller, which is noted in the size of such converters. Generally, all electric cruise ships have two types of propellers (for a total of 20-30 Mega Watt), with notable exceptions such as the Queen Mary 2, which has four propellers and a total installed propulsion capacity of roughly 86 MW.

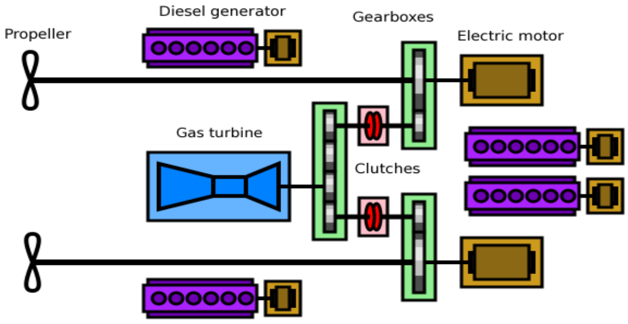


Fig. 1. Architecture of modern naval ships main propulsion and electrical distribution [11].

The major reasons that ship builders and owners adopt electric systems are reliability and efficiency. Because of these factors, as well as advancements in power electronics, the biggest power electronics converters are possible for ships EP have been used for many years.

Rotor speed variation requirements are typically disregarded about even electro-mechanical transient conditions; hence a traditional V/Hz performance of the controller is frequently used. On the network side, diode front ends (DFEs) or activity front ends (AFEs) may be employed. AFEs are employed in a variety of high-performance applications to enable unidirectional energy from and to propulsion technology while also increasing IEPS power quality. Because of acquired skills in the prior one or two years for big power High Action of electric drives, induction motors are progressively being utilized for maritime propulsion technology, especially when better power density and barrier properties are required (as in the Royal Navy's Type 45 vessels and the US Navy's DDG-1000 series). Because of the lack of stimulation systems and related auxiliary and control systems, purchase and upkeep costs are expected to be cheaper in this case [12].

Motors used in ship propulsion systems.

Marine propulsion systems employ electric motors, control circuits, and power conditioning. Electric motors are critical terms in ship propulsion technology since they convert mechanical energy from electrical energy for propellers or vice versa, enabling regeneration brake or recharging energies to be converted into power for on-board use. Before being sent to the processor, these signals are conditioned to the right level. Typically, interface circuits that function as power semiconductor devices power converters amplify processor output signals. Figure 2 depicts the classification of electric and hybrid ship drive motors into two basic categories: switching engines and motors that do not require commutation.

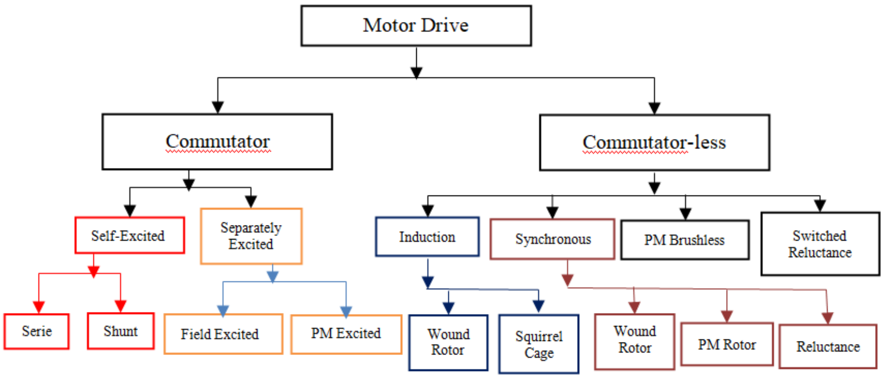


Fig. 2. Motor classification for electric ship propulsion systems [13].

The most popular switching drives are separately, series, shunt, compound and permanent magnet motors. Armature current must supply into the DC motor switches and brushes, which reduces their dependability and makes them unsuitable for heavy speed and free of maintenance operation and high speed. This is due to the less maintenance, low operating costs and high reliability. These control techniques, however, performance is low in light loads and during constant power in a limited operating range [13].

Highly dense motors are employed in ship electrical vehicles, hence, shifting gears may be used to achieve the requisite efficiency [14]. The use of induction systems with stator flux and a huge number of phases throughout electronically controlled ships' incorporated power systems (IPS) enables the use of induction systems with a permanent magnet pole and a huge number of stages to overcome adversity in ship power systems such as short circuits in phases and their failure, as well as to reduce motor size by leveraging very highly dense electric power. Figure 3 depicts a simplified schematic of a typical IPS, which employs numerous gasoline generators and two-stroke propellant motors [15].

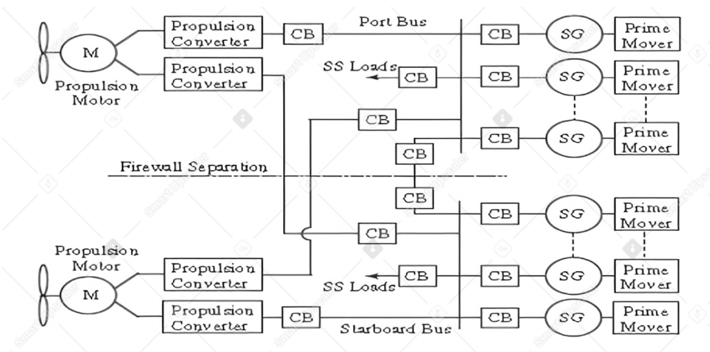


Fig. 3. An example of an integrated power system (IPS) for a ship's electric power system [14].

Even though US Naval Postgraduate School studied various electric motors for electric ship propulsion during in the year 2003, they conclude that the switching reluctance motor was found unsuitable for use in ship propulsion systems because of the rising cost of rare-earth metal, which is in short supply and expensive to obtain. SRM was introduced as a robust, cost-effective, and efficient motor for ship propulsion systems [13, 14].

3. Improve the Entire Electric Ships System's Performance

The electrically driven engine is a crucial element of the All Rechargeable Ships idea. Modern naval and corporate ships are flocking to SRM due to the benefits outlined above. For many years, several scholars have been researching on these problems. Most of the research focused on finding solutions to the problem by developing drives that reduce torque rippling and regulate thrust force [16], such as Direct torque control as reported by Hannoun et al. [17] and Direct Near instant Torque Regulation, as reported by Fang et al. [18]. Wave Torque Direct power control is demonstrated in Minimising of Direct Speed Controller using an Artificial Processor and Field Focused Control Approach [18]. Scientists have tried to reduce vibration in SRM for many years using any methodological approaches (as stated earlier) or alternate solution device design ideas such as deciding optimum magnetic loop main objective is to lessen low speed torque shockwave [19], rotor Framework architectural style [20], and assists in describing a novel alternator pole face idea with a quasi-air space and a pole foot attached to the rotor pole's transverse face [21].

4. Cascaded ANN Controller

The selection of a suitable controller is crucial in boosting the converter's dynamic performance while also providing the required error correction. In this scenario, a cascaded control strategy is applied to optimise the charging stations. Overall functioning. The cascaded ANN control technique consists of two ANN controllers connected in series, as shown in Fig. 4, with the output from the first controller serving as input to the second. In general, the ANN controller has a high computational speed, but it has the disadvantage of being less accurate. As a result, a cascaded ANN control technique is used to improve the controller's accuracy. In Fig. 4, the ANN contains three primary layers: the output layer, input layer, and hidden layer. These layers are entirely linked, although no neurons in each layer are connected.

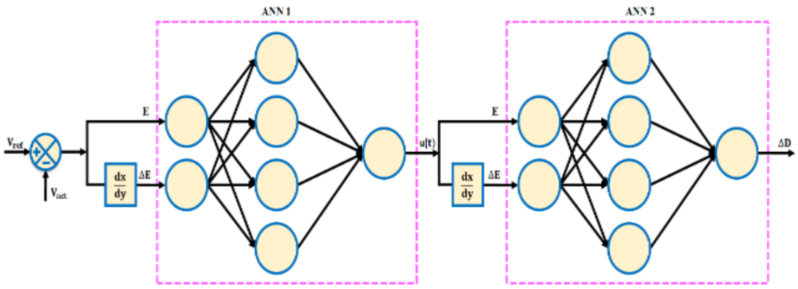


Fig. 4. Structure of cascaded ANN structure.

The magnitude and change in error are fed into the cascaded ANN controller, while the duty ratio of the converter is the main output. Again, the output of the first ANN controller determines the duty ratio range for the next ANN controller. As a result, the cascaded ANN controller's accuracy in determining the required change in duty ratio command is improved.

5. Methodology Proposed

Transient response affects the computational efficiency of a variable reluctance motor (SRM), which is dealt with adopting SRM modelling built on a cumulates artificial neural network (CANN). The schematic diagram of the CANN-based management system for a shifting resistance motor is shown in Fig. 5. Current flow cannot be used to power SRM; rather, a converter is needed.

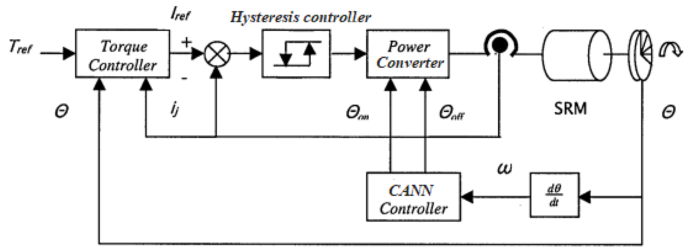


Fig.5. The proposed control block diagram for the torque ripple minimization technique.

Figure 6 depicts the SRM model, which is cantered on a four-leg, four-phase BR conversion. Each leg is made up of two rectifier and two IGBTs. In aggressive state, the SRM winding is connected to a positive supply voltage through an IGBT switch. As during conductance period, positively voltages flow in phase windings, and conversely even during no conductivity period. The potential glycogen is returned to the DC source via transistors [22, 23].

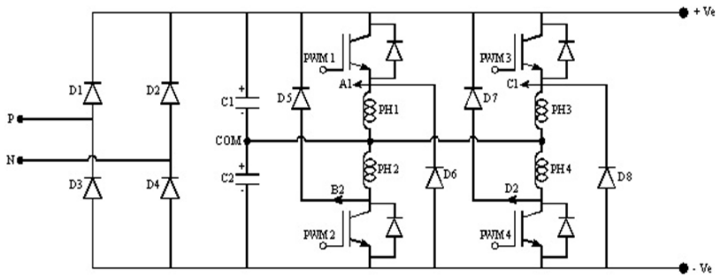


Fig. 6. Four phase BR converter circuit diagram.

The speed of the motor is regulating by the converter in large part by accurately activating the necessary windings in the stator. Input is given by the hysteresis band that will be powered by power converter which accepts gate pulses. The hysteresis band determines the switching frequency of an IGBT. For three-phase current hysteresis control, reference current is used. The position sensor regulates the motor windings' on and off phases. Similarly, noise is added separately to the motor's real three-phase current, and the three-phase current is then fed into the CANN-based three-phase current blocks in Fig. 7.

Three hysteresis controllers are utilised to regulate phase currents individually and create IGBT drive signals by comparing CANN-based 3-phase current with references. A CANN-based SRM is used to get the required outcome.

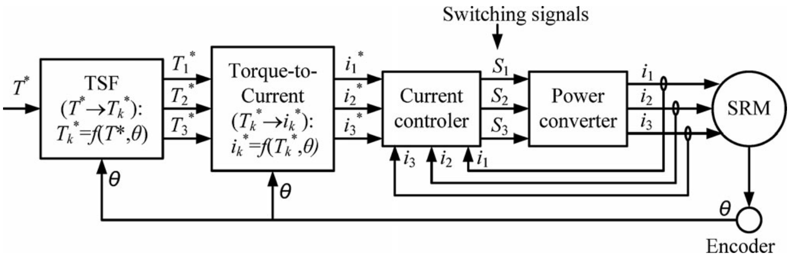


Fig. 7. Hysteresis current controller-based SR motor block diagram.

6. Results and Discussion

This study explores the Simulation results. Figure 8 depicts the Simulink model of the recommended systems of 10 KW four stages 8/6 SRM with 1500 rpm. Figure 9 depicts a Simulink model of a retro control strategy.

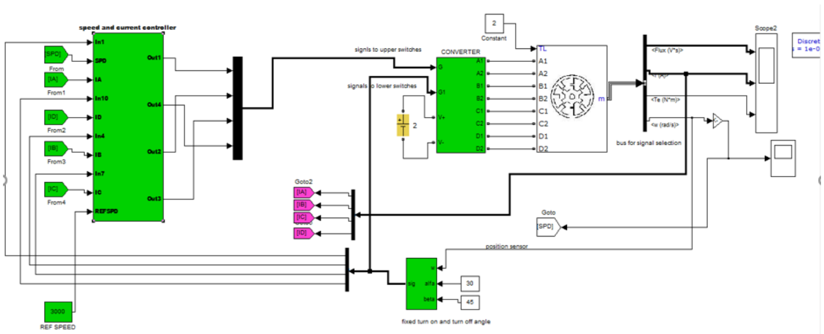


Fig. 8. Simulink model of four phases 8/6 SRM.

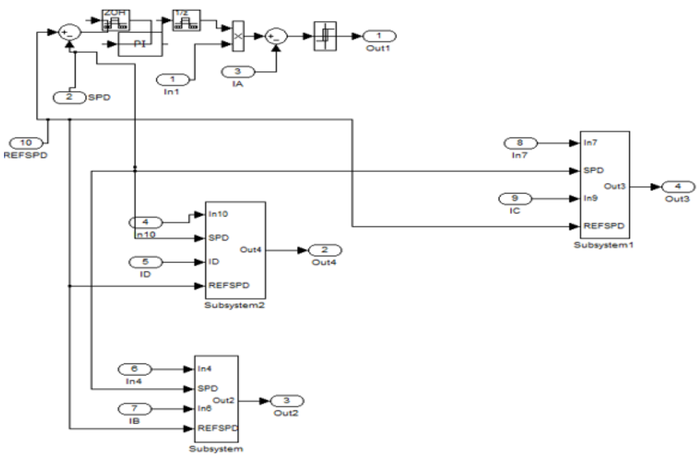


Fig. 9. Simulink model of a hysteresis current controller.

The SRM is supplied by the Bridges Resonant power converter and has four legs, each with two bidirectional switches and two IGBTs, as shown in Figs. 10 and 11 which depict the Cascaded ANN Simulation results.

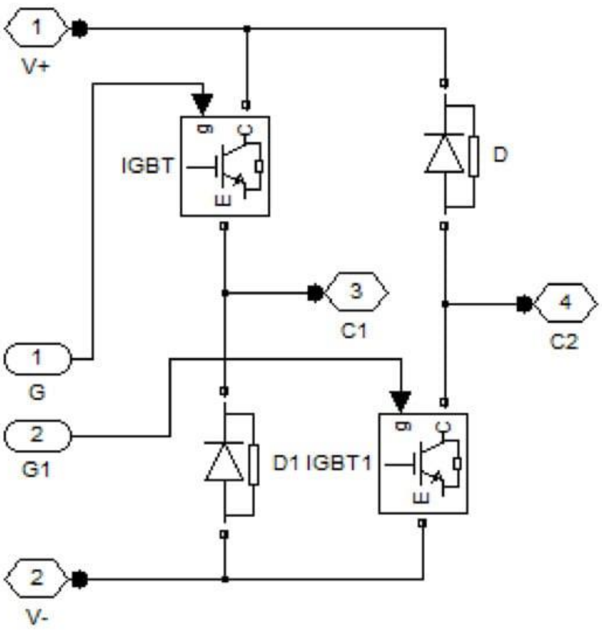


Fig. 10. BR converter simulation.

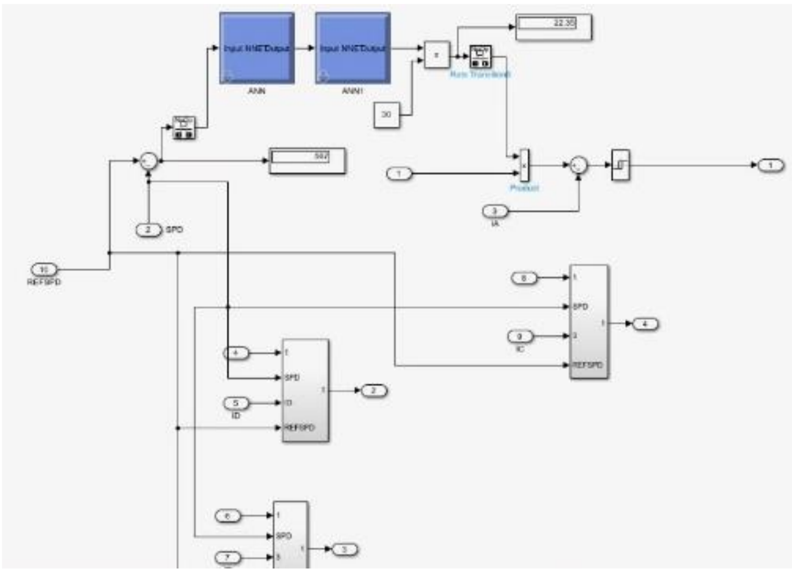


Fig. 11. Simulink Model of cascaded ANN structure SRM converter.

The pulses of the PWM to the BR converter are shown in Fig. 12. The torque is directly controlled instantaneously by the pulses. The rate of pulse switching is 25 KHz. It converts the DC tension to AC tension. The four-phase SR motor is then powered by this voltage.

The current, torque and flux waveform of the SR motor is shown in Fig. 13. Due to the nature of the material the machine initially takes high power. This causes noise in the torque also with higher orders of ripple currents.

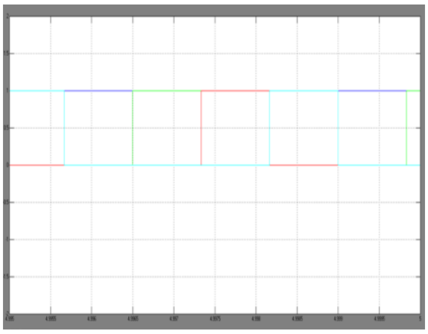


Fig. 12. Proposed system PWM pulses to the converter.

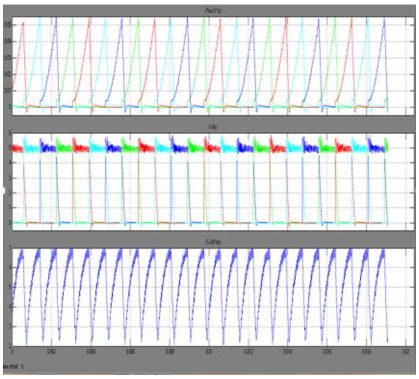


Fig. 13. Proposed system SR motor flux, current and torque waveform.

The step change parameter for speed control is shown in Fig. 14. Speed is set with 1500 RPM as an initial value and settled at 2000 RPM in shown in speed waveform for the proposed system in Fig. 15. Speed Response of SR motor with and without step change is shown in Figs. 15(a) and (b). Torque improvement from proposed and existing system is shown in Fig. 16, which is 7 N-m when compared to the existing system.

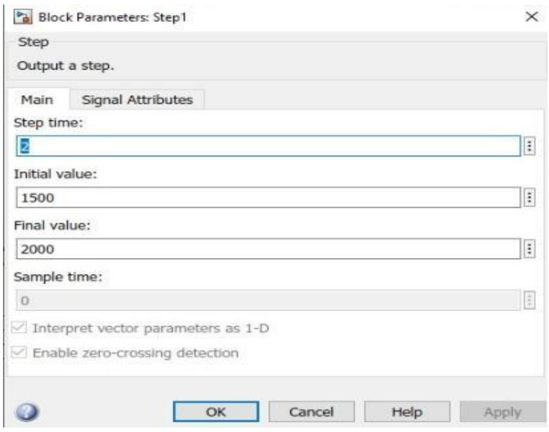
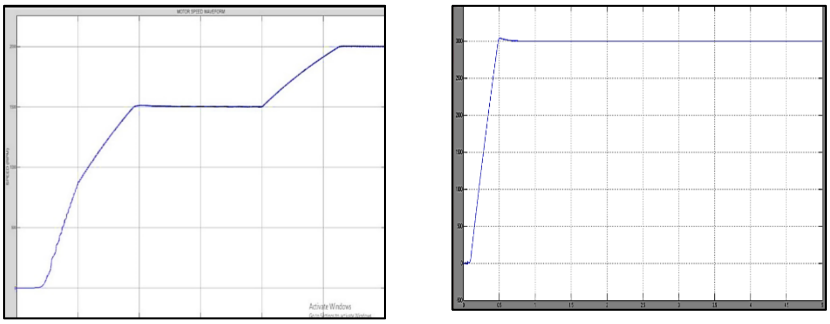


Fig 14. Step change parameter for speed control.

Existing System: 6.2 Nm, Proposed System:7 Nm



(a) Speed response of SR motor with step change **(b) Speed response of SR motor without step change**

Fig. 15. Proposed system SR motor speed waveform using Cascaded ANN controller.

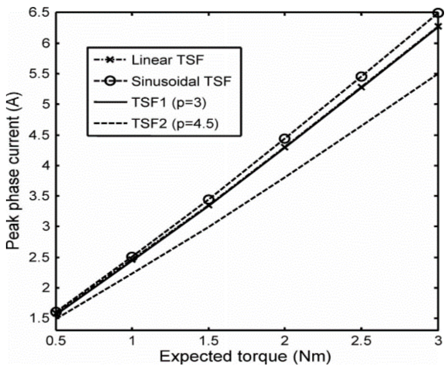


Fig. 16. Torque improvement.

7. Conclusions

Cascaded ANN is used in this study to enhance the performance in terms of current, torque and speed. The simulation results demonstrated the practicality of the devised strategy to reducing torque ripple, particularly in the low-speed area. Nevertheless, SRM runs at high speeds, the phase current's rate of change limits any torque-ripple improvement. In other words, an enhanced model of cascaded ANN-based SRM considerably lowers torque ripples, resulting in increased performance. As a consequence, simulation results demonstrate the validity and usefulness of an upgraded SRM model, as well as the Cascaded ANN algorithm's capacity to reduce torque ripples. Controlling high-speed applications is possible (stopped and loaded). High-speed motors benefit from a high-power density, which is an essential feature of traction motors in ship propulsion. Furthermore, CANN outperforms SRM due to its quick convergence, robustness, stability, and suitability for nonlinear situations. In addition, tare efforts which is made by this study is gravitating towards sustainability in engineering design and the eventual manufacturing process.

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