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Loss minimization DTC electric motor drive system based on adaptive ANN strategy

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ABSTRACT

Electric motor drive systems (EMDS) have been recognized as one of the most promising motor systems recently due to their low energy consumption and reduced emissions. With only some exceptions, EMDS are the main source for the provision of mechanical energy in industry and accounts for about 60% of global industrial electricity consumption. Large energy efficiency potentials have been identified in EMDS with very short payback time and high-cost effectiveness. Typical, during operation at rated mode, the motor drive able to hold its good efficiencies. However, a motor usually operates out from rated mode in many applications, especially while under light load, it reduced the motor's efficiency severely. Hence, it is necessary that a conventional drive system to embed with loss minimization strategy to optimize the drive system efficiency over all operation range. Conventionally, the flux value is keeping constantly over the range of operation, where it should be highlighted that for any operating point, the losses could be minimize with the proper adjustment of the flux level to a suitable value at that point. Hence, with the intention to generate an adaptive flux level corresponding to any operating point, especially at light load condition, an online learning Artificial Neural Network (ANN) controller was proposed in this study, to minimize the system losses. The entire proposed strategic drive system would be verified under the MATLAB/Simulink software environment. It is expected that with the proposed online learning Artificial Neural Network controller efficiency optimization algorithm can achieve better energy saving compared with traditional blended strategies.

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1. INTRODUCTION

In an effort moving towards new era of mechanization, realization of more precision and accuracy work can be attain by replaced the human with machines [1]. Electric drives have been getting popular and deployed in various of application which involved motion. In drive systems, a prime mover are necessary in order to generate energy that is used to create motion. This highlights in an enormous energy saving potential by energy-efficient electrical drive solutions [2]. This energy gain from different sources such as diesel and petrol engines, hydraulic motors and electric motors etc. Drives in which electric motors are the prime movers are known as electrical drives [1]. Plenty of advantages are reported by implement electric drives, such as nimble control, less maintainance, high efficiency, extensive limits of power, speed and torque, low noise, and neat operation.

A total of 65-70% total electricity supply to industry is consumed by the electric motor globally. It is expected to have a considerable amount of saving in energy price and reduction in coal consumption and greenhouse emission by having only 1% achievement in increasing electric motor efficiency. With the completeness implementation of the proper efficiency optimization technique, it is expected to have 7% lower electricity deman in globe, reported by various international agencies of developing countries [3, 4]. Operating of motor in unrated condition, especially partial loading for an extended time is the main reasons resulting in low energy efficiency in electric drive system, as compared to others factors. As make know in electric power research institute (EPRI), most of the period of time, 60- 65% of electric motor operates in industry are 60% below the rated load. That is, under rated condition, 35-40% of the motors is endlessly wasting the electricity due to the poor efficiency [5, 6], and seems to be focused as wide area for energy-saving and energy-efficient concept [7]. As per report in a Malaysia commercial building, it is close to 50% of electricity consumed in HVAC application, the induction motors are normally operated in unrated condition for a prolonged time [1]. Hence, an energy efficient control strategy are needed to ensure the maximum generated energy can be consumed[8-10].In order to fulfil the efficiency enhancement, some studies proposed high-quality materials, design and construction techniques [10]. Nevertheless, there is other valued solution, namely expert control algorithm which able to apply directly to a drive system [11].

In most cases, the electric motor are design and develop to run at 50-100% of rated load [5], which in turn hold a maximum efficiency when operating near to rated condition [12]. However, one efficiency is badly reduced [13, 14] due to over-excitation [8] while at partial load, which results in excessive in iron losses. Therefore, an energy efficient optimal control, a strategy that work for adjusting the flux level according to load changes to achieve maximum efficiency is required [5].which is also refer as efficiency optimization control.

Numerous of strategis has been reported to optimize efficiency for EMDS particularly at light load. Generally, the real-time optimization control technique of EMDS efficiency cab be assort as (1) Search Control (SC), and (2) Loss-Model-Based Control (LMC). The principal ideology for these methods is to alternate the amplitude of the flux with varies of motor operating condition although these two controls have different execution [15-17]. In SC, IM's power input or DC link power will be used in the optimization process. It manipulates the control input irrespective of motor parameter to minimize the input power from the measured current and voltage. This method worked on the basic to alternate the flux level in the drive system until the minimum power input is achieved for one point of operation [18-19]. The malpractice of this approach is that it denote a rather long response time and a slow convergence to the optimal value. In addition, the capability of SC is muchly depends on the input power quality. On the other hand, Loss model controller, LMC works depend on the motor parameter. It used the IM drive losses model to determine the optimum flux level which minimize the losses of the drive system for a given load and speed. This methods is free from power measurements but it utilize feedback [16, 20-21], yet, the LMC performance is greatly depends on motor drive modelling and it's losses. Development of LMC exist a trade-off between system complexity and accuracy [15, 22-24].

Therefore, the aim for this study is to designing a robust efficiency optimization control to predict the minimum flux value, at any operating point over the entire selected drive system speed range that able to maximize the drive's efficiency and maintain the system performance at the same time.

2. CHARACTERIZATION OF MAXIMUM ENERGY EFFICIENCY ACHIEVEMENT

Virtually, EM shows best transient response and impose high efficiency when operate at its rated torque and speed. However, EM works far from its rated condition in most of the application, especially at minimum load levels, which the initial value of the reference flux is kept, where it give rise to some problems in the drive systems. Owing to the imbalance between copper and iron losses at light loads, rated flux operation causes large core lose, thus reducing the efficiency of the drive [25, 26]. At a certain operating point, the efficiency of the EM can be improved by reducing to a minimum loss and decreasing the level of the magnetic flux appropriately or by balancing the copper and iron losses through programming the flux. As it is known, the losses of an electromagnetic in a machine are a direct function of the magnetic flux, therefrom, with an appropriate flux level calibration, the proportionate balance of losses between the copper and iron could be obtained. Hence, the air gap flux must be minimize to enhance the motor efficiency.

From the basic of the motor's torque is formed by the torque producing rotor current and magnetizing current, it is workable with different combination of current and flux value to gain the same torque value. Ordinarily, the EM is designed to operate close to the rated load, however, there is an optimum flux value where the drive's maximum efficiency can be achieved for any operating speed and load condition. In a simple way, less efficient occurrences at low load conditions happens because of the unsuitability of the flux level selection and it could be improved in a way of calibrating based on the ANN based efficienc optimization control strategy

3. DEVELOPMENT OF PROPOSED ANN BASED EFFICIENCY OPTIMIZATION CONTROL STRATEGY

On the basic of the flux reduction, at a certain load, full efficiency can be obtained with the correct flux level adjustment to get an optimum flux value. Therefore, the first step for this study is to characterise the efficiency behaviour pattern for any possible operating mode in EMDS to obtain its respective optimum flux values that enable the maximum efficiency in the drive system. In this study, the energy efficiency optimization controller is proposed and designed based on the flux reduction concept by the implementation of Artificial Neural Network (ANN) [22-23]. The maximum efficiency of EMDS can be achieved when the minimum input power is obtained with the constant output power required by the load. This proposed approach is based on varying the flux up to the point where the measuring input power is a minimum of one point of operation. The adaptive optimum flux value is predicted by the proposed efficiency optimization ANN based efficiency optimization controller algorithm for any different operation mode, ie, various speed and various load to obtain its optimum flux value corresponding to different cases as shown in Figure 1. The prediction of the flux value can be achieved due to the possession of the online learning ability in the proposed algorithm. The difference between the calculated input and the real input power is fed as input for the neural. [26-28]

The proposed ANN based energy efficiency optimization of DTC EMDS, as shown in Figure 1, where it is targeted to maintain the fast dynamic characteristics and better response, and also aimed in getting minimum losses especially for the light load and light speed drive's operation.

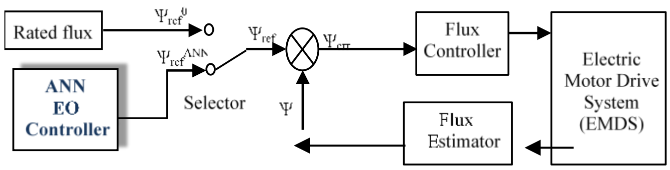


Figure 1. Block Diagram of the proposed ANN based energy efficiency optimization control EMDS.

4. RESULTS AND ANALYSIS

The proposed ANN efficiency optimization controller is shown in Figure 2. The error of input power is used as input for the proposed controller while the output of it implemented as the optimum flux reference.

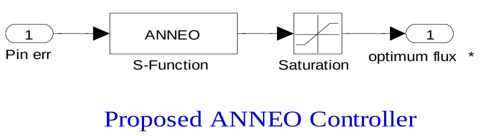
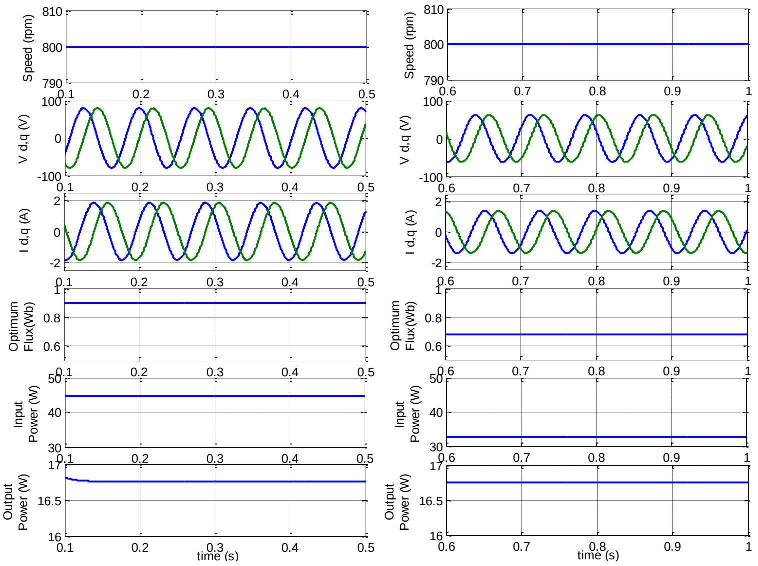


Figure 2. Simulink circuit for the proposed ANN efficiency optimization controller.

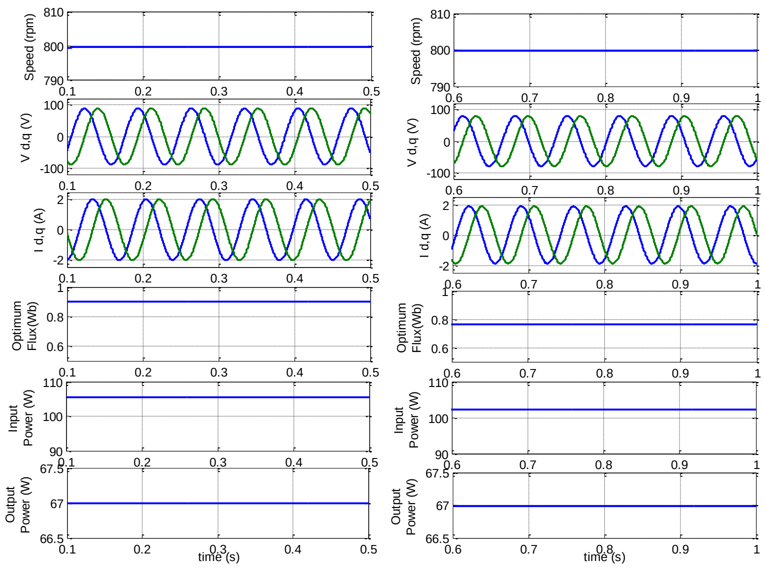
In order to verify the effectiveness of the proposed ANN efficiency optimization controller for the DTC electric drive system, the investigations of the drive system have been carried out for different values of speed and torque. The effects of speed and torque variation on the system's efficiency as well as the capability of the drive system to maintain the good speed response achievement for variety speed and torque are tested.

The selection time is set at time = 0.5s to activate the proposed ANN efficiency optimization controller to compare the efficiency performance before and after the proposed controller is injected into the system. The simulation results of motor speed of 1100 and 800rpm tested with maximum and minimum torques applied, which are 0.2 and 0.8Nm respectively are given in Figure 3- 6. The system response shown in Figure 3 -6, from top to bottom, represent the motor speed (rpm), the d-q axis voltage (V), the d-q axis current (A), optimal flux (Wb), and lastly the drive input power (W).



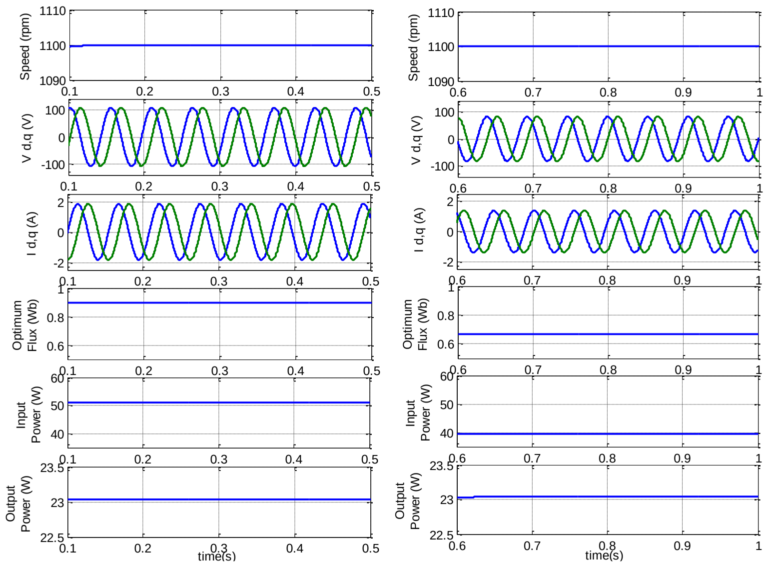
(a) (b)

Figure 3. Drive system performance where the proposed ANN efficiency optimization controller is initiated at the time =0.5*s* at the motor speed of 800*rpm* with an applied 0.2*Nm* load torque (a) before the ANN efficiency optimization controller is initiated; (b)after the ANN efficiency optimization controller is initiated.



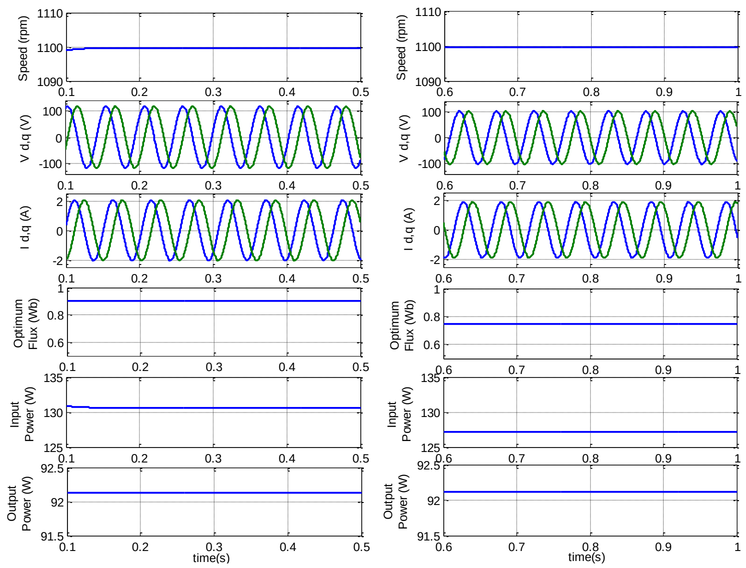
(a) (b)

Figure 4. Drive system performance where the proposed ANN efficiency optimization controller is initiated at the time =0.5s at the motor speed of 800*rpm* with an applied 0.8*Nm* load torque (a) before the ANN efficiency optimization controller is initiated; (b)after the ANN efficiency optimization controller is initiated.



(a) (b)

Figure 5. Drive system performance where the proposed ANN efficiency optimization controller is initiated at the time =0.5*s* at the motor speed of 1100*rpm* with an applied 0.2*Nm* load torque (a) before the ANN efficiency optimization controller is initiated; (b)after the ANN efficiency optimization controller is initiated.



(a) (b)

Figure 6. Drive system performance where the proposed ANN efficiency optimization controller is initiated at the time =0.5*s* at the motor speed of 1100*rpm* with an applied 0.8*Nm* load torque (a) before the ANN efficiency optimization controller is initiated; (b)after the ANN efficiency optimization controller is initiated.

The ANN efficiency optimization controller is aimed to produce an adaptive optimum flux value with respect to different speed under various torque level to gain the maximum drive efficiency, especially at light speed and light load operations. The resulting adaptive flux level generated from the ANN efficiency optimization for each tested operating condition is shown in Table 1, instead of a 0.9Nm constant reference flux.

Table 1. Resulting flux level obtained by the proposed adaptive ANNEO for various operating condition.

Torque (Nm)	0.2	0.8
Speed (rpm)	Optimum Flux Level	
1100	0.6697	0.7468
800	0.6753	0.7636

5. CONCLUSION

This paper presents a strategy to optimise the efficiency for DTC Electric Motor Drive System. An ANN based energy efficiency optimization controller with the objective of generating an adaptive flux level to optimize the efficiency of different operating points has been proposed in this study. The proposed optimum flux controller is able to decrease stator flux rapidly from rated value of 0.9Wb to its corresponding optimal value. Therefore, current and voltage will be reduced and thus minimizes the input power to achieve maximum efficiency of the drive system. At the same time, it is able to preserve good dynamic response of the drive system by maintaining the speed in constant according to speed reference command for different operating conditions of speed and torque. As a result, a significant efficiency improvement has been achieved by the optimal flux level determined by the proposed ANN based energy efficiency optimization compared with the constantly rated flux value, the objective of the study has been achieved.

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