Improved Direct Torque Control for Induction MotorUsing Artificial Neural Network Controller

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Abstract:
This project proposes an efficient Neural Network (NN) based Direct Torque Control (DTC) approach for induction motors in electric vehicles. The proposed approach aims to enhance the performanceof DTC by reducing the torque and flux ripples while ensuring a high degree ofaccuracy in controlling the motor speed. The proposed system employs a three- phase inverter to control the motor and a neural network to predict the voltage vectors that are required to maintain the desired motor speed. A Proportional Integral (PI) controller is used to fine-tune the output of the neural network to compensate for any errors in the predicted voltage vectors. Simulation results show that the proposed approach achieves a significant reduction in torque and flux ripples, resulting in smoother motor operation and higher energy efficiency. The system also exhibits a fast dynamic response, making it suitable for electric vehicle applications. The proposed system is implemented and evaluated using MATLAB/SIMULINK software. The proposed system outperformsconventional DTC techniques in terms of accuracy, stability and efficiency, making it a promising candidate for induction motor.

1. INTRODUCTION:

Field oriented control (FOC) and Direct torque control (DTC) schemes are widely applicable to control IM drive [1]- [4]. Both schemes allow torque and flux to be decoupled and controlled independently.In 1971, FOC was first proposed by F.Blaschke for induction motor control [5]. FOC makes control of IM similar to separately excited DC motor. The torque and flux both are independently controlled by transforming of 3- stator current into the flux and torque producing components [6]. Precise estimation of motor parameters is required in FOC. Direct version (DFOC) and indirect version (IFOC) are the twoways FOC can be implemented [7]. The technique was being developed from a longtime and has become mature from the industrial point of view. After thirteen years I. Takahashi developed and presented a newway to control torque as DTC [8]-[10], andas direct self-control (DSC) [11]-[13] by M.Depenbrock. The path of the flux vector control in DSC is the only difference against the DTC. DTC is having quasi-circular path, whereas DSC is having hexagonal which increases switchingfrequency of DTC as compared to DSC.

DTC abandons stator current control philosophy. Torque and flux control are achieved by directly modifying the stator voltage in accordance by torque and flux errors [14]. The advantage of DTC over FOC is that it does not require any current controller or pulse width modulation (PWM) generator. It is simple to implement and provides better torque control in steady state and transient operation. It doesn’t require any coordinate transformation and this controller is less sensible to parameter detuning. DTC has still some challenges which needs to be addressed like high torque and current ripple, switching frequency is lower than sampling frequency and has variable switching behaviour, control of torque at very low speed is difficult, annoying noise is generated at lower speed and it also lacksdirect current control [4]-[9].

Various modified DTC schemes have been evolved to control the Induction Motor drive effectively. Improved switching tables without changing the original topology is given in [15]-[18]. Solutions implemented by Space Vector Modulation (SVM) techniques in [19]-[22]. Fuzzy logic and neural

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network-based solutions are implemented in [23]-[24]. A new switching table is presented in [25] to solve the electromagnetic compatibility issue and reduce the common mode emissions called DTC EMC (Electro-magnetically compatible). Variable structure control (VSC) is effective for nonlinear system with uncertainties. It is robust and has fast response control but exhibits chattering in controlled quantities. In [14], authors proposed control by improving performance of different variable structure schemes and compared them. By using Feed Back Linearization (FBL), nonlinear control can be linearized, and controller is designed for the linear system, to use it intothe control for the original system by using inverse transformation. FBL is sensitive to modelling error and disturbances. FBL is used in [26] for linearization of IM model. To solve the issues of uncertainties or modelling errors sliding mode control is introduced in [27]. It provides very good dynamic response for wide speed range of operation. FBL is integrated with SMC in [28].

This paper proposed modified DTC scheme for IM to suppress the ripple content in the flux and torque. Couplings between the components are the main contributors to produce ripple content. This paper proposes decoupling method with DTC scheme to decouple axis components to reduce the ripple of the flux and torque as well as to improve the dynamics & transient response of the induction motor. The ANN controller is used to control the torque and flux is controlled by derivative controller. The dynamic behaviour of Induction Motor Drive is improved by using the above mentioned.

2. RELATED WORK:

Zamora, J.I. SanMartín , F.J. Asensio, V. Aperribay J. GarcíaVillalobos. Proposes plug-in electric vehicles (PEV)

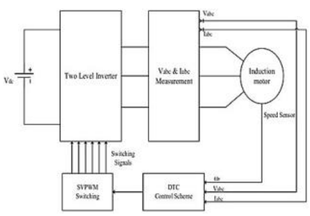
[1] are emerging as an efficient andsustainable alternative for private and public road transportation. From the point of view of electric grids, PEVs are currentlyconsidered as simple loads due to their low market penetration. However, as the PEVfleet grows, implementation of an intelligent management system will be necessary in order to avoid large capital expenditures in network reinforcements and negative effects on electric distribution networks, such as: voltage deviations, transformers and lines saturations, increase of electrical losses, etc. As a consequence, this topic has been researched in many papers where a wide range of solutions havebeen proposed. Finally, on the basis of thisreview, main findings and some recommendations are presented.

C. Chan, A. Bouscayrol and K. Chen. [2] proposes the advent of more stringent regulations related to emissions, fuel economy and global warming, as well as energy resource constraints, electric, hybrid and fuel-cell vehicles have attracted increasing attention from vehicle constructors, governments and consumers. Research and development efforts have focused on developing advanced powertrains and efficient energy systems. Although classic modelling approacheshave often been used, new systemic approaches that allow better understanding of the interaction between the numerous subsystems have recently been introduced.

In [3], various motors are comparedand concluded that for electric vehicles induction motors (IM) is consensual. Hence, for driveline topology, IM drive is considered one of the best options. However, designing of the electric vehicle drive for competing with IC engines is facing many challenges such as efficiency, lower maximum speed, efficient braking, and transient & dynamic responses under a sudden change in operating conditions. To mitigate/improve the aforesaid challenges, advanced and better control strategies are needed.

3. CONVENTIONAL DTCSCHEME:

DTC schemes can be controlled based on direct modification of stator voltage, torque and flux error. The output torque and stator fluxare estimated by the direct measurement ofvoltage and current.



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(Vabc), current (Iabc) and speed are measuredusing the measuring instruments. DTC control is used to control the torque and speed of the IM by generating control signals to the inverter, which is used by SVPWM switching block to generate switching signals.

A. Modelling of induction motor

The state equation of IM in stator frame of reference is

$\frac{d}{dt}\Psi_s = -\frac{1}{T_s\sigma}\Psi_s + \frac{L_m}{L_r T_s \sigma}\Psi_r +$ (1) u_s

$\frac{d}{dt}\Psi_r = \frac{L_m}{L_r T_s \sigma}\Psi_s - (\frac{1}{T_s\sigma} - j\ )$ (2) $\omega_r\ \Psi_r$

Where,

$\underline{\Psi}_s$	stator flux space vector
$\underline{\Psi}_r$	rotor flux space vector
u_s	stator voltage
L_s	stator inductances
L_r	rotor inductances
L_m	magnetizing inductances
R_s	stator resistance
R_r	rotor resistance
ω_r	rotor speed

$\sigma = 1 - L_m^2/L_sL_r,\ T_s = L_s/R_s,\ T_r = L_r/R_r,$

The electromagnetic torque is given by

Fig. 1. Block diagram conventional DTC

in Fig. 2, contains three main components: the torque and flux estimator, SVPWM switching signal generator and PI controller

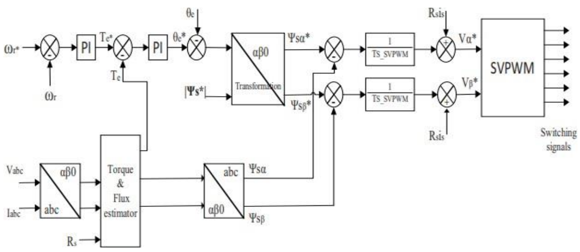

Fig.2. Basic scheme of conventional directtorque-controlled IM drive.

In order to estimate torque and flux voltage, current and stator resistance are considered as inputs, the estimated torque and flux are used further to calculate torque and flux errors respectively. An error influx component is estimated by using voltage, current direct and quadrature axes components and resistance (Rs).

$\Psi_{\alpha s} = \int(V_{\alpha ss} - i_{\alpha ss}R_s)dt + \Psi_{\alpha s0}$ (6) $\Psi_{\beta s} = \int(V_{\beta ss} - i_{\beta ss}R_s)dt + \Psi_{\beta s0}$ (7) The total stator flux (ψs) is calculated by

$\Psi_{\alpha s} = \sqrt{\Psi^2 + \Psi^2}$ (8)

$\alpha s\quad \beta s$

The developed torque is estimated using the direct andquadrature axis flux and current components speed, calculated by using reference speedn T 3 P (9)

$\alpha\quad L_rT_{s\sigma}$

and the measured speed of rotor, is passedthrough a PI to provide the reference torque. The PI torque regulator gives Error in flux is calculated using required flux and estimated flux. Required voltage is calculated by passing it through the differentiator. The SVPWM blockgenerates switching signals, such that flux and torque errors are minimized. The stator

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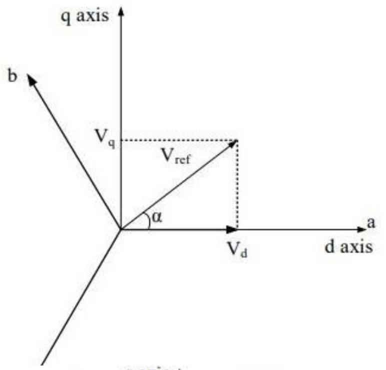
A. SVPWM-DTC Technique

In conventional DTC systems, the torque error and flux error are used to generate next switching condition of the VSI directly. However, this method uses two errors to produce stator reference voltage vectors, which are modulated by SVPWM technology. At last, a constant switching frequency signal is exported to the VSI. The DTC variable-speed system control principles will be introduced orderly as follows.

The six nonzero vectors form the axes of a hexagonal. The two zero vectors are at origin. The eight vectors are called the basic space vectors and are denoted by V0-V7. The six nonzero vectors divide equally the d-q plane into six sectors. The sectors are numbered by S1-S6 and the angle between two adjacent vectors is 60 degrees.

Step -2 Determine time duration T1, T2, T0

Step -3 Determine the switching time of each transistor (S1 to S6)



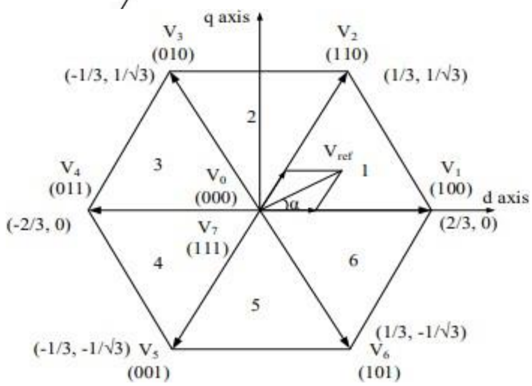


Fig.5 Determination of V_d, V_q, V_{ref}, and angle

The direct axis voltage V_d, quadrature axis voltage V_q, angle α and reference voltage V_{ref} can be determined using the voltage space vector and its components.

4. PROPOSED DTC SCHEME:

The proposed DTC is modification of the conventional one by using decoupling control to improve the transients anddynamic response of the IM under change in loading conditions.

Obtained the relation with output of the control scheme as can be written as:

$$u_{\alpha s}=\frac{\Psi_{\alpha r}}{2R}\left(V^{*}_{\alpha}-\frac{2L_m}{L_r T_s \sigma}R\right)-\Psi_{\beta s}\left(V^{*}_{\beta}+\omega_r R\right)(12)$$

Fig.4 Basic switching vectors and sectors

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u =Ψαr(V*- 2Lm R)-Ψαs(V*+ω R) (13)

Realization of Space Vector PWM:βs 2R R β r

Step -1 Determine Vd, Vq, Vref and angle Now, (12) & (13) are clearly showingthat the actual output is different against the conventional DTC scheme. This output is the decoupled version of the conventional DTC control. Therefore, the proposed DTCscheme includes additional decoupled block using (12) & (13) as shown in the Fig.6. Therefore, the system has reduced decoupling between the components andimproved overall performance of the IM drives.

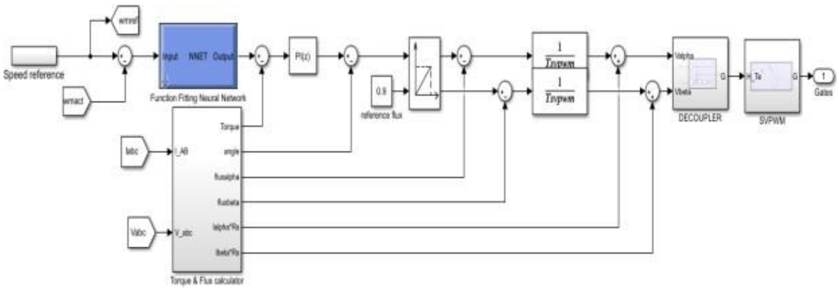

Fig. 6. Control scheme of ANN DTC of IM.

System Configuration using Neural Networks:

In artificial intelligence, a neural network refers to a computational model that is inspired by the structure and function of biological neural networks. These networks are composed of artificial neurons or nodes, which are interconnected through weighted connections. These weights are adjusted through a process called training, during which the network learns to perform a specific task, such as image recognition or language translation. Once trained, the network can be used to make predictions on new data by passing it through the network and producing an output. Biological neural networks, also known as neural circuits or neuronal networks, are composed of a group of neurons that are chemicallyconnected or functionally associated.

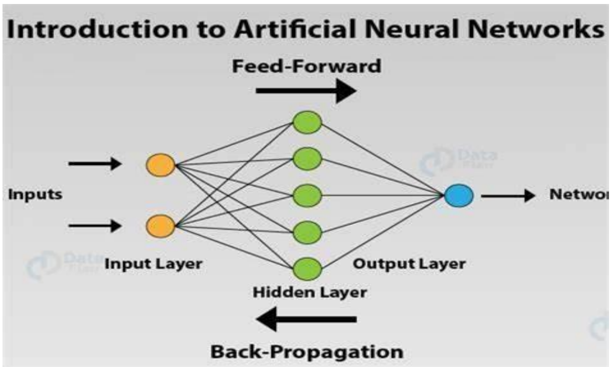

Fig. 7. Neural Network

A single neuron can receive input and send output to many other neurons, forming complex networks of interconnected neurons. These networks can be found throughout the nervoussystems of animals, including humans. Theconnections between neurons, also known as synapses, allow for the transmission of electrical and chemical signals between neurons, enabling neural circuits to process information and generate behaviour. Neural networks are essential for many functions of the nervous system, including sensory processing, motor control, learning, and memory

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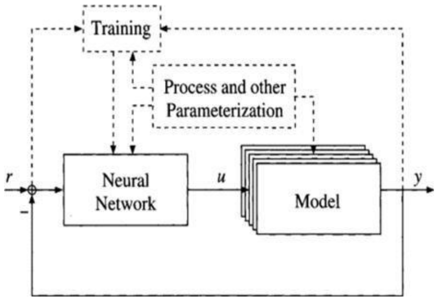

Fig. 8. Block Diagram of Neural Network The working of a neural network controller is correct. The input layer

receives sensory inputs, hidden layers process the inputs and extract relevant features, and the output layer produces the control signal based on the processed inputs. The neural network controller is trained on a dataset of input-output pairs, and the weights and biases of the neurons in the network are adjusted to minimize the error between the predicted output and the actual output. Once trained, the neural network controller can make accurate predictions and produce appropriate controlsignals in real-time based on the current inputs.

conventional control scheme. The system & IM parameters are presented in TABLE 1 as used in simulation.

TABLE 1: System & IM Parameters

Parameter	**Value**
R_s	1.405 Ω
R_r	1.395 Ω
L_s	0.00589 H
L_r	0.00589 H
L_m	0.1722 H
Inertia (J)	0.0131 kg.m^2
Pole pairs (P)	2
Rated speed (ωr)	1200 rpm
Rated power (P)	4000 W
Voltage (V)	400 V (L-L)
Frequency	50 Hz

The advantages of neural network controllers over traditional controllers, which include non-linearity, adaptability, fault tolerance, and generalization. Neural network controllers can handle non-linear systems, adapt to changing conditions and environments, tolerate faults and failures, and generalize well to new situations. These advantages make neural network controllers a powerful tool for controlling complex systems.

5. SIMULATION RESULTS:

The 4 kW IM drive system is taken into consideration to implement theconventional and proposed DTC schemes. The system is simulated in MATLAB platform to analyse the improved

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behaviourof IM using proposed control scheme over

A. Results of Conventional DTC

The voltage waveform shows the poor dynamic response of the IM drives as it takes significant time to settle down to thesteady state value.

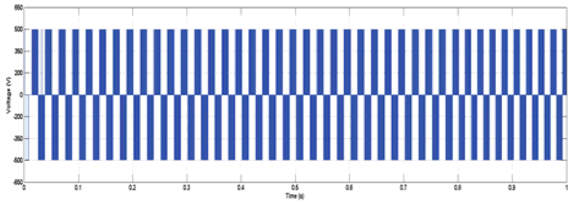

Fig. 9. Stator phase voltage withConventional DTC.

Similarly, which is sinusoidal due to the inductive nature of stator winding (behave as filter) and the current values are changing in proportional to the torque.

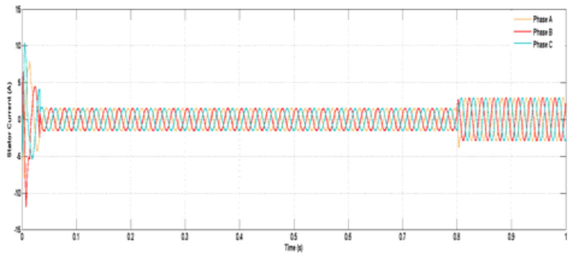

Fig. 10. Stator current with Results of the with conventional DTC.

Stator flux waveforms in a and β axis are shown in Fig. 11. The waveforms are in quadrature nature with respect to each other and sinusoidal. The stator flux of IM is maintained constant irrespective ofthe change in torque and speed.

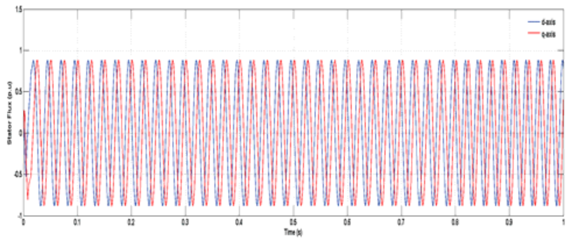

Fig. 11. Stator direct and quadrature axis flux with conventional DTC.

The reference speed is tracked by the actual speed of IM, can be seen clearly in the figure. This shows the effective

performance of the DTC scheme.

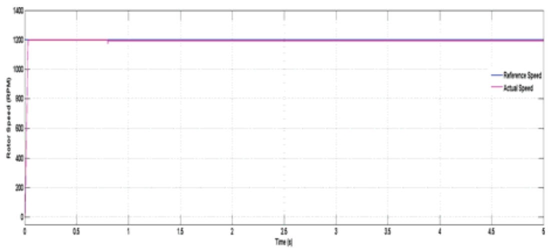

Fig. 12 shows the actual and reference speed of the IM.

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Similarly, actual and reference torquewaveforms are shown in Fig. 13. The actualtorque follows the reference torque, but thedynamic response is poor. Also, the transient response needs to be corrected as the actual torque reaches up to 30 under starting condition of IM drive using conventional DTC.

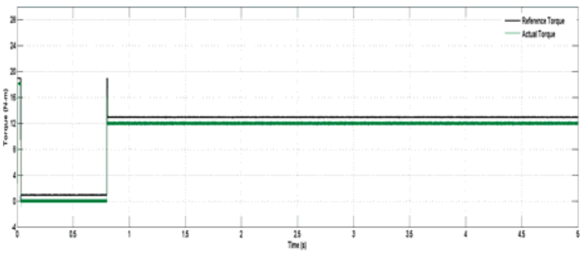

Fig. 13. Reference and measured torquewith conventional DTC.

B. Results of the Proposed Control Scheme

Fig. 14 shows the phase A invertervoltage waveform. The dynamic responseof the voltage waveform is better as compared to the conventional one.

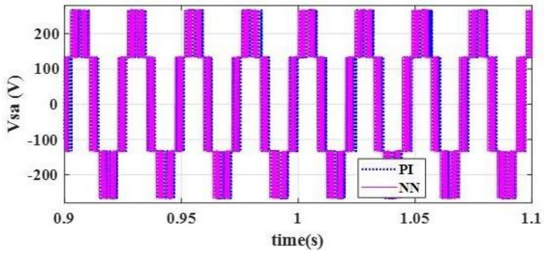

Fig. 14. Stator phase voltage with proposedDTC.

Similarly, stator current of IM is shownin Fig. 15. The current transient and dynamic response is better than conventional one as it takes much less timeto settle down at steady value.

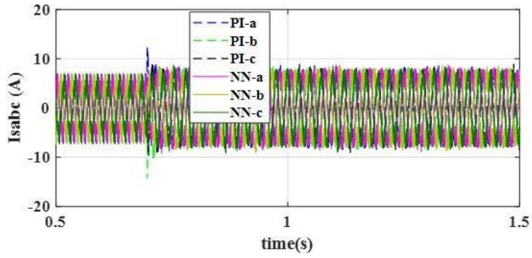

Fig. 15. Stator current with proposed DTC.

The stator flux of d and q-axis components are shown in Fig. 16. The flux is constant throughout the period justlike conventional DTC control.

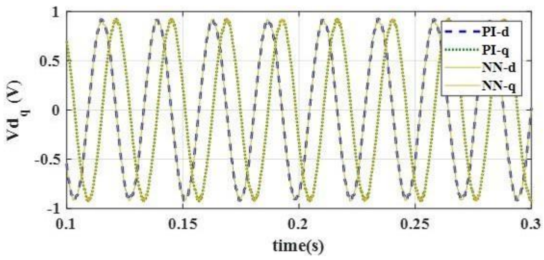

Fig. 16. Stator direct and quadrature axisflux with proposed DTC.

The reference and actual speed waveforms are shown in Fig. 17. This shows the better dynamic response of theIM drive as reference speed is tracked byactual speed only at 0.2s as compared conventional DTC which takes 0.4s.

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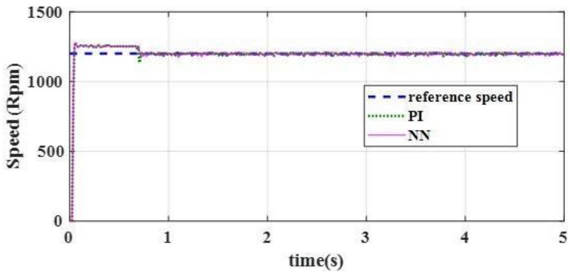

Fig. 17. Reference and measured speed withproposed DTC.

Similarly, the reference and actual torque waveforms are shown in Fig. 18. The transient and dynamic response of IM drive can be clearly seen from the waveform that actual torque hasreduced peak under transient conditions and tracked the reference value much earlier against the conventional DTC.

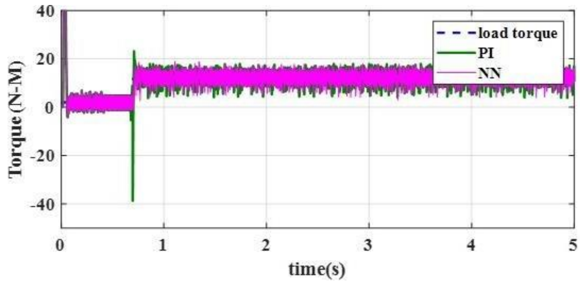

Fig. 18. Reference and measured torquewith proposed DTC.

6. CONCLUSION:

The Efficient Neural Network (NN) based Direct Torque Control (DTC) presents a promising approach to improve the performance and efficiency of IMs in EVs. This paper proposes a novel DTCstrategy based on NN model, which achieves accurate torque and speed control,reduced torque ripple and improveddynamic response. The implementation of the proposed system on MATLAB/SIMULINK software shows satisfactory results in terms of accuracy, efficiency and robustness. Overall, the above results demonstrate the potential of NN based DTC for IMs in EVs to enhance their performance and efficiency, thus contributing to the advancement of the EV industry towards a more sustainable future.

7. REFERENCES:

[1] [1] I. Zamora , J.I. SanMartín , F.J. Asensio, V. Aperribay J. GarcíaVillalobos, "Plug-in electric vehicles in electric distribution networks:A review of smart charging approaches", Renewable and Sustainable Energy Reviews, vol. 38, pp. 717–731, Oct. 2014.

[2] [2] C. Chan, A. Bouscayrol and K. Chen, “Electric, Hybrid, and Fuel- Cell Vehicles: Architectures and Modeling”, IEEE Transactions on Vehicular Technology , vol. 59, pp. 589-598, Oct. 2010.

[3] [3] Zeraoulia, M., Benbouzid, M.E.H., Diallo, D., “Electric motor drive selection issues for HEV propulsion systems: a comparativestudy”, IEEE Trans. Veh. Technol., vol. 55,pp. 1756–1764, 2006.

[4] [4] D. Casadei, F. Profumo, G. Serra, A. Tani, “FOC and DTC: two viable schemes for induction motors torque control”, IEEE Transactions on Power Electronics , vol. 17, Sep 2002.

[5] [5] F. Blaschke, “A new method for the structural decoupling of A.C. induction machines,” in Conf. Rec. IFAC, Duesseldorf, Germany, pp. 1–15, Oct.1971.

[6] [6] A. M. Trzynadlowski, Control of InductionMotors. Academic Press, San Diego, CA, 2001.

[7] [7] P. Vas, “Sensorless Vector and Direct Torque Control.” Oxford University Press,

 DOI: 10.36893.JK.2023.V13I04N16.00112-00122

ISSN: 2278-4632
Vol-13, Issue-04, No.06, April : 2023

Oxford, UK, 1998.

[8] [8] T. Noguchiand and I. Takahashi, "Quick torque response control of an induction motor based on a new concept" (inJapanese), IEEJ Tech. Meeting Rotating Mach., vol. RM84–76, pp. 61–70, Sept. 1984.

[9] [9] I. Takahashi and T. Noguchi, "A new quick-response and high- efficiency controlstrategy of an induction motor," IEEE Trans. Ind. Appl., vol. 22, no. 5, pp. 820–827, Sep./Oct. 1986.I.

[10] [10] Takahashi and Y. Ohmori, "High- performance direct torque control of an induction motor," IEEE Trans. Ind.Applicat., vol. 25, pp. 257– 264, Mar./Apr.1989.

[11] [11] M. Depenbrock, "Direkte selbstregelung (DSR) für hochdynamische drehfeldantriebe mit stromrichterspeisung"(in German), ETZ Archive, no. 7, pp. 211–218, 1985.

[12] [12] M. Depenbrock, "Direct self-control (DSC) of inverter-fed induction machine," IEEE Trans. Power Electron., vol. 3, pp. 420– 429, Oct. 1988.

[13] [13] U. Badder, M. Depenbrock and G. Gierse, "Direct self control (DSC) of inverter-fed induction machine: a basis for speed controlwithout speed measurement", IEEE Trans. on Industry Applications , Vol. 28, May/Jun1992.

[14] [14] C. Lascu and I. Boldea , "Variable- Structure Direct Torque Control— A Classof Fast and Robust Controllers for Induction Machine Drives" IEEE Trans. On Industrial Electronics, vol. 51, Aug 2004.

[15] [15] J.K. Kangand and S.K. Sul,"New direct torque control of induction motor for minimum torque ripple and constant switching frequency," IEEE Trans. Ind. Applicat., vol. 35, pp. 1076–1082,

[16] Sept./Oct. 1999.

[17] [16] P. Tiitinen, P. Pohkalainen, and J. Lalu, "The next generation motor control method: Direct torque control (DTC)," EPEJ., vol. 5, pp. 14– 18, Mar. 1995.

[18] [17] D. Casadei, G. Serra, and A. Tani, "Implementation of a direct torque control algorithm for induction motors based on discrete space vector modulation," IEEE Trans. Power Electron., vol. 15, pp. 769– 777, July 2000.

[19] [18] J. N. Nash, "Direct torque control, induction motor vector control without an encoder," IEEE Trans. Ind. Applicat., vol. 33, pp. 333– 341, Mar./Apr. 1997.

[20] [19] T. G. Habetler, F. Profumo, M. Pastorelli, and L. M. Tolbert, "Direct torque control of induction machines using space vector modulation," IEEE Trans. Ind. Applicat., vol. 28, pp. 1045–1053, Sept./Oct. 1992.

[21] [20] D. Casadei, G. Serra, and A. Tani, "Stator flux vector control for high performance induction motor drives using space vector modulation," Electromotion J., vol. 2, pp. 79–86, 1995.

[22] [21] B. H. Kenny and R. D. Lorenz, "Stator androtor flux based deadbeat direct torque control of induction machines," in Conf. Rec. IEEE-IAS Annu. Meeting, vol. 1, pp. 133–139, 2001.

[23] [22] C. Lascu, I. Boldea, and F. Blaabjerg, "A modified direct torque control for inductionmotor sensorless drive," IEEE Trans. Ind. Applicat., vol. 36, pp. 122–130, Jan./Feb. 2000.

[24] [23] S. A. Mir, S. Zinger, and M. E. Elbuluk, "Fuzzy controller for inverter fed inductionmachines," IEEE Trans. Ind. Applicat., vol.30, pp. 78– 84, Jan./Feb. 1994.

[25] [24] P. Z. Grabowski and F. Blaabjerg, "Direct torque neuro-fuzzy control of induction motor drive. DSP implementation," in Conf. Rec. IECON'98, Aachen, Germany, pp. 657–661, Aug.–Sept. 31–4, 1998.

[26] [25] M. Cirrincione, M. Pucci, G. Vitale and G. Cirrincione, "A new direct torque control strategy for the minimization of common- mode emissions", IEEE Trans. on Industry Applications, Vol. 42, pp. 504- 517, 2006

[27] [26] M. P. Kazmierkowski and D. L. Sobczuk, "High Performance Induction Motor

 DOI: 10.36893.JK.2023.V13I04N16.00112-00122

Control Via Feedback Linearization", IEEE International Symposium on Industrial Electronics, Vol. 2, pp. 633- 638, July 1995.

[28] [27] A. Sabanovic, D. B. Izosimov,"Application of Sliding Modes to InductionMotor Control", IEEE Transactions on Industry Applications , Vol. IA-17, Jan.1981.

[29] [28] C. Lascu, S. Jafarzadeh, "Direct Torque Control With Feedback Linearization for Induction Motor Drives", IEEE Trans. Power Electronics, Vol. 32, Mar. 2017.

[30] [29] R. Sharma, S. Suhag, "Novel control strategy for hybrid renewable energy-based standalone system", Turk. J. Elec. Eng. & Comp. Sci.., Vol. 25, pp. 2261-2277, 2017.