PI controller.

Figures 10 and 11 shows the output current and voltage from the boost, these quantities ensure the power supply to the vehicle after the conversion of the DC bus through the inverter to supply the induction motor controlled by the ANNDTC.

Figures 12, illustrate stator current of IM, oscillations appear at each period corresponding to changes in vehicle speeds. The Figure 13 shows the stator flux, at the beginning of the operation the amplitude of the flux vector increases.

Then, the amplitude remains constant and equal to its reference value with a low ripple, thus revealing a correct regulation of the flux decoupled from that of the torque during the transient regimes.

The control strategy with the ANN let the dc bus voltage and the current always maintained constant with high performance compared with the PI controller.

From these results, it can be said that the training system meets the shifting requirements at different levels.

5. CONCLUSIONS

This work presented a detailed dynamic model of an EV that is associated with a DTC control use the ANN strategy for an induction motor drive.

The design method for Direct Torque Control of induction motor using Artificial Neural Network Controller replacing the PI regulator block have been successfully developed and implanted in MATLAB-Simulink environment. The performance of the speed motor electromagnetic torque behavior of the motor model using Neural Network Controller replacing both PI controller of Conventional DTC of IM have been evaluated and compared to use in electric vehicle drives. The results of simulation show that the proposed ANN for DTC provides better performance than that of conventional DTC technique use the PI regulator. The Proposed regulator based DTC significantly and easily tracks the reference speed and torques thereby improves the efficiency of speed-torque of induction motors with faster responses for fast changing of speed reference and torque as that of Electric Vehicles in any uneven roads conditions. The proposed ANN models are also simple and can be implemented easily with DSP or Dspace platform.

REFERENCES

[1] Ghosh D, Willich C. (2018). Development of a novel AC hybrid concept for a fuel cell-battery hybrid electric aircraft with power electronics switches. 2018 14th Int Conference on Power Electronics (CIEP): IEEE, pp. 105-110. https://doi.org/10.1109/CIEP.2018.8573370

[2] Kimiabeigi M, Widmer J, Long R, Gao Y. (2016). High-performance low-cost electric motor for electric vehicles using ferrite magnets. IEEE Transactions on Industrial Electronics 63(1): 113-22. https://doi.org/10.1109/TIE.2015.2472517

[3] Ehsani M, Gao Y, LongoandEbrahimi SK. (2018). Modern Electric, Hybrid Electric, and Fuel Cell Vehicles. CRC Press 572. https://doi.org/10.1201/9780429504884

[4] Ghezouani A, Gasbaoui BandGhouili J. (2018). Modeling and sliding mode DTC of an EV with four in-wheel induction motors drive. 2018 Int Conference on Electrical Sciences and Technologies in Maghreb (CISTEM)2018, pp. 1-9. https://doi.org/10.1109/CISTEM.2018.8613379

[5] Alloui H, Berkani A, Rezine H. (2010). A three level NPC inverter with neutral point voltage balancing for induction motors Direct Torque Control. The XIX International Conference on Electrical Machines-ICEM, pp. 1-6. https://doi.org/10.1109/ICELMACH.2010.5608161

[6] Nguyen TS, Song J, Yu L, Fang S, Yandlu TZ. (2018). Design and development of a real-time simulation and testing platform for a novel seamless two-speed transmission for electric vehicles1. Journal of Dynamic Systems, Measurement, and Control 141(2): 021007-12. https://doi.org/10.1115/1.4041358

[7] Oh Y, Park J, Lee J, MDandPark ES. (2014). Modeling effects of vehicle specifications on fuel economy based on engine fuel consumption map and vehicle dynamics. Transportation Research Part D: Transport and Environment 32: 287-302. https://doi.org/10.1016/j.trd.2014.08.014

[8] Aziz S, Wang H, Liu Y, JandFu PX. (2018). An approach to kinetic energy recovery system for electric vehicle considering SC and bi-directional converters. 2018 IEEE Innovative Smart Grid Technologies - Asia (ISGT Asia) 2018, pp. 1273-7. https://doi.org/10.1109/ISGT-Asia.2018.8467846

[9] Reddy KJ, Natarajan S. (2018). Energy sources and multi-input DC-DC converters used in hybrid electric vehicle applications–A review. International Journal of Hydrogen Energy 43(36): 17387-17408. https://doi.org/10.1016/j.ijhydene.2018.07.076

[10] Liu H, Zheng ZD, Li YD, Yao RD, Xu Z. (2018). Urban rail transit power system integrated with electric vehicles based on CLLC resonant and buck-boost converter. 2018 IEEE International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles & International Transportation Electrification Conference (ESARS-ITEC)2018, pp. 1-7. https://doi.org/1109/ESARS-ITEC.2018.8607797

[11] Amir A, Elkhateb A, Rahim NA, Che H. (2018). Transformerless high gain boost and buck-boost DC-DC converters based on extendable switched capacitor (SC) cell for stand-alone photovoltaic system. Solar Energy 171: 212-22. https://doi.org/10.1016/j.solener.2018.06.078

[12] Camara M, Fodorien D, Gualous H, Bouquain DandMiroui A. (2008). Hybrid sources control for electric drives traction applications. 19th IEEE Int Symposium on Power Electronics, Electrical Drives, Automation and Motion 2008, pp. 11-3. https://doi.org/10.1109/SPEEDHAM.2008.4581331

[13] Allirani S, Jagannathan AV. (2014). Direct torque control technique in induction motor drives-a review. Journal of Theoretical & Applied Information Technology 60(3).

[14] Gupta ANS. (2019). Direct torque control scheme of induction motor drive using space vector Modulation. Int J of Recent Advances in Science and Technology 6(1): 1-7

[15] Rubino S, Bojoi R, SA, Zanchetta PO. (2018). Model predictive direct flux vector control of multi-three-phase induction motor drives. IEEE Transactions on Industry Applications 54(5): 4394-404. https://doi.org/10.1109/TIA.2018.2829458

[16] Ali KM. (2018). Commande de vitesse de Dtc-Svm pour entraînement de moteur à induction à l'aide d'un contrôleur fuzzy PI à autotunisation ann anfis. J of Al-Qadisiyah For Engineering Science 11(3). https://doi.org/10.30772/qjes.v11i3.562
[17] Shaket A, Rathore PK, Jhala AK. (2018). A review analysis of artificial neural network controller-based wind power generation system. International Journal of Engineering, Management & Medical Research (IJEMMR) 4(3): 1-7.
[18] Khan H, SandBazaz MAH. (2015). Neural network modulation for a Direct Torque controlled Induction Motor Drive. 2015 IEEE Student Conference on Research and Development (SCOReD)2015, pp. 461-6. https://doi.org/10.1109/SCORED.2015.7449379
[19] Negadi K, Mansouri A, FandTouan MM. (2014). A MRAS based estimation method with artificial neural networks for high performance induction motor drives and its experimentation. International Review of Automatic Control (IREACO) 7(2): 123-30.
[20] Messaif I, Berkouk EM, Saadia N. (2010). Sensorless DTC of induction motor using improved neural network switching state selector controller. Archives of Control Sciences 20: 435–56. https://doi.org/10.2478/v10170-010-0025-4
[21] Babani L, Jadhav S, Chaudhari B. (2016). Scaled conjugate gradient based adaptive ANN control for SVM-DTC induction motor drive. IFIP International Conference on Artificial Intelligence Applications and Innovations: Springer, pp. 384-395. https://doi.org/10.1007/978-3-319-44944-9_33
[22] Venkateswara Rao VM, Chandra Sekhar G, Obulesh YP. (2018). Artificial neural network and adaptive neuro fuzzy control of direct torque control of induction motor for speed and torque ripple control. 2018 2nd International Conference on Trends in Electronics and Informatics (ICOEI)2018, pp. 1416-1422.

NOMENCLATURE

μ	dynamic viscosity, kg. $m^{-1}.s^{-1}$
AC	Alternating Current
A_f	frontal surface area of the vehicle, m^2
ANNC	Artificial Neural Network Control
C_w	aerodynamic drag coefficient,
d, q	Synchronous reference frame index
DC	Direct Current
DTC	Direct Torque Control
EVs	Electric Vehicles
F_{add}	Aerodynamic drag force
FC	Fuel Cell
F_{cr}	Climbing and downgrade resistance force
F_{ro}	Rolling resistance force, N
F_{sf}	Stokes or viscous friction force, N
F_w	Road load force, N
g	gravity acceleration, $m.s^2$
G	Gear speed ratio
i	Transmission ratio
I_{bat}	Battery Current
IM	Induction Motor
J	Total inertia (rotor and load), kg m^2
L (Lm)	Inductance (magnetizing inductance)
m	vehicle total mass, kg
p	pole-pair number
P_{bat}	Battery Power
PI	Proportional Integral Controllers
Pv	Vehicle driving power, W
PWM	Pulse-Width Modulation
r	tire radius, m
R	Resistance, Ω
ref	Reference
ref ,*	Reference index
Rpm	Revolutions per minute
S1, S2	Duty Ratio
SS	System Storage
T_B	Load torque accounting for friction
T_{em}	Electric motor torque
T_L	Load torque
T_r	Rotor time constant $(T_r = L_r/R_r)$
T_s	Stator time constant $(T_s = L_s/R_s)$
v	Vehicle speed, m/s
V (I)	Voltage (current), V(A)
V_{bat}	Battery Voltage
α	Road angle slope, rad
δ	Steering angle, rad
η_t	Transmission efficiency
ξ	air density, kg/m^3
σ	Leakage coefficient, $\sigma = 1 - L^2 m/L_s L_r$
φ	Flux of motor,Wb
ω_r	Electric motor mechanical speed, rad/s
ω_r^*	Reference Electric motor mechanical speed, rad/s

Appendix

Table 2. Induction motor parameters

Components	Rating values
Rated power	38 kW
Stator resistance	Rs=0.01965 Ω
Rotor resistance	Rr=0.01909 Ω
Stator/rotor inductance	Ls=Lr=0.0397 H
Mutual inductance	Lm=1.354 H
Moment of inertia	J=0.09526 Kg.m^2
Viscous friction	f=0.05479 N.m/rad/sec
Number of pole pairs	p=2