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Various control methods of permanent magnet synchronous motor drives in electric vehicle: a technical review

Marulasiddappa Hallikeri Basappa, Pushparajesh Viswanathan
Electrical and Electronics Engineering Department, Faculty of Engineering and Technology, JAIN - A Deemed to be University, Bengaluru, India

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ABSTRACT

Day by day use of internal combustion engines (ICE) compared to electric vehicles (EV) is deteriorating because mainly of pollution and their less fuel availability. In the present scenario, an electric vehicle plays a major role in place of an ICE vehicle. So that performance of EV can be improved by proper selection of electric motor. Initially, EV prefers induction motors for traction purposes, but complexity in controlling induction motor, permanent magnet synchronous motor (PMSM) presently used in EV by most of the electric vehicle manufacturers due to its advantages. This paper reviews on various control methods for PMSM used in EV. Various control methods are being used for EV applications. Initially, conventional direct torque control (DTC) technique being used in controlling electric motors but it has a drawback of high torque and flux ripples. Hence, intelligent controllers are predominantly using in controlling PMSM drives.

Corresponding Author:

Pushparajesh Viswanathan
Electrical and Electronics Engineering Department, Faculty of Engineering and Technology
JAIN - A Deemed to be University, Bengaluru, India
Email: v.pushparajesh@jainuniversity.ac.in

1. INTRODUCTION

In future days, there is a chance of depletion of petroleum products. Because the availability of petroleum products is only in particular areas of the world. For past years, we were using these petroleum products for running internal conbution (IC) engines. However, it produces harmful pollutants to the environment, which increases global warming. Hence, we should move towards the alternating source for a vehicle that replace the internal combustion engines (ICE) vehicle. Obviously, eclectic vehicles are the alternative source for the vehicle.

Pollution is not only parameter to be considered in designing electric vehicle but also very important is its driving performance [1]. So to improve the performance, choice of electric motor and corresponding technique adopted for controlling motor is also important [2]. The Figure 1 represents various parts of electric vehicles (EV).

Complete electric vehicle consists both electrical components and mechanical components. It consists of converter system, controller, electric motor, mechanical device and wheel drive. Controller, power converter and motor are electrical components of the entire EV system and rest are mechanical components. It also consists of battery system [1], [3]. Controller and electric motors are heart of the EV system. Hence, selection of electric motor plays an important role in EV system. Selecting motor should have more torque density, simple to control, more efficient and low cost.

Early day's direct current (DC) motor was better choice for electric vehicles because of their simpler control method and its characteristics are most preferable for EV motor. Presence of commutator and brushes makes the motor more complex for electric vehicle. To overcome this drawback of dc motor, induction motor plays a pivot role in EV applications [4]. Absence of commutator and brushes makes it simple in construction [5]. Analysis become complex due its non-linear characteristics [6], [7]. To overcome induction motor drawbacks permanent magnet synchronous motor (PMSM) finds development in EV applications. PMSM has higher current density and more efficient than induction motor. Hence it is very much suitable for EV applications. Comparison is done in Table 1 on electric motors with respect to different parameters.

It is better to choose particular motor for electric vehicle depend on its requirements. It is better to go with brushless dc motor for 2-wheelers. PMSM or Induction motors are good choice for four-wheeler vehicles. But when considering to efficiency and power density PMSM is better choice for electric vehicle. By employing modern control techniques, it is possible to control PMSM drive very efficiently. Section 2 explains modelling of PMSM drive. Section 3 describes the control techniques involved in controlling PMSM drives.

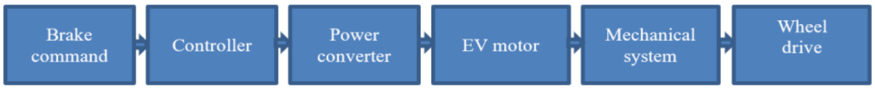

Figure 1. Various parts of EV system [2]

Table 1. Comparison of different motors for electric vehicle [8]

Parameter/motor	PMSM	SRM	IM	DC
Efficiency	High	Low	Low	Low
Power density	High	Low	Low	Low
controllability	Medium	Low	High	High
Reliability	Medium	High	High	Low

2. PMSM MATHEMATICAL MODELLING

PMSM modelling is explained by taking rotor as reference. The following [9], [10] are expressed for PMSM with respect to rotor reference.

$$\begin{bmatrix} v_{qs}^{r} \\ v_{ds}^{r} \end{bmatrix} = \begin{bmatrix} R_s + L_q p & \omega_r L_q \\ -\omega_r L_q & R_s + L_d p \end{bmatrix} \begin{bmatrix} i_{qs}^{r} \\ i_{ds}^{r} \end{bmatrix} + \begin{bmatrix} \omega_r \Psi_{af} \\ 0 \end{bmatrix} \quad (1)$$

$$\Psi_{af} = L_q \times i_{fr} \quad (2)$$

Where: superscript 'r' represents rotor reference frame, v_{ds}^{r} = d-axis voltage, i_{ds}^{r} = d-axis current, v_{qs}^{r} = q-axis voltage, i_{qs}^{r} = q-axis current p-is number of poles, Ψ_{af} = permanent magnet flux linkage, L_m= mutual inductance, L_d = d-axis inductance, L_q = q-axis inductance, R_s = stator resistance, and ω_r = rotor speed. The torque equation of a PMSM is given as:

$$T_e = \frac{3}{2} \times \frac{P}{2} (\Psi_{af} \times i_{qs}^{r} + (L_d - L_q) \times i_{qs}^{r} \times i_{ds}^{r} \quad (3)$$

The resultant flux linkage is:

$$\Psi_{res} = \sqrt{((\Psi_{af} + L_d \times i_{ds}^{r})2 + (L_d \times i_{qs}^{r} 2)} \quad (4)$$

In following section literature review is done on various control techniques available for PMSM drive.

3. CONTROL TECHNIQUES

For EV applications, controlling torque over wide range is necessary. Complexity in controlling PMSM drive is one of the drawbacks. Scalar and vector controls are the basic control methods for ac drives. Scalar control gives good steady state performance. To get high accurate and good dynamic performance vector control methods are used. Proportional integral (PI) controller is commonly applied controller rather than propotional integral derivative (PID) controller, but it leads to instability in the system. Major techniques like field-oriented control and direct torque control have their own advantages and disadvantages for controlling PMSM drive. Field oriented control (FOC) is used to improve steady state performance and to reduce the torque ripples. FOC improves the dynamic response [11], [12] and its performance can be increased. However, this method is sensitive to small changes in the parameter when temperature changes [13]. Takanashi and Noguchi [14] and Depenbrock [15] established a new technique called direct torque control

(DTC) in place of FOC drawbacks. DTC has a capability to control torque and flux directly by increasing efficiency of PSMS drive. Simplicity of DTC has its one of major advantage. The conventional DTC produces more torque and flux ripples and parameters like torque and flux are measurable efficiently [16]-[18]. The main limitation of DTC PMSM is high torque and flux ripple. It explains new technique called sliding mode controller (SMC) to increase the drive performance [19]-[22]. Chattering phenomenon is major drawback of SMC technique. A combination of two controller's namely fuzzy logic controller (FLC) and sliding mode controller are used to maximize the performance of the system [23], [24]. But the process of using hybrid technique is complex compared to individual technique. Viswanathan and Thathan [25] gives intelligent controllers are better compared to conventional controllers.

Liu *et al*. [26], and Sun *et al*. [27] explains fuzzy logic control based PMSM drive. Viswanathan and Thathan [28] DTC which is based on neural network controller for switched reluctance motor (SRM) to reduce torque ripples. Niu *et al.* [29] uses predefined switching table to minimize the torque and flux ripples by using online optimization method. Pushparajesh *et al.* [30] uses look up table-based vector control for switched reluctance motor to improve the torque response. Navardi *et al.* [31] combines conventional DTC and finite predictive control methods to improve performance of PMSM. Fu *et al.* [32] paper analyses the sliding mode controller in place of PI and traditional DTC to improve the stability of the system. But SMC algorithm has drawback of chattering phenomenon. Sharma, and Bhattacharva [33] explains model reference adaptive control (MRAC) for improving efficiency of PMSM using DTC method.

Vafaie *et al.* [34] proposes new predictive DTC method, where it improves both steady state and transient state responses of PMSM. Sekour *et al.* [35] paper proposes PI-fuzzy resistance estimator to remove the error caused by the change in the resistance which happen in low speed of DTC. Shakunthala *et al.* [36] explains how flux and torque ripples can be lowered in PMSM by using combination of PI and FLC. Rahideh *et al.* [37] improves performance of PMSM drive compared to conventional DTC by using genetic algorithm (GA)-FLC method. Here propotional intergral ontroller is also used and it is tuned using GA. Nicola *et al.* [38] explains new strategy called combination of PI and iterative learning control (PI-ILC) for repetitive task in control system. This control technique is used to reduce the speed signal ripples if this motor has repetitive tasks. Jlassi and Cardoso [39] explains model predictive torque (MPT) control for PMSM drives. It has high complexity in calculation process, which reduces the performance of the system, because complexity increases torque ripples. Nicola *et al.* [40] proposes multiple neural networks used to improve the performance of PMSM. Depending on estimated value of load torque corresponding ANN is selected. It increases the complexity of the network.

Cheng *et al.* [41] replaces PI controller and conventional DTC (CDTC) controller by model predictive controller (MPC) to get required voltage vector in order to reduce the ripples in the torque, still it suffers from varying switching frequency. It marginally decreases torque ripples compared to conventional MPC. Kakouche *et al.* [42] replaces combination of PI and DTC by two fuzzy controllers. It gives good performance compared to PI and DTC. As it uses two fuzzy sets, it increases the complexity of the system. This paper does not talk about maximum torque range, as it is applicable for EV. Li *et al.* [43] proposes new predictive control technique to reduce the cost function and to reduce the computational burden. Wu *et al.* [44] proposes DTC based on random zero vectors space vector pulse width modulation (SVPWM) to reduce torque ripples. But it has slow torque responses. Marulasiddappa, and Pushparajesh [45] reviews on different control algorithms for induction motor-based EV. The technique used Zhang *et al.* [46] gives slow torque response. This Table 2 compares four different controllers namely CDTC, SMC-DTC, MPC-DTC and Intelligent controllers. Torque ripples can be minimized by using intelligent controllers in PMSM drives. And also torque response is very high for intelligent controller in PMSM drives.

Table 2. Comparison among different controllers

Parameter/technique	CDTC	SMC-DTC	MPC-DTC	Intelligent controller
Torque ripples	H	M	L	VL
Torque response	H	H	H	VH

4. CONCLUSION

This review paper is done in over viewing the different control methods for PMSM drive, which are used in electric vehicle. Electric vehicles are used over wide range of torque and speed. It is observed that PMSM drive is more preferable than induction motor drive due to various advantages. Various control methods have been employed in controlling over wide range of torque for PMSM. It has been observed that conventional DTC produce more torque ripples compared to other control methods. Due to high ripples performance of PMSM drive will reduce. Hence in order to improve performance of PMSM intelligent controllers are introduced. Comparison is made for different electric motors used in EV. Advantages and drawbacks of each control algorithms are briefed. Control techniques are compared on various performance parameters.

REFERENCES

[1] M. Aktas, K. Awaili, M. Ehsani, and A. Arisoy, “Direct torque control versus indirect field-oriented control of induction motors for electric vehicle applications,”*Engineering Science and Technology, an International Journal*, vol. 23, no. 5, pp. 1134-1143, 2020, doi: 10.1016/j.jestch.2020.04.002.

[2] C. C. Chan, “The state of the art of electric and hybrid vehicles,” *Proceedings of the IEEE*, 2002, vol. 90, no. 2, pp. 247- 275. [Online]. Available: https://core.ac.uk/download/pdf/37883668.pdf

[3] C. Hu, Y. Gao, and A. Q. Huang, “Power management strategy of hybrid electric vehicles based on particle swarm optimization,” In *2015 IEEE Transportation Electrification Conference and Expo (ITEC)*, 2015, pp. 1-6, doi: 10.1109/ITEC.2015.7165795.

[4] B. Tabbache, A. Kheloui, and M. E. H. Benbouzid, “Design and control of the induction motor propulsion of an electric vehicle,” *2010 IEEE Vehicle Power and Propulsion Conference*, 2010, pp. 1-6, doi: 10.1109/VPPC.2010.5729102.

[5] K. L. Butler, M. Ehsani, and P. Kamath, “A Matlab-based modeling and simulation package for electric and hybrid electric vehicle design,” *IEEE Transactions on vehicular technology*, vol. 48, no. 6, pp. 1770-1778, 1999. [Online]. Available: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.476.2182&rep=rep1&type=pdf

[6] P. C. Sen, “Electric motor drives and control-past, present, and future,” *IEEE Transactions on Industrial Electronics*, vol. 37, no. 6, pp. 562-575, 1990, doi: 10.1109/41.103462.

[7] S. Gdaim, A. Mtibaa, and M. F. Mimouni, “Design and experimental implementation of DTC of an induction machine based on fuzzy logic control on FPGA,” *IEEE Transactions on Fuzzy Systems*, vol. 23, no. 3, pp. 644-655, 2015, doi: 10.1109/TFUZZ.2014.2321612.

[8] N. Hashemnia and B. Asaei, “Comparative study of using different electric motors in the electric vehicles,” *2008 18th International Conference on Electrical Machines*, 2008, pp. 1-5, doi: 10.1109/ICELMACH.2008.4800157.

[9] R. Krishnan, *Electrical motor drives: modelling, analysis, and control*, New Delhi: PHI Learning Pvt. Ltd. vol. 1, 2001. [Online]. Available: https://www.academia.edu/26714897/R_Krishnan_Electric_Motor_Drives_Modeling_Analysis_and_Control_2001_

[10] P. Pillay, and R. Krishnan, “Modeling, simulation, and analysis of permanent-magnet motor drives. I. The permanent-magnet synchronous motor drive,” *IEEE Transactions on industry applications*, vol. 25, no. 2, pp. 265-273, 1989, doi: 10.1109/28.25541.

[11] N. El Ouanjli, A. Derouich, A. El Ghzizal, A. Chebabhi, and M. Taoussi, “A comparative study between FOC and DTC control of the Doubly Fed Induction Motor (DFIM),” *2017 International Conference on Electrical and Information Technologies (ICEIT)*, 2017, pp. 1-6, doi: 10.1109/EITech.2017.8255302.

[12] F. Mehazzem, A. L. Nemmour, and A. Reama, “Real time implementation of backstepping-multiscalar control to induction motor fed by voltage source inverter,” *International Journal of Hydrogen Energy*, vol. 42, no. 28, pp. 17965-17975, 2017, doi: 10.1016/j.ijhydene.2017.05.035.

[13] D. W. Novotny, and T. A. Lipo, *Vector control and dynamics of AC* drives, Inggris: Clarendon Press Oxford, 1996

[14] I. Takahashi, and T. Noguchi, “A new quick-response and high-efficiency control strategy of an induction motor,” *IEEE Transactions on Industry applications*, vol. IA-22, no. 5, pp. 820-827,1986, doi: 10.1109/TIA.1986.4504799.

[15] M. Depenbrock, “Direct self control (DSC) of inverter-fed induction machine,” *IEEE Transactions on Power Electronics*, vol. 3, no. 4, pp. 420–429, 1988, doi: 10.1109/63.17963.

[16] C. M. F. S. Reza, M. D. Islam, and S. Mekhilef, “A review of reliable and energy efficient direct torque controlled induction motor drives,” *Renewable and Sustainable Energy Reviews*, vol. 37, pp. 919-932, 2014, doi: 10.1016/j.rser.2014.05.067.

[17] M. N. A. Kadir, S. Mekhilef, and H. W. Ping, “Direct torque control permanent magnet synchronous motor drive with asymmetrical multilevel inverter supply,” *2007 7th Internatonal Conference on Power Electronics*, 2007, pp. 1196-1201, doi: 10.1109/ICPE.2007.4692567.

[18] N. V. Naik, A. Panda, and S. P. Singh, “A three-level fuzzy-2 DTC of induction motor drive using SVPWM,” *IEEE Transactions on Industrial Electronics*, vol. 63, no. 3, pp. 1467-1479, 2016, doi: 10.1109/TIE.2015.2504551.

[19] A. Nasri, A. Hazzab, I. K Bousserhane, S. Hadjeri, and P. Sicard, “Two wheel speed robust sliding mode control for electric vehicle drive,” *Serbian journal of electrical engineering*, vol. 5, no. 2, pp. 199-216, 2008, doi: 10.2298/SJEE0802199A.

[20] S. Alagna, G. Cipriani, M. Corpora, V. Di Dio, and R. Miceli, “Sliding mode torque control of an induction motor for automotive application with sliding mode flux observer,” *2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA)*, 2016, pp. 1207-1212, doi: 10.1109/ICRERA.2016.7884525.

[21] A. Ltifi, M. Ghariani, and R. Neji, “Performance comparison of PI, SMC and PI-Sliding Mode Controller for EV,” *2014 15th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA)*, 2014, pp. 291-297, doi: 10.1109/STA.2014.7086731.

[22] A. Nasri, B. Gasbaoui, and B. M. Fayssal, “Sliding mode control for four wheels electric vehicle drive,” *Procedia Technology*, vol. 22, pp. 518-526, 2016, doi: 10.1016/j.protcy.2016.01.111.

[23] B. Allaoua and A. Laoufi, “A novel sliding mode fuzzy control based on SVM for electric vehicles propulsion system,” *Energy Procedia*, vol. 36, pp. 120-129, 2013, doi: 10.1016/j.egypro.2013.07.015.

[24] A. Nasri, A. Hazzab, I. K. Bousserhane, S. Hadjeri, and P. Sicard, “Fuzzy-sliding mode speed control for two wheels electric vehicle drive,” *Journal of Electrical Engineering & Technology*, vol. 4, no. 4, pp. 499-509, 2009, doi: 10.5370/JEET.2009.4.4.499.

[25] P. Viswanathan and M. Thathan, “Torque ripple minimization of direct torque controlled four phases witched reluctance motor using artificial intelligent controller,” *World Journal of Modelling and Simulation*, vol. 12, no. 3, pp. 163-174, 2016. [Online] Available: http://www.worldacademicunion.com/journal/1746-7233WJMS/wjmsvol12no03paper01.pdf

[26] J. Liu, P. Wu, H. Bai, and X. Huang, “Application of fuzzy control in direct torque control of permanent magnet synchronous motor,” *Fifth World Congress on Intelligent Control and (IEEE Cat. No.04EX788)*, 2004, vol. 5, pp. 4573-4576, doi: 10.1109/WCICA.2004.1342383.

[27] D. Sun, Y. He, and J. G. Zhu, “Fuzzy logic direct torque control for permanent magnet synchronous motors,” *Fifth World Congress on Intelligent Control and Automation (IEEE Cat. No.04EX788)*, 2004, vol. 5, pp. 4401-4405, doi: 10.1109/WCICA.2004.1342345.

[28] V. Pushparajesh and T. Manigandan, “Minimization of Torque Ripple in Direct Torque Controlled Switched Reluctance Drive Using Neural Network,” *Asian Journal of Research in Social Sciences and Humanities*, vol. 6, no. 8, pp. 65-80, 2016, doi: 10.5958/2249-7315.2016.00593.1.

[29] F. Niu, B. Wang, A. S. Babel, K. Li, and E. G. Strangas, “Comparative evaluation of direct torque control strategies for permanent magnet synchronous machines,” *IEEE Transactions on Power Electronics*, vol. 31, no. 2, pp. 1408-1424, 2016, doi: 10.1109/TPEL.2015.2421321.

[30] V. Pushparajesh, M. Balamurugan, and N. S. Ramaiah, “Artificial Neural Network Based Direct Torque Control of Four Phase Switched Reluctance Motor,” *Available at SSRN 3371369*, 2019, doi: 10.2139/ssrn.3371369.

[31] M. J. Navardi, J. Milimonfared, and H. A. Talebi, “Torque and flux ripples minimization of permanent magnet synchronous motor by a predictive-based hybrid direct torque control,” *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 6, no. 4, pp. 1662-1670, 2018, doi: 10.1109/JESTPE.2018.2834559.

[32] H. Fu, G. Tian, Y. Chen, and Q. Chen, “Sliding mode-based DTC-SVM control of permanent magnet synchronous motors for plug-in hybrid electric vehicles,” *2009 IEEE Vehicle Power and Propulsion Conference*, 2009, pp. 500-505, doi: 10.1109/VPPC.2009.5289807.

[33] T. Sharma, and A. Bhattacharva, “Sensorless Direct Torque Control of PMSM Drive for EV Application,” *2018 2nd International Conference on Power, Energy and Environment: Towards Smart Technology (ICEPE)*, 2018, pp. 1-6, doi: 10.1109/EPETSG.2018.8659157.

[34] M. H. Vafaie, B. M. Dehkordi, P. Moallem, and A. Kiyoumarsi, “Minimizing torque and flux ripples and improving dynamic response of PMSM using a voltage vector with optimal parameters,” *IEEE Transactions on industrial electronics*, vol. 63, no. 6, pp. 3876-3888, June 2016, doi: 10.1109/TIE.2015.2497251.

[35] M. Sekour, K. Hartani, A. Draou, and A. Allali, “Sensorless fuzzy direct torque control for high performance electric vehicle with four in-wheel motors,” *Journal of Electrical Engineering & Technology*, vol. 8, no. 3, pp. 530-543, 2013, doi: 10.5370/JEET.2013.8.3.530.

[36] S. Shakunthala, R. Kiranmayi, and P. N. Mandadi, “Investigation of PI and Fuzzy controllers for speed control of PMSM motor drive,” *2018 International Conference on Recent Trends in Electrical, Control and Communication (RTECC)*, 2018, pp. 133-136, doi: 10.1109/RTECC.2018.8625636.

[37] A. Rahideh, A. Rahideh, M. Karimi, A. Shakeri, and M. Azadi, “High performance direct torque control of a PMSM using fuzzy logic and genetic algorithm,” *2007 IEEE International Electric Machines & Drives Conference*, 2007, pp. 932-937, doi: 10.1109/IEMDC.2007.382799.

[38] M. Nicola, C. I. Nicola, and D. S. ȚIanu, “Sensorless Control of PMSM using DTC Strategy Based on PI-ILC Law and MRAS Observer,” *2020 International Conference on Development and Application Systems (DAS)*, 2020, pp. 38-43, doi: 10.1109/DAS49615.2020.9108974.

[39] I. Jlassi, and A. J. M. Cardoso, “Lookup-Table-Based Model Predictive Torque Control Without Weighting Factors for PMSM Drives,” *IECON 2019-45th Annual Conference of the IEEE Industrial Electronics Society*, 2019, pp. 1165-1170, doi: 10.1109/IECON.2019.8927151.

[40] M. Nicola, C. -I. Nicola, and M. Duţă, “Sensorless Control of PMSM using FOC Strategy Based on Multiple ANN and Load Torque Observer,” *2020 International Conference on Development and Application Systems (DAS)*, 2020, pp. 32-37, doi: 10.1109/DAS49615.2020.9108914.

[41] L. -J. Cheng, Z. -J. Zeng, L. -R. C. -Chien, M. -C. Tsai, K. V. Ling, and I. H. Wu, “Model Predictive Direct Torque Control of Permanent Magnet Synchronous Motor for Torque Ripple Reduction,”*2019 IEEE 4th International Future Energy Electronics Conference (IFEEC)*, 2019, pp. 1-6, doi: 10.1109/IFEEC47410.2019.9014681.

[42] K. Kakouche, W. Guendouz, T. Rekioua, S. Mezani, and T. Lubin, “Application of fuzzy controller to minimize torque and flux ripples of PMSM,” *2019 International Conference on Advanced Electrical Engineering (ICAEE)*, 2019, pp. 1-6, doi: 10.1109/ICAEE47123.2019.9015066.

[43] Y. Li, J. Ren, and Q. Yang, “Predictive control with variable amplitude of voltage vector of interior PMSM direct torque control system,” *2019 IEEE International Symposium on Predictive Control of Electrical Drives and Power Electronics (PRECEDE)*, 2019, pp. 1-6, doi: 10.1109/PRECEDE.2019.8753367.

[44] W. Wu, F. Xie, G. Li, K. Liang, C. Qiu, and H. Jiang, “Research on Direct Torque Control Based on RZVSVPWM of PMSM,” *2019 14th IEEE Conference on Industrial Electronics and Applications (ICIEA)*, 2019, pp. 2507-2511, doi: 10.1109/ICIEA.2019.8833809.

[45] H. B. Marulasiddappa and V. Pushparajesh, “Review on different control techniques for induction motor drive in electric vehicle,” *IOP Conference Series: Materials Science and Engineering*, 2021, vol. 1055, doi: 10.1088/1757-899X/1055/1/012142.

[46] C. Zhang, X. Wang, D. Wang, Q. Sun, and G. Ma, “Comparative Analysis of Electromagnetic Force Inverter Fed PMSM Drive Using Field Oriented Control (FOC) and Direct Torque Control (DTC)” *2019 22nd International Conference on Electrical Machines and Systems (ICEMS)*, 2019, pp. 1-4, doi: 10.1109/ICEMS.2019.8921693.

BIOGRAPHIES OF AUTHORS

Marulasiddappa Hallikeri Basappa is currently a research fellow at Jain University, Kanakpura, Karnataka, India. He received his B.E. in Electrical and Electronics Engineering in 2005, kuvempu university, Davanagere, Karnataka, India. And M-Tech degree in Power Electronics in 2011 from Visweswaraya Technological University, Belagavi, Karnataka, India. He worked as an assistant professor in various top engineering colleges of Karnataka, India. Total he has 15 years of teaching experience. Area of Interest Power Electronics and Drives, Electric Vehicle and Artificial Intelligence. He guided many under graduate students in these areas. He has published many papers in International journals and also in International conferences. And he received best paper award for international conference. He can be contacted at email: marul.bethur@gmail.com.

Pushparajesh Viswanathan has been serving as Associate Professor in the in the Department of Electrical and Electronics Engineering, School of Engineering and Technology, Jain Deemed to be University since 2017.He has completed his Ph.D from Anna University in Electrical Engioneeing specialised in Power Electronics and Special Electrical Drives. He has received the International Best Research Award for the year 2018-2019 instituted by SDF Internation, London, UK. Adding to his credit he also received national award like Best Academic Researcher, Outstanding faculty award, Best faculty award and Best Placement coordinator from various Research Organisation. He has published many papers in International and National journals with high Impact factor. He has received a fund from AICTE worth of Rs.6,60,000/- for Power Electronics laboratory in MODROB Scheme in the Academic Year 2012-2013. He can be contacted at email: v.pushparajesh@jainuniversity.ac.in.