Torque ripple reduction in brushless DC motor utilizing 120 degree conduction inverter is superior than vector control approach.

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ABSTRACT
Aim:The aim of this proposed work is to control torque ripples in a BLDC motor using a Novel 120 Degree conductioninverter compared with the Vector control method. **Materials and Methods**: A total number of 14 samples of torque values which are collected from various voltages and the efficiency and torque values were calculated to quantify the torque ripple control in a BLDC motor of their Novel 120 Degree Conduction Inverter and Vector control method. The G power is taken as 0.8. **Results:** Novel 120 Degree Conduction Inverter achieved the accuracy specifically 94.34% respectively compared to 90.70% of Vector Control method based on efficiency. The significant value obtained is 0.383 ($p>0.05$) which is statically insignificant. **Conclusion**: It is observed that the Novel 120 Degree conduction inverter performed significantly better than the vector control method in torque ripples control of the BLDC motor on the basis of efficiency.
Keywords: Novel 120 degree conduction Inverter, Vector control method, Efficiency, Torque Ripple reduction, Brushless dc motor, Hall effect sensor, Power electronics.

INTRODUCTION

The major objective of this research is to reduce torque ripple in Brushless DC motors (BLDC) via phase current commutation (Zhang, Zhang, and Wu 2016). The underlying occurrence of torque ripple formation is given in full, along with the relevant equations (Baby and George 2012). Torque ripple can be reduced by injecting more voltage at the moment of commutation, according to the findings. The quantity and duration of the excess voltage that must be injected in the Hall effect sensor and power electronics are determined using the obtained equations for phase currents (Iqbal and Moinuddin 2007). A Brushless DC Electric Motors (BLDCs) are electric motors that are powered by a DC voltage supply and are commutated electronically rather than with brushes, as in traditional DC motors. The idea of a BLDC motor is identical to a Brushed DC motor. A novel architecture is developed for supplying additional voltage during commutation and therefore reducing torque ripple during commutation. (Aghdam, Hosseini Aghdam, and Fathi 2006). The percentage torque ripple has decreased from 13.71 to 6.5 when the new scheme is used for the same input power. Permanent magnet poles are found on the rotor of a Brushless DC motor (BLDC). High efficiency, high power to torque ratio, low noise, superior operational characteristics, and torque ripple reduction are all benefits for BLDC motors. The converter powers a BLDC motor that regulates stator voltage and currents. Due to the BLDC motor's electrical commutation. Effective speed control is achievable, making BLDC motors operate much better than DC brush motors and AC motors (Sharoffa.M and Steffi 2013). The main applications of 120 degree conduction inverter converter is to modify an unregulated input-power supply and mostly used for USB on the go, point of load converters for PC's and laptops, Battery Chargers, QuadCopters, Solar Chargers, power audio amplifier, asymmetrical Half-Bridge converter for LED applications (Nagne et al. 2018).

More than 1000 articles were published in Google scholar, Elsevier springer and IEEE Xplore in recent years. The most cited article is (R. Kumar and Singh 2016). In power electronics.The Novel 120 degree conduction inverter and BLDC motor driving advantages and desirable qualities lead to the development of a simple, efficient, cost-effective, and dependable system (M and Sudhakaran 2020). Inverter with a 120-degree conduction angle that generates a positive output from a negative input voltage. It could be employed to change the voltage's direction. The converter offers short circuit safety and is suitable for power factor correction applications. With only one power processing stage, it delivers controlled output voltage. It's a method of controlling the unregulated power supply to circuits (Kamaraj, Ravishankar, and Jeevananthan 2021). Based on a novel 120 degree conduction inverter, a new way to minimize commutation torque ripple for BLDC motors in both low and high-speed operation has been developed (Hendershot and Miller 1994)). A new circuit topology with a converter and a dc-link voltage control circuit is presented to minimize the commutation torque ripple. The ideal DC link voltage for the innovative configuration is then determined (A.Kumar, Sharma, and Singh 2020) in order to have the incoming and outgoing phase currents vary simultaneously during commutation and successfully eliminate the commutation torque ripple.(Parakh et al. 2020; Pham et al. 2021; Perumal, Antony, and Muthuramalingam 2021; Sathiyamoorthi et al. 2021; Devarajan et al. 2021; Dhanraj and Rajeshkumar 2021; Uganya, Radhika, and Vijayaraj 2021; Tesfaye Jule et al. 2021; Nandhini, Ezhilarasan, and Rajeshkumar 2020; Kamath et al. 2020)

The majority of extant research is based on data obtained from certain ethnic groups and results in less accuracy(Murali, Panda, and Panda 2018). Many previous studies looked at how torque control in a BLDC motor is performed by a 120 degree conduction inverter and vector control method,by hall effect sensor. The aim of this research is to assess the effectiveness of the Novel 120 degree conduction inverter to control the torque ripples in BLDC compared with the vector control method based on efficiency.

MATERIALS AND METHODS

The research was performed in the Power electronics simulation lab, Department of

Electrical and Electronics Engineering, Saveetha School of Engineering, Saveetha Institute of Medical And Technical Sciences. This work involves two groups of torque values. Group 1 is Novel 120 degree conduction inverter and group 2 is a vector control method that has a sample size of 7 torque values in each group from the dataset and Gpower 0.8 considered for testing. Matlab R2021a software tool kit is used to write the code and to simulate (Garg et al. 2017). Using matlab the efficiency values have been calculated for the required algorithm and then results have been compared based on the efficiency.

The sample preparation of group 1 was done by collecting the different torque values in BLDC by varying the voltage of the 120 degree conduction inverter, here the parameters considered are voltage and torque.

Group 2 sample preparation was done by collecting the different torque values in BLDC by varying the voltage of the vector control method converter, here voltage and torque are the parameters considered.

Novel 120 Degree Conduction Inverter

The 120^0 mode is identical to the 180o mode in every way except the shutting time of each switch is shortened to 120 seconds. A three-phase star-connected radial flux machine is the motor under investigation. The rotor construction is made up of surface mounted permanent magnets, and the stator is made up of focused non-overlapping three phase winding. The back emf has a trapezoidal shape, while phase currents have a rectangular shape (Sharoffa.M and Steffi 2013). A three-pole inverter arrangement drives the motor. The switches (T1-T6) are switched by power electronics such that two out of three phases are excited at the same time, and the resulting flux rotates either forward or backward. The switching instants are determined by hall sensors located 120 degrees apart on the stator structure, which receive rotor position data. As indicated in Fig 1, the BLDC motor is coupled to a 120 degree inverter. The main focus of this research is on back emfs, phasecurrents, conducting switches and switching periods (SP), as well as torque ripple caused by phase current commutation. Current commutation needs a finite amount of time in the hall effect sensor due to the machine windings' finite inductance. Torque ripple is caused by the operation of freewheeling diodes, which creates variations in rising and falling periods of currents in windings. It has been discovered that by providing a changing input voltage at the time of commutation, the torque ripple caused by phase current commutation can be decreased. By using a two-level input voltage, the current research provides a unique architecture for reducing torque ripple. When the switch T5 is turned off and T1 is turned on, the current flowing through windings 'c' and 'b' is transferred to windings 'b' and 'a' in switching period I. The current running through winding 'c' decreases as the transition progresses, while the current flowing through winding 'a' increases. Since T5 is turned off, current flowing through winding 'c' finds its way through D6, i.e. current flows through both the paths "T4-D6-Rc-Lc-Lb-Rb" and "T1-Ra-La-Lb-Rb-T4-Vdc" as soon as it abandons the road "T5-Rc-Lc-Lb-Rb-T4-Vdc." The length for which current flows through both paths during a switching period of time is known as the freewheeling zone, while the rest is referred to as the build up region. Figure 1 shows the phase current waveforms in SP I, freewheeling region and build up region, and torque ripple reduction.

Vector Control method

To reduce torque ripple, an overlap commutation method is used, in which the outgoing or incoming phase commutation is delayed or advanced. These methods differentiate between the commutation and non-commutation processes (Kumari, Pandit, and Sherpa 2021) , resulting in control method complexity. The commutation torque ripple is decreased by adjusting the shoot-through vector and active vector duty cycles in the hall effect sensor, which is powered by a Z-source inverter supplied BLDC. The topology of a three-level NPC inverter with a pi controller. As shown in Figure 2, the vector control mechanism is linked to the BLDC motor. However, the complexity of the circuit hardware increased as a result of these solutions, and state switching chattering became an issue. Direct torque control approaches are also developed to reduce commutation torque ripple, and the magnitude of the phase current is predicted, which can increase torque performance while simultaneously reducing torque ripple. Three phase-on solutions to reduce torque ripple have been developed in addition to existing commutation torque ripple suppression methods under two-phase-on square current drive. The torque performance of a Brushless dc motor under square-wave and sine-wave drives was analyzed, and it was discovered that the torque speed characteristic is higher with the sinusoidal current control, especially when it reaches the base speed, and the torque ripple is smaller. It demonstrates that the harmonic components of torque in BLDC are primarily constituted of 4th and 6 times harmonics, and that eliminating these torque harmonics results in the best current waveform. This strategy, however, necessitates precise back EMF data, and the ideal solution of the optimization technique is often not attainable. The study provides a multivariate structure control approach for reducing commutation torque ripple, in which the 5th and 7th harmonic currents are employed to achieve MTPA and torque ripple suppression. Moreover, the regulatory system is complex and difficult to understand, resulting in a lack of immunity. The ideal current vector is determined from the equations of instantaneous electromagnetic torque in this study, which is a novel current vector control strategy for minimizing BLDC torque ripple. During the commutation period, phase currents are present. The back-EMF vector rotates along the trajectory of the regular hexagon when the BLDCM is powered by the ideal square current, and the current vector changes stepwise at six discrete places in a complicated frame.

A Google colab open source stage with a center i5, tenth era processor and 8GB RAM is utilized for proposed work.

Statistical Analysis

The statistical analysis is done by using SPSS tools and python tools for obtaining the speed values of the Novel 120 degree conduction inverter and vector control method. The statistical features such as mean, standard deviation and standard mean error are obtained for both the algorithms using the statistical tools. Independent t test has been carried out in research work. Voltages are independent variables and torque values are dependent variables. Analysis is done to compare the Novel 120 degree conduction inverter and vector control method performance in the torque control of the BLDC motor (Jahan et al. 2017).

RESULTS

The proposed Novel 120 degree conduction inverter has a high torque controlling in BLDCmotor drive at an accuracy of 94.34% and it is then compared with vector control technique with an accuracy of 90.7%.

Table 1 reflects the number of samples taken, the mean values and their precision, as well as the result of the Novel 120 degree conduction inverter approach and vector control method. Novel 120 degree conduction inverter technique is computationally efficient when the dataset is accurate for the torque in terms of efficiency and it cannot overlap. In this work it is observed that the Novel 120 degree conduction inverter technique will predict the accuracy of torque ripple control.

Table 2 Illustrates the standard deviation and significance difference of Novel 120 degree conduction inverter technique and vector control technique. Standard error mean for the Novel 120 degree inverter technique is 0.07419.And the vector control method is 0.05558. These were utilized to determine whether the method produces substantial results in spss.

Table 3 represents statistical analysis of independent sample tests for both sample groups. P value should be less than 0.05. Considered to be statistically significant and 95% confidence value is calculated. The significant value obtained is 0.383 ($p>0.05$) which is statically insignificant.

Figure 1 represents the simulation as a 120 degree conduction inverter and it is connected to the BLDC motor to know the torque ripples in the BLDC drive.

Figure 2 represents the simulation as a vector control method and it is connected to the BLDC motor to know the torque ripples in the BLDC drive.

Figure 3 displays about torque ripples in a BLDC motor by using a Novel 120 degree inverter.

Figure 4 displays about torque ripples in a BLDC motor by using a vector control method.

Figure 5 Comparison of 120 degree inverter and vector control method in terms of mean torque. The mean torque of the 120 degree inverter and vector control method and the standard deviation of the 120 degree inverter is slightly better than the vector control method. X Axis : 120 degree inverter vs vector control method. Y Axis : Mean torque of detection ± 1 SD.

DISCUSSION

Novel 120 degree conduction inverter technique has higher accuracy than vector control technique. The torque values of 120 degree conduction inverter is 94.34 % and for vector control method is 90.70 %.

The accuracy variations are investigated by varying the voltages. Initially, the 120 degree conduction inverter converter is utilised in the BLDC motor for torque control and power factor to give high accuracy of 95.88% (A. Kumar, Sharma, and Singh 2020). The goal of this step is to control torque in the BLDC motor drive for use with the 120 degree conduction inverter converter technique,by using the pi controller it changes to 94.84% (Chandan, Dwivedi, and Bose 2020)**.** This research represents the 120 degree conduction inverter technique which predicts the accuracy of the torque from the datasets with accuracy 96.88% (Kommula and Kota 2017) then the accuracy will be increased. According to the author, the 120 degree conduction inverter converter technique predicts the accuracy of the torque with 95.68% which is greater than the vector control technique and 120 degree conduction inverter technique.In this research 120 degree conduction inverter technique and vector control technique which are both torque controllers in BLDC motor drive were compared. According to the result, the 120 degree conduction inverter technique appears to be better with a 80.86% accuracy, (Raj, Gowtham Raj, and Rajesh Kumar 2017) compared to the pi controller method. These authors use a 120 degree conduction inverter technique of converter topology to improve the accuracy of it (Hosur 2019). According to the other method, the 120 degree conduction inverter technique gives less accuracy of 79.58% based on the different torque values (Sanjay and Raghavendra 2017) of Brushless dc motor.

The limitations of this work is that the BLDC motor is friction of brushes sliding along the rotating commutator segments causing power loss that is significant to low power motors. In future, the 120 degree inverter combined with the pi controller will perform a more efficient torque control of the BLDC motor and improve more efficiency.

CONCLUSION

Novel 120 degree technique for torque control in BLDC motor drive with an efficiency of 94.34% compared with vector control technique with an efficiency of 90.70%. From this work it is observed that torque control in a BLDC motor using Novel 120 degree conduction converter technique is significantly better than the vector control technique. The Independent T-test analysis reveals that the significance value is 0.383 ($p>0.05$) which is statistically insignificant.

DECLARATION

Conflict of Interest

No conflict of interest in this manuscript.

Author Contribution

Author KN was involved in data collection, data analysis and manuscript writing, and author BTG involved in conceptualization, data validation, and critical review of the manuscript.

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TABLES & FIGURES

Table 1. Statistical torque values of BLDC motor by using 120 degree conduction inverter and vector control method based on efficiency.

Sl.No	**EFFICIENCY (%)**	
	120 degree conduction inverter	**Vector control method**
1	94.56	90.21
2	94.21	90.23
3	94.72	90.43
4	94.43	90.56
5	94.32	90.25

6	94.62	90.52
7	94.71	90.27

Table 2. Group Statistical analysis of Novel 120 degree inverter and vector control method by taking each of 10 variables. Standard error mean for the Novel 120 degree inverter technique is .07419.And the vector control method is .05558. From this it is observed that the Novel 120 degree inverter technique performed better than the vector control method.

	Groups	No of Samples	Mean	Std.Deviation	Std.Error Mean
Efficiency	**120 DEGREE CONDUCTION INVERTER**	7	94.5100	.19630	.07419
	VECTOR CONTROL METHOD	7	90.3529	.14705	.05558

Table 3. Statistical analysis of independent sample tests for both sample groups. P value should be less than 0.05. Considered to be statistically significant and 95% confidence value is calculated. The significant value obtained is 0.383 (p>0.05) which is statically insignificant.

Independent Samples Test										
Levene's Test for Equality Variances						T-test for Equality of means		95% Confidence Interval of the 95% confidence interval of the Differnce		
		F	Sig	t	diff	Sig(2-tailed)	Mean Difference	Std Error Difference	Lower	Upper
Efficiency	Equal variances assumed	.819	.383	44.844	12	.000	4.15714	.0927	3.95516	4.35913
	Equal variances not assumed			44.844	11.121	.000	4.15714	.0927	3.95338	4.36091

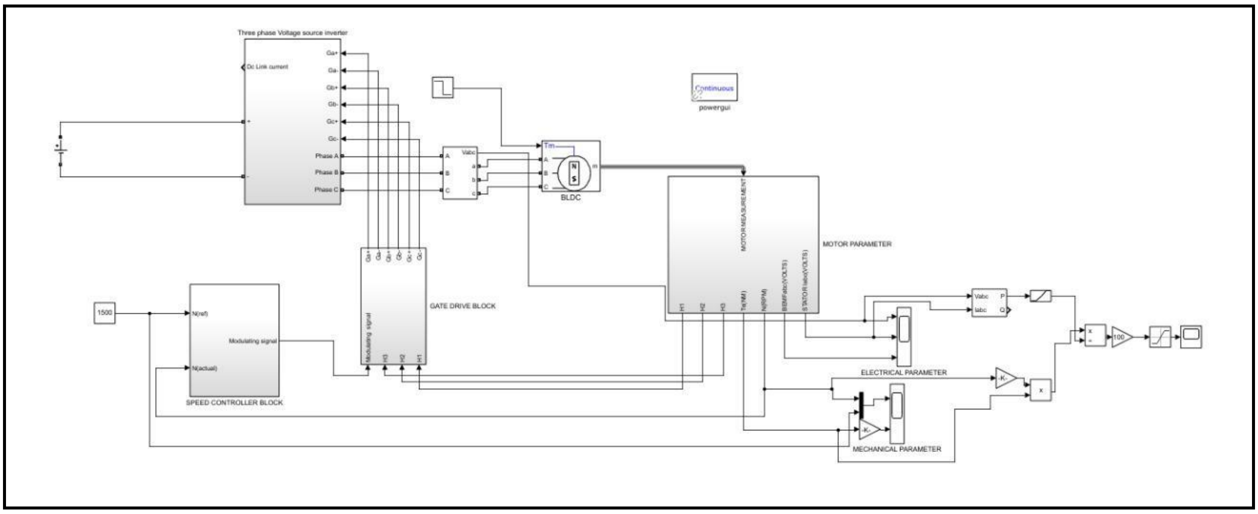

Fig. 1. The simulation diagram of a 120 degree conduction inverter and it is connected to the BLDC motor to know the torque ripples in the BLDC drive.

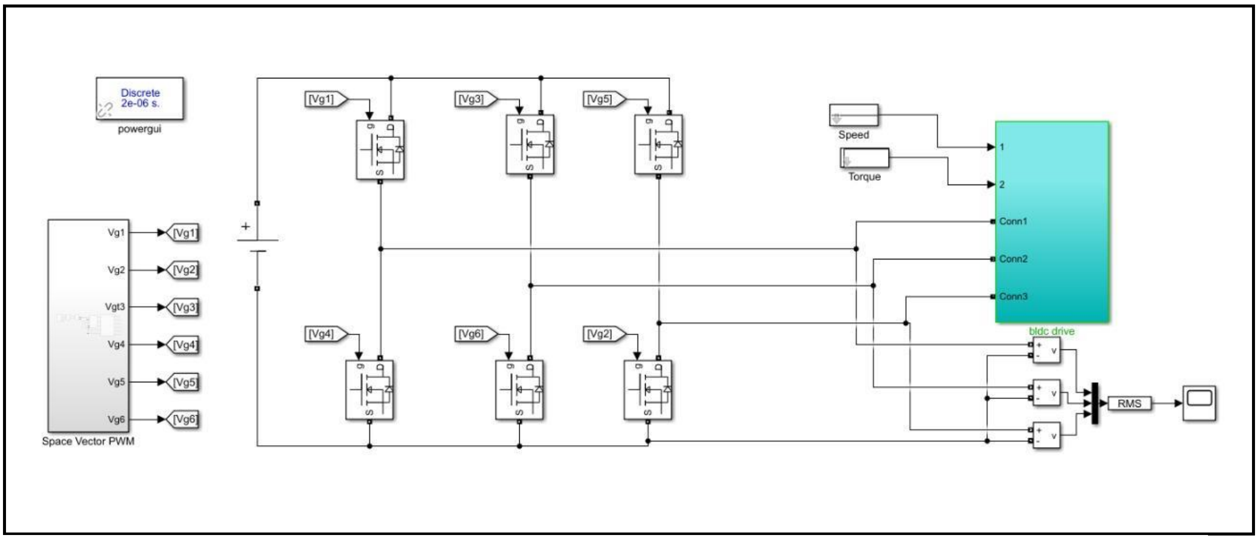

Fig. 2. The simulation diagram of vector control method and it is connected to the BLDC motor to know the torque ripples in the BLDC drive.

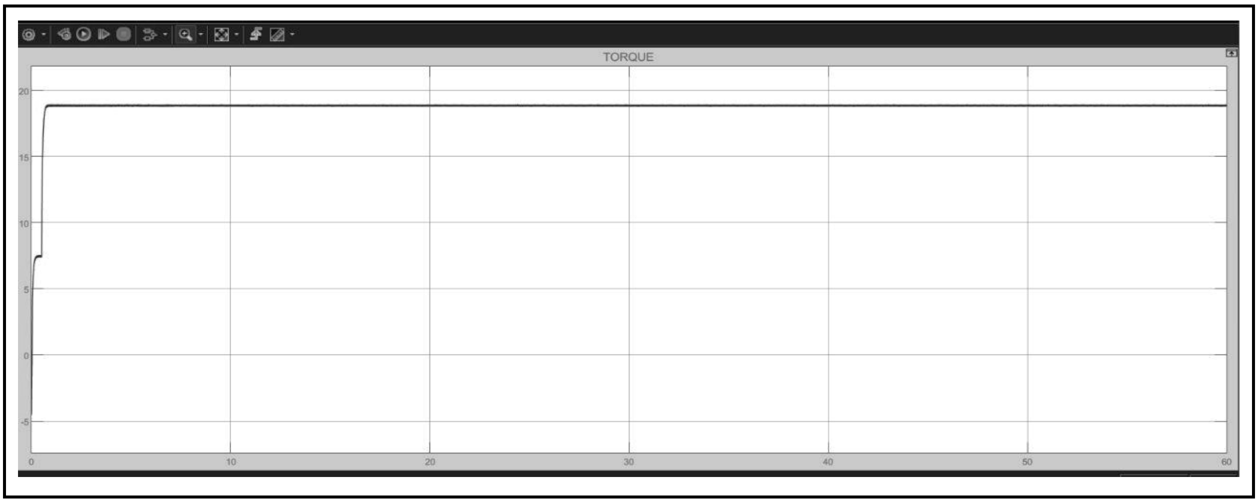

Fig. 3. Torque ripples graph in a BLDC motor by using a Novel 120 degree inverter.

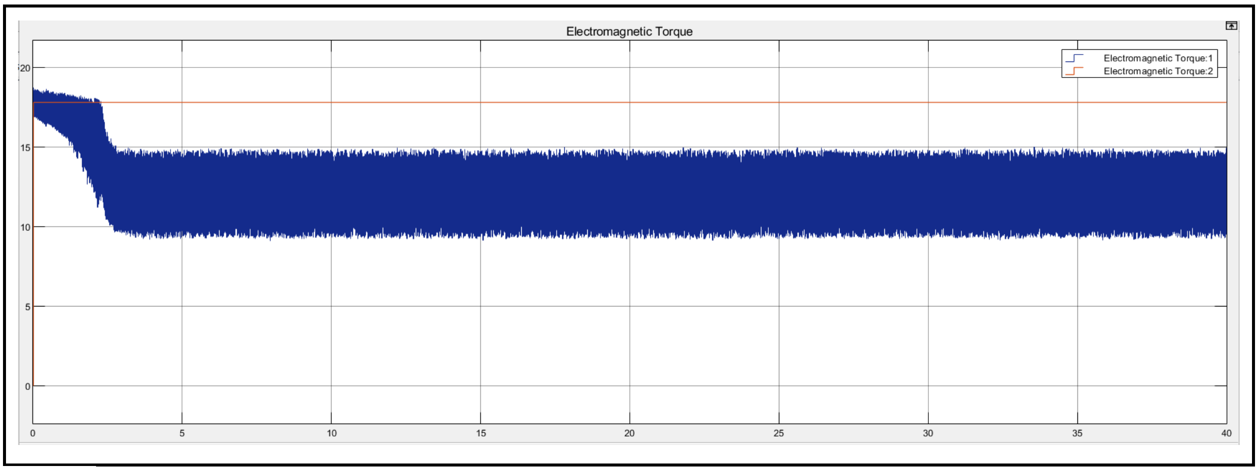

Fig. 4. Torque ripples graph in a BLDC motor by using a vector control method.

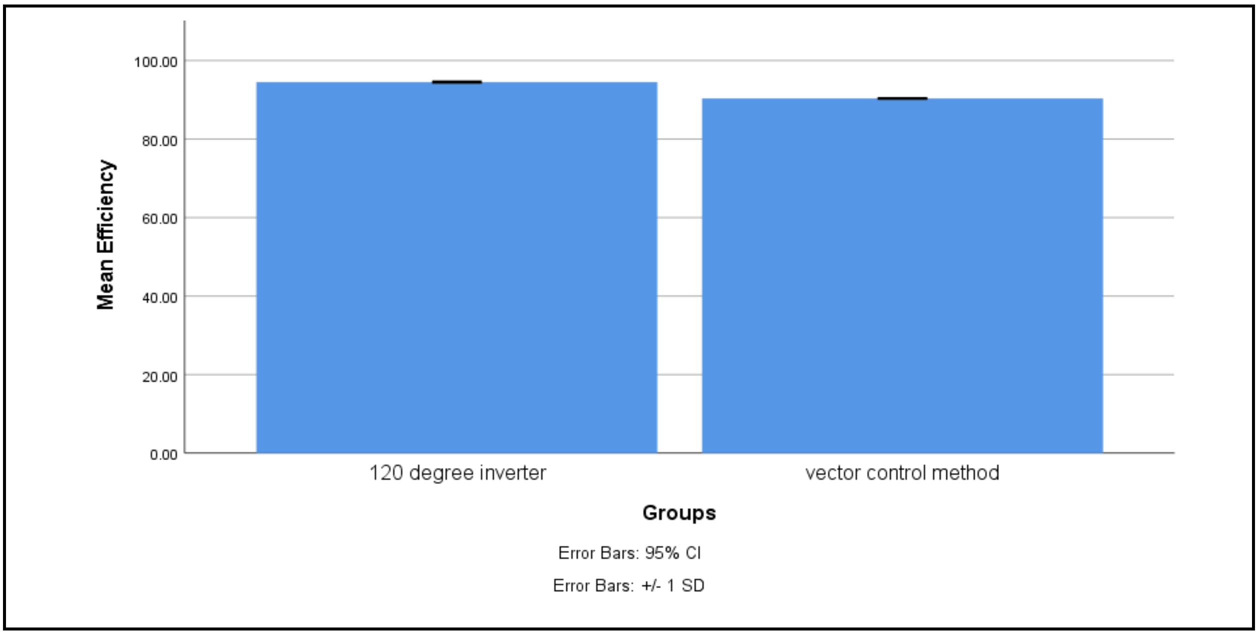

Fig. 5. Comparison of 120 degree inverter and vector control method in terms of mean torque.The mean torque of the 120 degree inverter converter and vector control method and the standard deviation of 120 degree inverter is slightly better than the vector control method. X Axis : 120 degree inverter vs vector control method. Y Axis : Mean torque of detection ± 1 SD.