The Performance Brushless Motor Direct Current 3 Phase Axial Flux Triple Stator Double Rotor with Star and Delta Connection

[1]Widyono Hadi, [2]Errysta Triyana Putri, [3]Gamma Aditya Rahardi, [4]Ali Rizal Chaidir, [5]R.B. Moch. Gozali

Electrical Engineering, Faculty of Engineering
University of Jember

***Abstract*: Electric motors are one of today's technological innovations. An electric motor is a machine or device that converts electrical energy into mechanical energy. BLDC motor is one type of electric motor that is often used in everyday life. BLDC motors are an alternative to the shortage of AC and DC electric motors. This study discusses the performance of a brushless direct current motor 3 phase axial flux 3 stator 2 rotor with star and delta connections. The purpose of this study was to determine the effect of the addition of a stator and rotor on motor rotational speed and torque and to determine the best performance of a 3 phase axial flux BLDC motor when star and delta connection. This study uses 3 stators and 2 rotors. In the stator, 6 coils are installed, each coil consisting of 450 turns with a wire size of 0.3 mm. While the rotor uses neodymium magnets with magnetic dimensions of 15 mm x 15 mm x 5 mm as many as 16 pieces. The test was carried out 5 times with a voltage source starting from 11 V to 24 V. The first test was testing a brushless direct current 3 phase axial flux motor with 1 stator and rotor construction producing a rotational speed of 739 RPM to 1940 RPM and a torque of 0.0327 Nm to 0.0424 Nm. The second test is a brushless direct current motor testing 3 phase axial flux construction 2 stator 1 rotor produces a rotational speed of 855.5 RPM to 2551 RPM and a torque of 0.1285 Nm to 0.1412 Nm. The third test is testing a brushless direct current motor 3 phase axial flux construction 3 stator 2 rotor produces a motor rotation speed of 350.2 RPM to 1411 RPM and a torque of 0.4506 Nm to 0.618 RPM. The fourth test is testing a brushless direct current motor 3 phase axial flux 3 stators 2 rotors star and delta connection. The delta connection produces a rotating speed of 350.2 RPM to 1411 RPM and a torque of 0.4506 Nm to 0.618 Nm. While the delta connection produces a rotational speed of 185.6 RPM to 772.1 RPM and a torque of 0.7782 Nm to 1.3136 Nm. The fifth test is testing a brushless direct current motor 3 phase axial flux 3 stator 2 roto star and delta connected with a load. The star connection produces a rotating speed of 112.8 RPM to 280 RPM, a torque of 0.4139 Nm to 0.9369 Nm, and efficiency of 0.0127% to 0.3519%. While the delta connection produces a rotating speed of 255 RPM to 422.7 RPM, a torque of 1.4531 Nm to 1.7291 Nm, and efficiency of 0.000044675% to 0.000087577%. The addition of the number of rotors affects the torque produced with a very high torque value, this is based on the construction data of 3 stators 2 rotors with a torque value of 0.618 Nm compared to the construction torque value of 2 stator 1 rotors of 0.1412 Nm. The addition of the number of stators affects the rotational speed of the resulting motor where the value is greater, this is evident in the construction data of 2 stators 1 rotor motor rotational speed of 2551 RPM compared to the construction of 1 rotor 1 stator which is 1940 RPM. The addition of the number of stators and rotors will affect the rotational speed of the motor, where the resulting value is getting lower or smaller. It also affects current, voltage, power, and torque, where the three parameters increase or the value gets bigger. The best performance of brushless direct current motor 3 phase axial flux 3 stator 2 rotors between star and delta connection, the performance is better when connected to star because the rotational speed is higher. The performance of a brushless direct current motor 3 phase axial flux 3 stator 2 rotor when switching between star and delta connections, its performance is better when star connected because of the higher efficiency value.**

***Index Terms*: Electrical Motor, BLDC, 3 Stator 2 Rotor.**

I. INTRODUCTION

As civilization develops, the need for electrical energy is also increasing. Indonesia is a developing country with a population of more than 272,229,372 million and will continue to grow every year. Electrical energy is a major commodity for daily use. As the demand for electrical energy sources increases, technological innovation is needed to meet the needs of electrical energy. One form of technological innovation today is the electric motor. An electric motor is a machine or device that converts electrical energy into mechanical energy [1, 2].

In addition, there are also other electric motors that are often used in everyday life, namely brushless direct current or BLDC electric motors. BLDC motors are an alternative to the shortcomings of DC electric motors and AC electric motors. The advantage of the BLDC motor is that it uses electricity so that it does not use a brush to operate and has no commutator losses, making BLDC motor maintenance easier. In addition, BLDC motors also have advantages such as high efficiency, smoother rotation so that the noise level is low, speed and torque are high and have a longer service life. BLDC motors are included in the type of synchronous motor, because the value of the magnetic field generated by the rotor and stator has the same frequency value. Although it is a type of 3-phase AC synchronous electric motor, this motor is still called a BLDC motor because in its implementation the BLDC motor uses a DC source as the main energy source which is then converted into AC voltage using a 3-phase inverter [3]. The purpose of using a 3-phase AC voltage on a BLDC motor is to create a rotating magnetic field in the stator to attract the rotor magnets [4].

BLDC motors are divided into 2 types based on their construction, namely the out-runner and in-runner construction types. The out-runer type is a type of construction where the rotor is outside the stator where the commutation process is outside the stator. The function of this type is to get high torque. The in-runner type is the type of construction where the rotor is located inside the stator where the commutation process is inside the stator, the function of this type is to get high speed [5]

In a previous study [6] related to the performance of a brushless direct current 3 phase axil type motor with a different shape of a neodymium magnet using a single stator, using 6 coils with 450 turns on the stator, using enamel wire measuring 0.3 mm and on the rotor using 8 pieces of neodymium magnets with magnetic dimensions of 15 mm x 15 mm x 5 mm and 10 mm x 10 mm x 2 mm [6]. In this study, 3 stators were used with each coil on the stator totaling 6 with 450 turns for each coil, and the wire used was 0.3 mm. In the rotor there are 16 permanent magnets of the neodymium type with a square shape measuring 15 mm x 15 mm x 5 mm and the installation of opposite poles. In this study, two rotors were used, each of which was attached to 8 magnets. When the first magnet is installed in the order of the north pole, the second magnet is attached to the south magnetic pole, and the third magnet is installed with the north pole, and so on until 8 magnets are attached. The two rotors have the same order so that the rotor can rotate. The difference between this study and previous studies lies in the number of stators and rotors. Previous studies used a single rotor and a single stator, while in this study 2 rotors and 3 stators were used. This study was conducted to determine the effect of the number of stators on rpm speed, torque and to improve torque output and to determine the best performance of a BLDC motor when connected to star and delta.

II. METHODS

The tools used include cutting pliers, combination pliers, soldering iron, screwdrivers, bench type Krisbow digital multimeter, tachometer counter extech 461920, power supply CODY 3005DT (30V-5A), roll machine wire, oscilloscope, BLDC driver controller 12V-36V DC 500W PWM brushless motor, hall sensor, tesla meter, 12V 1000RPM DC motor, 12V lamp. The materials used are square type neodymium magnets with a size of 15 mm x 15 mm x 5 mm, 0.3 mm enamel wire, 2 cm diameter metal spool, nuts, bolts, 625-RS bearing, 5 mm diameter stainless axles, connecting cables, fire wire, rainbow wire, lead, 5 mm acrylic, terminal block, pulley, belt and wooden plank.

The flowchart of this research is depicted in fig 1 and the design of our brushless DC is illustrated in fig 2.

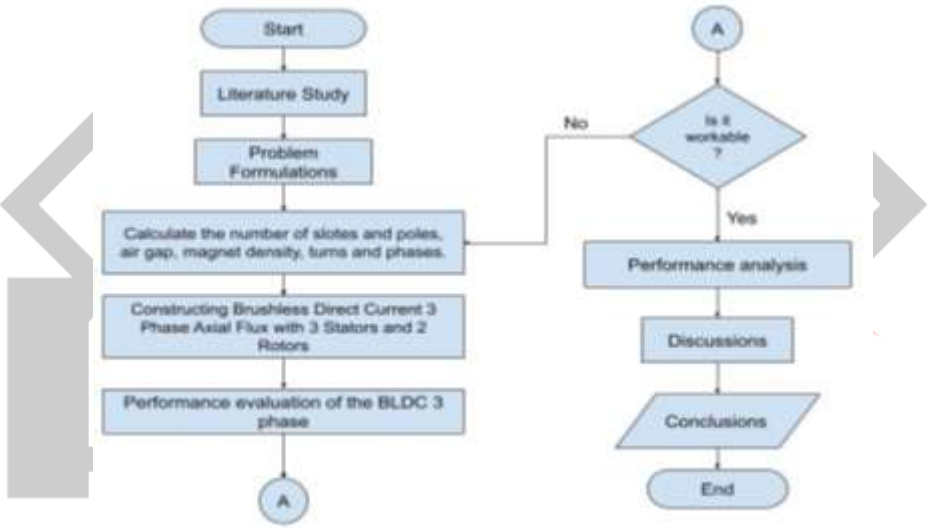
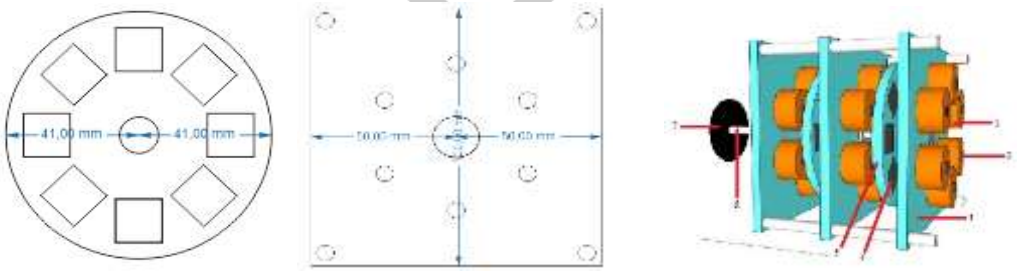


Figure 1. Research Flowchart



2a 2b 2c

Fig (2a). Rotor design 8 poles brushless direct current motor 3 phase axial flux.
Fig. (2b). Stator design 6 coil brushless motor direct current 3 phase axial flux.
Fig (2c). 3-dimensional design brushless direct current motor 3 phase axial flux triple stator double rotor

Fig 2c items:
1. Stator Coil
2. Iron Core

3. Stator Disc
4. Neodymium Magnets
5. Rotor Disc
6. Iron Shaft (As)
7. Encoder

III. RESULTS AND DISCUSSIONS

TABLE 1
BLDC specs in this research

Parameter	Symbol	Value
Phase	*Nph*	3 phase
Stator		3 stator
Height (stator)	*P*	10 cm
Width (stator)	*L*	10 cm
Coins in each stator		6 coils
Surface Length	*L*	1 cm
Number of turns per coil	*N*	450 turns
Diameter of wires	*D*	0.3 mm
Number of rotor		2 rotor
Diameter of rotor	*D*	82 mm
Poles	*P*	16 poles
Pole Dimension		15 mm x 15 mm x 5 mm
Air gap	*X*	0.5 cm

Fig 3. Brushless direct current motor 3 phase axial flux with triple stator double rotor

This research will carry out the process of making and testing a brushless direct current 3 phase axial flux motor by comparing the motor construction by adding the number of stators and rotors and connecting the coils to the BLDC motor stator (star and delta). In this test, a variation of the source voltage from the power supply is given of 11 volts to 24 volts.

The test was carried out 3 times, namely testing the addition of the number of stators and rotors, testing the coil connection, namely star and delta connections, and testing brushless direct current motors 3 phase axial flux triple stator double rotor using a load. The three tests were carried out to determine the working performance of a brushless direct current 3 phase axial flux motor. Methods of data collection is done by two methods, namely measurement and calculation. In performing calculations, it takes the value of the magnetic field of the neodymium magnet to determine the value of the repulsive force on the motor. The value of the magnetic field is obtained from the measurement of neodymium magnets using a Tesla Meter.

Fig 4 Measurement of magnetic Field using Neodymium

A. Various Evaluations for Motor Brushless Direct Current 3 Phase Axial Flux Constructions

1) An Evaluation of Brushless Direct Current 3 Phase Axial Flux with 1 Stator and 1 Rotor:

TABLE II
Evaluation Results of Brushless Direct Current 3 Phase Axial Flux with 1 Stator and 1 Rotor

Source (V)	Freq (Hz)	RPM	Motor Voltage (V)	Motor Current (A)
16	78.36	1130	14.3	0.229
20	100.8	1549	17.83	0.241
24	126.2	1940	23	0.246

Based on the explanation in Table II above, the greater the source voltage given, the greater the rotational speed of the motor, frequency, motor voltage, and motor current generated.

TABLE III
Calculations of the Output from Brushless Direct Current 3 Phase Axial Flux with 1 Stator and 1 Rotor

Source (V)	RPM	*Error* (%)	Torque (Nm)	Power (W)
16	1175.4	0.3860	0.0394	5.6719
20	1512	0.0245	0.0415	7.4427
24	1893	0.0248	0.0424	9.7999

Based on the explanation in Table III, the increase in the voltage source affects the torque value and the resulting motor power. The greater the source voltage provided, the greater the torque and motor power produced. In the column error percent motor rotational speed, the resulting value in the measurement is precision.

2) An Evaluation of Brushless Direct Current 3 Phase Axial Flux with 2 Stators and 1 Rotor:

TABLE IV
Evaluation Results of Brushless Direct Current 3 Phase Axial Flux with 2 Stators and 1 Rotor

Source (V)	Freq (Hz)	RPM	Motor Voltage (V)	Motor Current (A)
16	103.3	1522	13.84	0.395
20	136.2	2036	17.48	0.404
24	171.8	2551	23.6	0.41

Based on Table IV, each increase in the frequency source voltage, motor rotational speed, motor voltage, and motor current also increases.

TABLE V
Calculations of the Output from Brushless Direct Current 3 Phase Axial Flux with 2 Stators and 1 Rotor

Source (V)	RPM	*Error* (%)	Torque (Nm)	Power (W)
16	1549.5	0.0177	0.1361	9.4688
20	2043	0.0034	0.1392	12.2316
24	2577	0.0101	0.1412	16.7593

Based on Table V, the value of torque and motor power is highest when the source voltage is 24 V with a value of 0.1412 Nm and 16.7593 W. The percent error value generated as a whole is below the 0.01 range, meaning that the motor rotational speed value between calculations and measurements is close to the same, resulting in a value of small percent error. Based on the percent error value, the motor rotational speed can be said to be accurate.

3) An Evaluation of Brushless Direct Current 3 Phase Axial Flux with 3 Stators and 2 Rotors:

TABLE VI
Evaluation Results of Brushless Direct Current 3 Phase Axial Flux with 3 Stators and 2 Rotors

Source (V)	Freq (Hz)	RPM	Motor Voltage (V)	Motor Current (A)
16	41.32	637.2	14.23	1.079
20	68.49	998.4	17.77	1.135
24	96.15	1411	23.9	1.196

Based on Table VI, the increase in source voltage also has an impact for the additional of the value of frequency, motor rotational speed, motor voltage, and motor current. The highest rotational speed of the motor is produced when the source voltage is 24 V.

B. *Performance Assessment of Brushless Direct Current 3 Phase Axial Flux Triple Stator Double Rotor With Star and Delta Configurations.*

1) Performance Assessment of *Brushless Direct Current 3 Phase Axial Flux Triple Stator Double Rotor With Star and Delta Configs:*

TABLE VIII
EVALUATIONS OF BRUSHLESS DIRECT CURRENT 3 PHASE AXIAL FLUX WITH 3 STATORS 2 ROTORS AND STAR CONFIGURATION

Source (V)	Freq (Hz)	RPM	Motor Voltage (V)	Motor Current (A)
16	41.32	637.2	14.23	1.079
20	68.49	998.4	17.77	1.135
24	96.15	1411	23.9	1.196

TABEL IX
EVALUATIONS OF BRUSHLESS DIRECT CURRENT 3 PHASE AXIAL FLUX WITH 3 STATORS 2 ROTORS AND DELTA CONFIGURATION

Source (V)	Freq (Hz)	RPM	Motor Voltage (V)	Motor Current (A)
12	11.73	185.6	10.72	1.506
20	36.49	541.3	18.57	2.232
24	53.19	772.1	25.2	2.542

Tables VIII and IX explain that the best performance between star and delta connections is the performance of a brushless direct current 3 phase axial flux 3 stator 2 rotor motor with a star circuit. This is evident in the rotational speed of the motor produced by the star circuit, the value is higher than the value of the motor rotational speed of the delta circuit. In table VIII, the input voltage value starts from 12 V instead of starting from 11 V. This is because the delta-connected motor when given an input voltage of 11 V the motor does not run or work. However, the motor starts working when the input voltage is 12 V. Therefore, the test is carried out starting from the input voltage of 12 V. The motor current and the resulting motor voltage are better when the delta connection is compared to the star connection.

2) *Analysis and Calculations of the Output of Brushless Direct Current 3 Phase Axial Flux Triple Stator Double Rotor with Delta and Star Configurations:*

TABEL X
ANALYSIS AND CALCULATIONS OF THE OUTPUT OF BRUSHLESS DIRECT CURRENT 3 PHASE AXIAL FLUX WITH 3 STATORS 2 ROTORS AND STAR CONFIGURATION

Source (V)	RPM	*Error* (%)	Torque (Nm)	Power (W)
16	309.9	1.0561	0.5576	26.5942
20	513.675	0.944	0.5865	34.9336
24	721.125	0.9567	0.618	49.5096

TABEL XI
ANALYSIS AND CALCULATIONS OF THE OUTPUT OF BRUSHLESS DIRECT CURRENT 3 PHASE AXIAL FLUX WITH 3 STATORS 2 ROTORS AND DELTA CONFIGURATION

Source (V)	RPM	*Error* (%)	Torque (Nm)	Power (W)
16	170.4	1.0599	1.0299	49.7085
20	273.675	0.9779	1.1534	71.7905
24	398.925	0.9355	1.3136	110.9524

Based on Table X and Table XI, the highest torque produced is when the motor is brushless direct current 3 phase axial flux 3 stator 2 rotor when the delta is connected. This is because the repulsive force generated in the delta connection is greater than the star

connection. Apart from the repulsive force, the motor current also affects the torque output. The motor current generated in the delta connection is higher than the star connection so that the torque generated in the delta connection is higher. The percent error generated in brushless direct current motors 3 phase axial flux 3 stator 2 rotor when delta connection and star connection is the same value, which is in the range of 0.9% to 1.1%, this is because the rotational speed value between measurement and calculation has a very large difference in value so that produces a large percent error. The resulting motor power is higher when the brushless direct current 3 phase axial flux 3 stator 2 rotor motor is delta-connected compared to star-connected. This is because the motor current and motor voltage generated in the delta connection are higher than the star connection so that the power generated is higher in the delta connection.

C. *Performance Assessment of Loaded Brushless Direct Current 3 Phase Axial Flux Triple Stator Double Rotor with Star and Delta Configurations*

TABLE XII
EVALUATIONS OF LOADED BRUSHLESS DIRECT CURRENT 3 PHASE AXIAL FLUX WITH 3 STATORS 2 ROTORS AND STAR CONFIGURATION

Source (V)	Freq (Hz)	RPM	Motor Voltage (V)	Motor Current (A)	Load Voltage (V)	Load Current (A)
16	15.38	224.4	14.08	1.289	2.636	0.019
20	18.18	260	17.48	1.551	2.802	0.066
24	21.11	280	22.5	1.813	2.825	0.088

TABLE XIII
EVALUATIONS OF LOADED BRUSHLESS DIRECT CURRENT 3 PHASE AXIAL FLUX WITH 3 STATORS 2 ROTORS AND DELTA CONFIGURATION

Source (V)	Freq (Hz)	RPM	Motor Voltage (V)	Motor Current (A)	Load Voltage (V)	Load Current (A)
20	20.32	290.1	15.55	2.854	3.525	2E-05
24	27.93	422.7	21.2	3.346	5.38	2E-05

Based on Table XII and Table XIII, it is explained that the rotational speed of the motor produced when given a load, the resulting rotational speed decreases and is smaller than when it is not loaded. Motors with star and delta circuits both experience the same thing for the resulting rotational speed, which decreases. In testing the motor with a delta connection, the input voltage starts with a voltage of 19 V, this is because in the delta test when a source voltage of 11 V to 18 V is given the BLDC motor does not work and works when a voltage of 19 V is given. The highest load current value is produced by a brushless motor. direct current 3 phase axial flux 3 stator 2 rotor star connection while the highest load voltage value is generated by a brushless motor direct current 3 phase axial flux 3 stator 2 rotor delta connection. The highest load voltage value on a brushless direct current motor 3 phase axial flux 3 stator 2 rotor delta connection. Based on the two motor connections, namely star and delta, every increase in the source voltage given, the rotational speed of the resulting motor increases.

IV. CONCLUSION

Therefore, based on the evaluation and test results of the brushless direct current motor 3 phase axial flux 3 stator 2 rotor with star or delta connection, we can conclude that:

1. The addition of the number of stators affects the rotational speed of the resulting motor where the value is getting bigger. The addition of the number of rotors affects the torque produced with a very high torque value. The addition of the number of stators and rotors will affect the rotational speed of the motor, where the resulting value is getting lower or smaller. It also affects current, voltage, power, and torque, where the three parameters increase or the value gets bigger.
2. Brushless direct current motor 3 phase axial flux 3 stator 2 rotor with star circuit produces high motor speed output compared to delta circuit. However, in a brushless motor direct current 3 phase axial flux 3 stator 2 rotor delta connection produces the highest torque output, motor current and motor voltage compared to star circuit. The best performance of a brushless direct current motor 3 phase axial flux 3 stator 2 rotor is the best when connected to a star, because the motor is a device that converts electrical energy into motion energy, a very high rotational speed is required.
3. Brushless direct current motor 3 phase axial flux 3 stator 2 rotor with star or delta connection when loaded the resulting motor rotation speed decreases and the value is very small. In contrast to the torque produced, when loaded, the torque value produced is very high from the two connections. The best efficiency is produced by a brushless direct current motor 3 phase axial flux 3 stator 2 rotor star connection compared to delta circuit. So, the best performance of the brushless direct current 3 phase axial flux 3 stator 2 rotor motor when it is loaded is with a star circuit.

REFERENCES

[1] S. Sharifan, S. Ebrahimi, A. Oraee, H. Oraee. Performance comparison between brushless PM and induction motors for hybrid electric vehicle applications. 2015 Intl Aegean Conference on Electrical Machines & Power Electronics (ACEMP). Sept 2015.

[2] N. Hashemnia, B. Asaei. Comparative study of using different electric motors in the electric vehicles. 2008 18th International Conference on Electrical Machines. Sept 2008.

[3] P. R. Upadhyay, K. R. Rajagopal. A novel Integral-force technique for the analysis of an axial-field permanent-magnet brushless DC motor using FE method. IEEE Transactions on Magnetics. Vol 41. Issue 10. Oct. 2005.

[4] A, D. The Control of Brushless DC Motor Using Sinusoidal PWM and ATMega16. Indonesia: Universitas Indonesia. 2009.

[5] H.B, G. Sensorless Three Phase BLDC Motor Out-Runner Type. 2017.

[6] E. F. Adelina, Brushless Direct Current Motor Performance 3 Phase Axial Flux Type With Different Shapes Of Neodymium Magnets. 1, 105–112. 2021.