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Prognosis of BLDC Drive Faults Using Autoregressive Integrated Moving Average Algorithm

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Abstract **:**Generally, Brushless DC (BLDC) machines attract many industrialists due to their unique characteristics like better output, stabilized performance, and high torque to current ratio. BLDC drive has a long life, and they do not need maintenance; however, the drive has low starting torque and high cost. Thus, Non-stop monitoring and future prediction methods can reduce fault occurrence and improve system performance. In this paper, we have proposed the prognosis of BLDC drive faults using the Autoregressive Integrated Moving Average (ARIMA) Algorithm. Here, we consider the open circuit (OC) and short circuit (SC) faults in BLDC drive to prognosis by ARIMA technique. The ARIMA has a fixed structure, and it is particularly built for time series data. By data acquisition system, the drive parameters such as current, torque, and speed will be continuously obtained. Filtering out the high-frequency noise present in the data is the main principle of the ARIMA model. Matlab/Simulink platform is used to implement the process and analyze the results using prediction efficiency, the fault analysis in speed, flux, torque, current, and voltage.

Key Words: Brushless DC Drive, OC, Fault Circuit, Speed, Torque, and ARIMA.

1. Introduction

A Brushless DC drive is an electronically commutated DC motor. As the name indicates, it does not have any brushes because they are commutated electrically by using an electronic drive. BLDC motor is derived from Brushed DC motor (BDC), and brushes are available in BDC motors. A Brushless motor is similar to a permanent magnet synchronous motor (PMSM). In this motor, the stator is surrounded by the rotor, and the stator surrounds the rotor. Brushes may cause sparking, and they also decrease the lifetime of the motor. To increase the lifespan of motor and also to avoid some faults, BLDC motor drive has been developed [1]. BLDC drive has a rotor, and it is specified in the way of a permanent magnet, and the stator is computed in the way of poly-phase armature winding [2]. A permanent magnet will generate more power than the BDC motor. BLDC motor drives are widely used in industrial applications such as instrumentation, industrial, automotive equipment, aerospace, and automotive [3]. BLDC motor drive has some advantages: noiseless operation, long lifetime, high efficiency, low inertia, high dynamic response other than the brushed DC motors and induction motors [4]. However, the motor has a few disadvantages like high cost and risk of inverter failures. The drive is used in a hybrid vehicle, electric vehicle, DVD/CD players, medical industries, industrial robots, etc. [5-9].

Mostly Hall Effect sensor is used in BLDC drive. Hall Effect sensor is used to rectify the position of the rotor and also to monitor the working of the rotor [10-12]. The Hall sensor will generate the high or low-level signal and also evaluate the position of the shaft when the rotor magnetic poles pass nearby the sensors [13-15]. BLDC drive is affected by both external and internal faults. Bearing faults and demagnetization faults are the internal faults, and both will affect the BLDC drive [16-17]. Continuous wavelet transform (CWT) and Discrete Wavelet Transform (DWT) are used to determine the time frequency domain and also to overcome the fault that occurs in the BLDC drive [18]. In fault diagnosis, the Hall Effect sensors with the high-value frequency are sampled, and the speed of the sampling is consumed with the help of a rapid counter. If the value of the sampling signal exceeds the threshold value, the fault will occur in the drive [19]. The winding of the stator will take a decade due to High Resistance Connection (HRC) fault and this fault may damage the resistors present in the winding [20].

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1) Motivation:

Generally, BLDC machines attracts many of the industrialists due to their special characteristics like better output, stabilized performance and high torque to current ratio. BLDC drive has some advantages like practically they require no maintenance and have a long life. They also have low frequency, low inertia and friction, and low radio frequency interference and noise. The only disadvantage of the drive is that they have high costs and low starting torque. Thus, Non-stop monitoring and future prediction methods can helps to reduce fault occurrence and improve the system performance. Prognosis is the ability to offer early fault detection by means of different techniques. Generally, neural network methods like Markov, ANN, CNN and RNN are used for the prediction purpose of faults in BLDC drives. Anyhow, none of them are explained clearly for BLDC drive applications as well as they provide poor prediction accuracy. So, we plan to propose a new fault prognosis method for BLDC drive in our work which should provide highly accurate fault prognosis for BLDC drives.

2) Literature Review

Ahamad Jafari *et al.* [21] had implemented a current based scheme in BLDC drive for detecting an Inter-turn Fault. The modal current was derived by three phase proper linear mixing currents. For identifying the change occurred in the motor the method utilized three main indices. To enhance the scheme for discrimination of faulty condition from healthy zone, an auxiliary correlation based index was suggested. Three main indices were introduced to detect the Inter- turn fault occur in the drive. Indices include energy-based index (EBI), variance-based index (VBI), and mean based index (MBI). The Auxiliary index was used to determine the corrupt condition from the perfect drive, and also it includes three-phase signal. In which the main signal was used to rectify the fault in the drive. The indices mentioned above were calculated parallel to determine the modifications in BLDC drive at some basic conditions such as speed and load. The indices were compared with some different techniques to detect the Inter –turn fault occur in BLDC drive.

Edwin jose.s *et al.* [22] had proposed wavelet transform (WT) technique to overcome the power quality disturbances present in BLDC drive. They had determined the Hysteresis Current Controller (HCC) and Digital proportional integral controller (DPIC) in BLDC drive to predict the issues with the help of WT algorithm. In this case, phase to phase fault, short circuit fault, open circuit fault, inter-turn short detection and DC voltage swell and sag variations were analysed for BLDC motor drive. Either OC and SC faults can be identified by electronic circuit whereas to categorize the BLDC additional faults the WT was used. The magnetic field had been generated in motor dive by the rotation of the stator and rotor at the same frequency. However, the power issues may occur in the drive due to the estimated motor speed. The wavelet transform technique gave an accurate result when compared with electric circuit designs.

By using FPGA based Hysteresis current controller and Hybrid modelling technique, Adil Usman [23] had proposed design and control of BLDC motor drive. The hybrid technique may include both Numerical Method (NM) and Electrical Equivalent Circuit (EEC) to improve accuracy with low topological time. The motor drive was operated with FPGA by adapting HCC method. PI speed controller senses the BLDC drive via the Hall Effect sensor and produces an inducing current for HCC. FPGA algorithm has been implemented to reduce the speed and to resist the fault that occurred in the BLDC drive. The motor attains steady speed with less time and thus achieving the efficiency of the designed controller. Based on dynamic fault condition, the fast response of the controller makes it deployable in industries.

Tanvir Alam Shifat and Jang-Wook Hur [24] had proposed an EEMD supervised learning for diagnosis of the fault and maintenance in BLDC drive using vibration signal. Three health states were chosen under BLDC drive and the states such as severe failure state, incipient failure, and healthy state. Intrinsic mode function (IMF) was introduced to compensate for the required signal decayed by Ensemble Empirical Mode decomposition (EEMD). IMF was verified by Continuous Wavelet Transform (CWT) in terms of frequency domain for a better outcome. Principal Component Analysis (PCA) was dissembled by supervised machine learning method, which was named as K-nearest neighbour (KNN) to reduce feature dimensions. Therefore, the fault was detected by supervised learning at the incipient state itself.

For BLDC motor drive, Mohd Afroz Akhtar *et al*., [25] introduced a current control technique. It involves a positive current reference generation in BLDC drive to control the drive speed and the current control technique was implemented in open loop configuration to discriminate its performance. In each case, the positive current was generated to operate the drive positively and the positive values were given as feedback to the controller.

Generally, BLDC machines attract many industrialists due to their special characteristics like better output, stabilized performance and high torque to current ratio. Low starting torque and high cost are the main disadvantages which present in the BLDC drive. Thus, Non-stop monitoring and future prediction methods can reduce fault occurrence and improve system performance.

3) Contribution and Paper Organization

Contribution of the work is listed as follow,

- To design BLDC motor with SC and OC fault for consideration.
- To develop a better fault diagnosis algorithm for BLDC drive
- BLDC drive faults is prognosis using the ARIMA Algorithm
- To validate our proposed work in Matlab/Simulink environment through comparative analysis with previous related works.

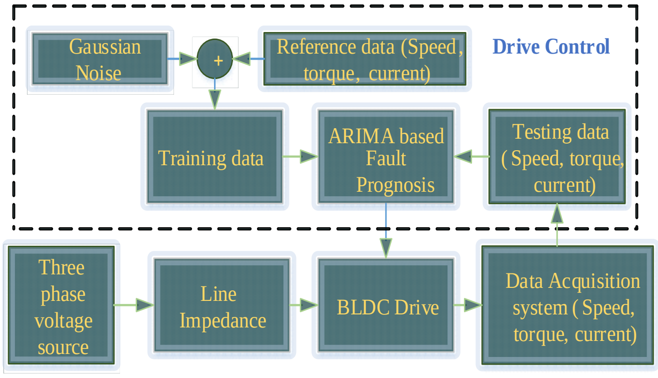
The remaining section is organized as follow,

Section 1 includes introduction, motivation, literature review and contribution of proposed work. Section 2 gives the proposed method, including the construction of BLDC drive, OC and fault circuit analysis, and fault prediction in BLDC drive using ARIMA. Section 3 gives the implementation process with graphical analysis, and section 4 gives the overall conclusion of the process.

2. Proposed Methodology

In this paper, we have proposed a fault prognosis in BLDC drive using the ARIMA algorithm. The block diagram for the proposed model is shown in figure 1. In our work, three-phase voltage source is connected to BLDC drive-through line impedance. It mainly avoids the reflection of incoming voltage from BLDC drive to the voltage source. OC and SC faults are causing heavy damages in the BLDC drive. The drive parameters like speed, current, torque will be continuously obtained by the data acquisition system. Such data are used as test data to the ARIMA model in order to provide fault prognosis and proper control of BLDC drive. Filtering out the high-frequency noises which present in the data is the main principle of ARIMA model. The advantages of ARIMA model in extracting and fitting the linear part of the original time series, while the non-linear information in residual is abandoned. So, we have selected ARIMA in our work for the fault prognosis purpose. Initially, reference data with the addition of Gaussian noise is given as the training data to

ARIMA. Based on the training of ARIMA model, our proposed scheme provides better drive control through effective fault diagnosis.



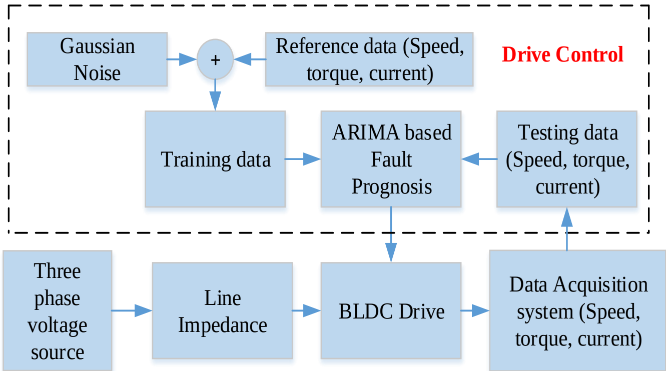


Figure 1: ARIMA based fault Prognosis in BLDC Drive

2.1 Construction of BLDC Drive

The equation of BLDC drive is,

$$V = R_I + \frac{d}{dt}\left(L_S[\theta_R]I + \lambda_m\right) \quad (1)$$

$$V = R_I + L_S(\theta_R)\frac{di}{dt} + I\omega_R \frac{d}{d\theta_R} L_S(\theta_R) + e \quad (2)$$

However, according to the position, there is no changes in the inductance; thus, the term $I\omega_R \frac{dL(\theta_R)}{d\theta_R}$ is zero.

So, the motor can be denoted as,

$$V = R_I + L_S \frac{d}{dt} I + e \quad (3)$$

The BLDC motor drive modelling equation can be denoted in the matrix form,

$$\begin{bmatrix} V_X \\ V_Y \\ V_Z \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} I_X \\ I_Y \\ I_Z \end{bmatrix} + \begin{bmatrix} L_S & 0 & 0 \\ 0 & L_S & 0 \\ 0 & 0 & L_S \end{bmatrix} \frac{d}{dt} \begin{bmatrix} I_X \\ I_Y \\ I_Z \end{bmatrix} + \begin{bmatrix} e_{XS} \\ e_{YS} \\ e_{ZS} \end{bmatrix} \quad (4)$$

Where, phase voltage is represented as $V_X, V_Y \,\&\, V_Z$, phase current is denoted as $I_X, I_Y \,\&\, I_Z$, trapezoidal back EMF is represented as the $e_{XS}, e_{YS} \,\&\, e_{ZS}$.

The back EMF of BLDC motor is expressed in the below equations,

$$e_{XS} = K_{be} f(\theta_{be})\omega_M \quad (5)$$

$$e_{YS} = K_{be} f\left(\theta_{be} - \frac{2\pi}{3}\right)\omega_M \quad (6)$$

$$e_{ZS} = K_{be} f\left(\theta_{be} - \frac{2\pi}{3}\right)\omega_M \quad (7)$$

Where, rotor angle is denoted as ω_m, trapezoidal function is indicated as θ_{be} and back EMF constant is indicated as K_{be}.

The electromagnetic torque is calculated as follow,

$$T_e = \frac{1}{\omega_r}\left(e_{XS} I_X + e_{YS} i_Y + e_{ZS} I_Z\right) \quad (8)$$

Let us assume; there is no phase variances in between the back-EMF and current, the electromagnetic torque can be calculated as follow,

$$T_e = \frac{2EI}{\omega_r} \quad (9)$$

The T_e interaction along with load torque, which explains how the speed of the motor is built up,

$$T_e = T_L + J\frac{d\omega_r}{dt} + B\omega_R \quad (10)$$

Where, viscous damping is represented as B, inertia is represented as J and load torque is represented as T_L.

2.2 Consideration of Open Circuit and Fault Circuit

BLDC drives are conventionally used in industrial and domestic appliances since it is an electronically commutated motor. Hall Effect sensor is utilized to determine the rotor position. BLDC drive will be affected by many faults such as rotor fault, stator fault, bearing fault, and also many interior and exterior faults. SC and OC fault will corrupt the BLDC drive heavily. Our paper focus on introducing an ARIMA technique to prognosis the OC and SC fault occur in BLDC drive [26] with the help of some parameters such as speed, torque and current.

OC Fault:

When the fault of OC occurs in the switch, the waveform of the current gets disappeared in-accordance with the fault switch position. The speed controller will generate the reference current to observe the switching signals generated by Hysteresis Current Controller (HCC). The detection of fault can be executed between the reference current, and the actual current can be defined as follows:

If $\left(\left|i_{ref} - i_{act}\right| > th\right)$ THEN error

ELSE normal:

If the difference between the actual current and reference current is greater than the certain threshold value, then the error will be detected, or else the normal operation occurs. The time taken to detect the fault is given by:

$$T_{fault} = F \times \frac{2}{p \times \eta_{ref}} \times \frac{1}{Mode} \quad (11)$$

T_{fault} Represent the time of detection fault, F represents the fault sensitivity, p denotes the amount of poles and η_{ref} denotes the speed of reference.

When error detecting time is greater than the fault detecting time, the fault will be diagnosed and the algorithm is given a:

$If\,(count > T_{fault})$ THEN fault

ELSE normal:

Where, the count represents the error detecting time.

If the condition satisfies, the fault will be satisfied; otherwise, the normal operation takes place. The equivalent circuit of BLDC drive with OC fault is shown in the above diagram:

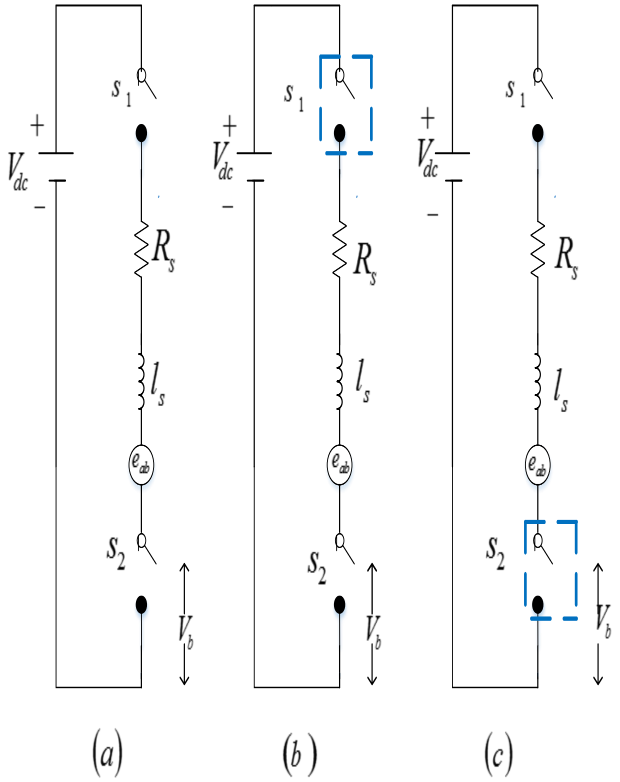


Figure 2: OC Fault (a) Normal Operating Switch (b) OC Fault Occur in Upper Switch (c) OC Fault Occur in Lower Switch

Figure 2 (a) represent, when both switches operate normally, the voltage across the lower level are given by

When $V_b = 0$; the switch s_2 turns on and when $v_b = v_{dc}$; the switch s_2 turns off

$$V_{dc} = R_s . i_{ab} + l_s \frac{di_{ab}}{dt} + e_{ab} \quad (12)$$

V_{dc} Represent the DC link voltage, R_s represent the line to line resistance, the line current is denoted as i_{ab}, l_s represent the line to line inductance, line to line back- EMF is denoted as e_{ab}

Figure 2 (b) represents the OC fault that occurs in switch s_1 (upper switch). If the lower switch s_2 turns on to observe the reference current, the voltage across the lower level will not include in the OC fault due to fault occur in the upper switch, and the voltage equation will be given as:

$$V_b = 0 \quad (13)$$

Figure 2 (c) represents the OC fault that occurs in switch s_2 (lower switch). If the upper switch s_1 turns on to observe the reference current, the voltage across the lower level will not include in the OC fault because of fault occur in the lower switch, and the voltage equation will be given as:

$$v_b = v_{dc} \quad (14)$$

Therefore the fault can be achieved due to the alteration of voltage beyond the lower level, and the sensitivity can be defined as the range of 0.2 to 0.5.

SC Fault:

SC fault is one of the major faults in BLDC drive, mainly the output of the drive is affected due to SC fault. SC fault can be affected within less time when compared with OC fault. SC fault can be differentiated under the achievement of BLDC dive into three different ways:

- Automatic isolating situation (A.I)
- Over the current situation (O.C)
- One-switch control situation (O.S.C)

Automatic isolating situation:

In this situation, the faulty switch will be isolated automatically. If the SC fault occurs either in the upper or lower switch (s_1, s_2) the corrupted switch will be isolated independently

Over current situation:

In this situation, if the SC fault occurs in a lower switch, the phase current flows via a motor winding and the detection of the fault will be achieved by sensing the phase current or the complementary switch is turned ON

One switch control situation:

When SC fault occurs in a lower switch, the line current i_{ab} will be controlled by the upper switch. When the fault occurs in the upper switch, then the line current will be controlled by the lower switch. Moreover, the SC fault will not heavily affect the performance of BLDC drive.

2.3 Fault prediction in BLDC drive using ARIMA

The ARIMA will examine and predict the data or function in a respect time series of its past values and past error. It is also called shocks or innovations [27]. If an ARIMA model gives input with other time series, it will be represented as ARIMAX model of dynamic regression. The ARIMA model will forecast the data or function and it will also estimate the parameter identification. The most benefit of ARIMA model is it will predict future needs, and it also uses time series data for valuable interpretation.

This section deals with the formulation of the ARIMA model to prognosis the fault specified by drive. In our approach, we are introducing the ARIMA model for predicting the fault that occurred in the BLDC drive. ARIMA model will also use for forecasting weather, and also it will predict future extractions. The application of the ARIMA model will also use in many industrial applications such as refinery and network security. The process includes three models: Autoregressive (AR), Moving average (MA), and Autoregressive and moving average (ARMA).

The fault of the drive will be denoted as x_t , y_t and it has real values in (15 and 16)

$$x_t = \{x_{1,} x_2, x_{3,} ....\} \quad for all \ t > 1 \tag{15}$$

$$y_t = \{y_{1,} y_2, y_{3,} ....\} \quad for all \ t > 1 \tag{16}$$

Order p with Autoregressive model is represented as AR (p). In this model, the future fault is supposed to combine past values with constant and Gaussian noise. The mathematical formulation of AR (p) is denoted as:

$$x_t = c + \sum_{j=1}^{q} \varphi_j \ x_{t-j} + \varepsilon_t \tag{17}$$

x_t Represent OC fault, the constant is denoted as c, the parameter is denoted as φ_j and j $(1 \le j \le q)$ is an integer and ε_t is a Gaussian noise and the constant term in (17) will be neglected.

The below equation expressed the lag operator function

$$l^j x_t = x_{t-j} \tag{18}$$

To represent AR (p) model, substitute equation (18) in (17) in the lag operator

$$x_t = \sum_{j=1}^{q} \varphi_j \ l^j x_t + \varepsilon_t \tag{19}$$

Rearrange the above equation in terms of ε_t

$$\varepsilon_t = x_t - \sum_{j=1}^{q} \varphi_j \ l^j x_t \tag{20}$$

The autoregressive model can be expressed in the lag operator can be defined as

$$\varepsilon_t = (1 - \sum_{j=1}^{q} \varphi_j \ l^j) \ x_t \tag{21}$$

The fault occurs in the drive will be represented as MA (q). In this model, the past error is utilized as a variable. The mathematical representation of MA (q) is represented as:

$$y_t = \mu + \varepsilon_t + \sum_{j=1}^{p} \phi_j \ \varepsilon_{t-j} \tag{23}$$

y_t Represent the SC fault, μ Represent the expectation which is assumed to be zero, ϕ_j represent the parameter model, $(1 \le j \le p)$ represent integer, and $\varepsilon_t , \varepsilon_{t-j}$ represent the Gaussian noise.

The below equation expresses the lag operators

$$l^j \varepsilon_t = \varepsilon_{t-j} \tag{24}$$

To implement MA (q) model in lag operator substitute equation (24) in (23)

$$y_t = \varepsilon_t + \sum_{j=1}^{p} \phi_j \ l^j \varepsilon_t \tag{25}$$

The above equation can be rearranged as

$$y_t = (1 + \sum_{j=1}^{p} \phi_j \ l^j) \varepsilon_t \tag{26}$$

The AR (p) (17) and MA (q) (23) is the combination that produces ARMA model. The ARMA (p, q) model is mathematically represented as:

$$z_t = x_t + y_t \tag{27}$$

$$z_t = c + \varepsilon_t + \sum_{j=1}^{q} \varphi_j \ x_{t-j} \sum_{j=1}^{p} \phi_j \varepsilon_{t-j} \tag{28}$$

φ_j *and* ϕ_j denotes the autoregressive and moving average part of AR (p) and MA (q).

The defined ARMA (p, q) is in terms of the lag operator by the combination of an autoregressive and moving average of equation (21) and (26) is defined as

$$(1 - \sum_{j=1}^{q} \varphi_j \ l^j) \ x_t = (1 + \sum_{j=1}^{p} \phi_j \ l^j) \varepsilon_t \tag{29}$$

ARMA (p, q) requires only a stationary time series. But in our work, we need a non-stationary time series. For this purpose, we are selecting an ARIMA (p, d, and q) by introducing the finite differencing of data points.

The ARIMA model notation will be denoted as P, D, and Q, but it is similar to ARMA (p, q). Therefore, the above equation will be modified to procedure an ARIMA (p, d, and q), and it is denoted as:

$$x_t = (1 - l)^d x_t \tag{30}$$

The ARIMA (p, d, q) is derived from ARMA (p, q), and its expression is calculated as:

$$(1 - \sum_{j=1}^{q} \varphi_j \ l^j) \ (1 - l)^d \ x_t = (1 + \sum_{j=1}^{p} \phi_j \ l^j) \varepsilon_t \tag{31}$$

Where, d is the order of the integrated part, q is the order of moving average part and P is the order of the Autoregressive part.

In our working design p, d and q is represented as parameters such as speed (p), Torque (d) and current (q). In ARIMA, the parameters can be varied at different conditions.

Let us assume speed (p) =3000 rpm, Torque (d) = 20 Nm, current (q) = 60 amps

i. When the parameters speed (p=0) and torque (d=0), the ARIMA model (0,0,60) will be reduced to moving average MA(q) and also OC fault will occur
ii. When the parameters torque (d=0) and current (q=0), the ARIMA model (3000,0,0) will be reduced to autoregressive AR(p) and also SC fault will occur
iii. When the parameters speed (p=0) and current (q=0), the ARIMA model (0, 20, 0), then the Gaussian noise may occur.

Based upon the above conditions, we can able to predict the fault that occurs in BLDC drive.

3. Results and Discussion

Matlab/Simulink platform is used to implement the process and analyze the results using prediction efficiency and fault analysis in speed, flux, torque, current and voltage. Figure 3 shows the process of the Simulink model and Table 1 shows the simulation parameters.

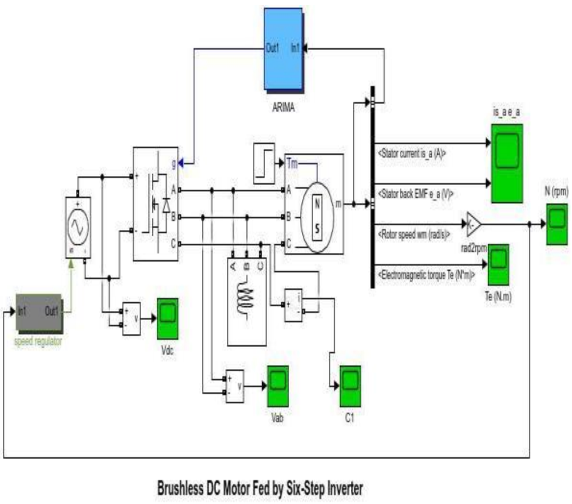


Figure 3: Proposed Simulink Model

Table 1: Simulation Parameters

Parameters	Values
Number of bridge arms	3
Snubber Resistance	50000 ohms
Snubber Capacitance	1e-6F
Stator Phase Resistance	2.8750 ohms
Stator Phase Inductance	8.5e-3
Flux Linkage	0.175 wb/m^2
Back EMF flat area	120 degree
Speed	3000 Rpm
Rated Power	1000 W

Figure 4 shows the DC link voltage source by varying the time. In this design, the DC bus voltage feed forward control gives the ripple voltage compensation. The voltage which presents in the BLDC motor is 490V, which ensures the voltage applied to the motor is constant at any time without any additional faults. By varying the time 0 to 0.2, the Dc bus voltage will be constant at the time of 0.12 to 0.2.

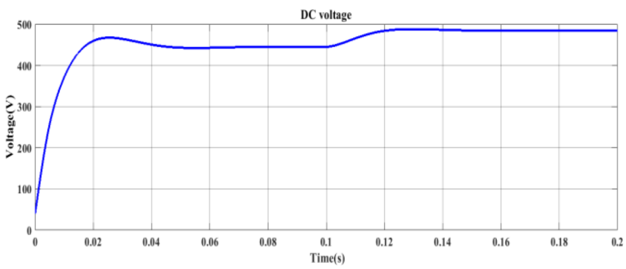


Figure 4: DC Link Voltage

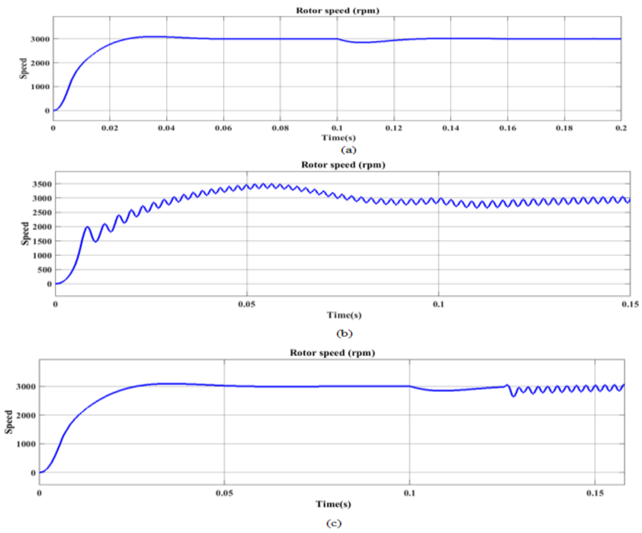


Figure 5: Performance of Speed (a) Normal Condition, (b) OC Faulty Condition (c) SC Faulty Condition

Figure 5 shows the performance of speed (a) normal condition, (b) OC faulty condition and (c) SC faulty condition. At normal conditions, the speed of BLDC motor occurred in the range of 3000 rpm without any fault. At OC fault condition, the speed of BLDC motor has occurred at the range of 0 to 3500 rpm with an unstable condition. Unstable speed is at the above particular time, the motor will occur the OC fault, which may cause the unstable speed. Likewise, the speed of BLDC motor has occurred at the range of 0 to 3000 rpm with unstable speed at SC faulty condition. At the above particular time of 1.13s the motor will occur the SC fault, which causing unstable speed.

Figure 6 shows the performance of stator current (a) at normal condition, (b) at OC faulty condition and (c) at SC faulty condition. The stator current is calculated by varying time. At normal conditions, the stator current of BLDC motor is occurred in the range of -4A to 4A. At OC fault condition, the stator current of BLDC motor has occurred at the range of -20A to 20A with the unstable current. An unstable stator current is at the above particular time the motor will occur the OC fault, which may cause the unstable stator current. Likewise, the BLDC motor stator current is occurred at the range of -20A to 24A with unstable stator current at SC faulty condition. At the above particular time of 0.125s the motor will occur the SC fault, which may cause the unstable stator current.

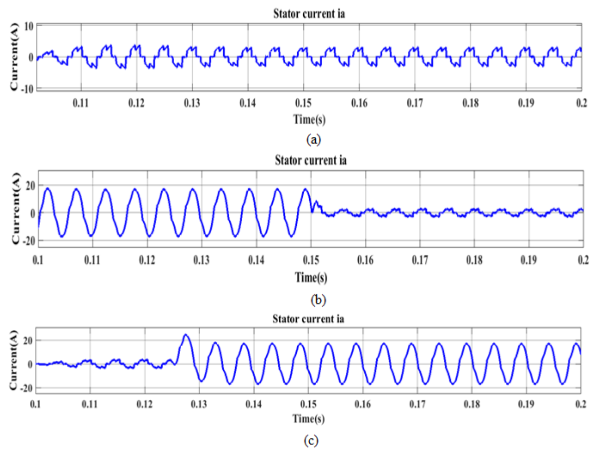


Figure 6: Performance of Stator Current (a) Normal Condition, (b) OC Faulty Condition (c) SC Faulty Condition

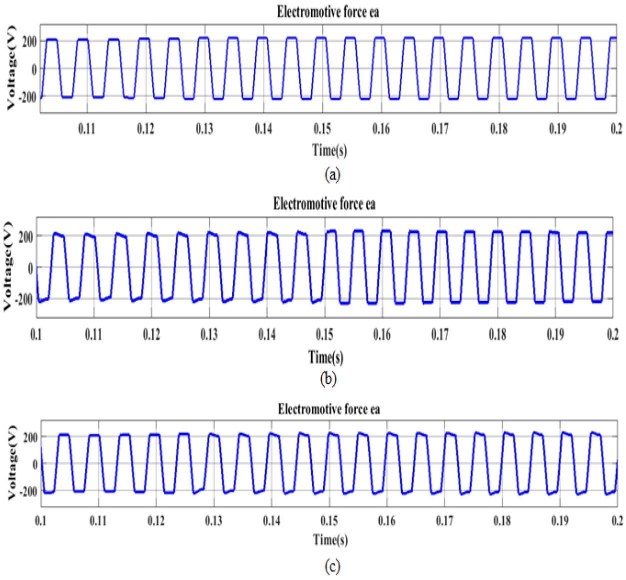


Figure 7: Performance of EMF (a) Normal Condition, (b) OC Faulty Condition (c) SC Faulty Condition

Figure 7 shows the performance of Electromotive force (EMF) voltage (a) at normal condition, (b) at OC faulty condition and (c) at SC faulty condition. The EMF voltage will be calculated by varying time. At normal conditions, the EMF voltage of BLDC motor has occurred in the range of -200V to 200V without any faults. At OC fault condition, the EMF voltage of the BLDC motor has occurred with some distortion. The reason for the distortion of EMF voltage is the BLDC motor will occur the OC fault. Likewise, the EMF voltage of the BLDC motor has occurred with some distortion at SC faulty condition, which may affect the the motor.

Figure 8 shows the torque performance (a) at normal condition, (b) at OC faulty condition and (c) at SC faulty condition. At normal conditions, the torque of BLDC motor is occurred by varying time. At OC faulty condition and SC faulty condition, the torque of the BLDC motor has occurred with some distortions.

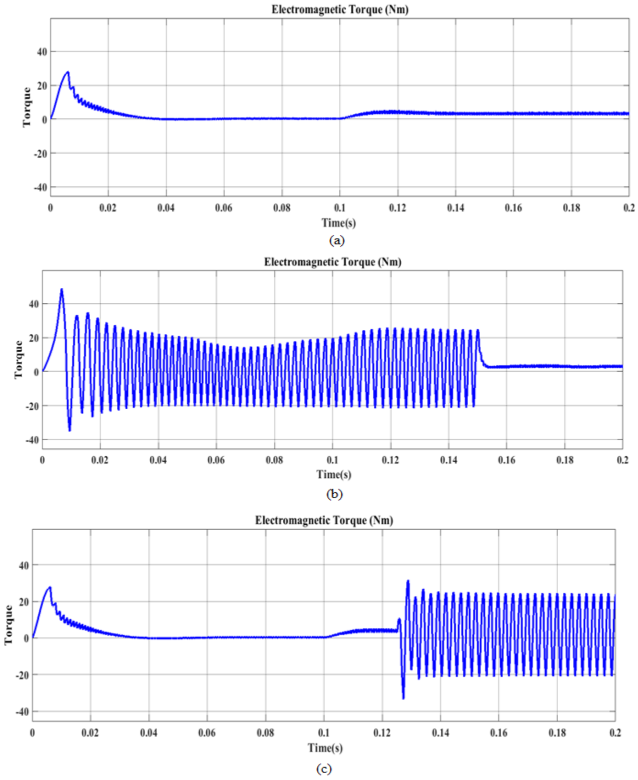


Figure 8: Performance of Torque (a) Normal Condition, (b) OC Faulty Condition (c) SC Faulty Condition

Figure 9 shows the comparison of the proposed efficiency by varying the load rate. Our proposed three phase BLDC motor with the ARIMA model is compared with single phase and three phase induction motor [28]. The efficiency of three phase BLDC motor with ARIMA model is 94.5%, the induction motor efficiency of single phase is 90% and BLDC motor efficiency of three phase is 71% for 100% load. From that, we know our model of three phase BLDC motor with ARIMA is higher efficiency than others.

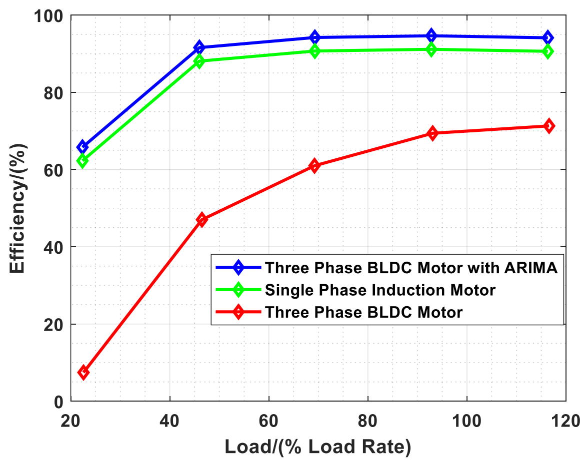


Figure 9: Efficiency Comparison

4. Conclusion

This paper presented a prognosis of BLDC drive fault using ARIMA model. Here, we considered the OC and SC faults in BLDC drive to prognosis by ARIMA. The drive parameters such as speed, torque and current values are continuously monitored. Thus high frequency noises are filtered out in the data by ARIMA model. Matlab/Simulink platform is used to implement the process and analyze the results using prediction efficiency, the fault analysis in speed, flux, torque, current and voltage. The results were taken in BLDC drive by three conditions such as normal condition, OC faulty condition and SC faulty condition. Finally, the efficiency of our proposed work is compared with three phase BLDC motor and single phase induction motor. The efficiency of our proposed work is 94.5% by the varying rate of load. In future, we will consider motor faults in BLDC drive to prognosis by using artificial intelligent techniques.

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