# Wavelet Analysis Based Overcurrent Protection for Permanent Magnet Brushless DC Motor

**Thati. Venkata M Lakshmi, M.V.Ramesh**

***Abstract— The objective of this paper is to progress the over current protection for Permanent Magnet Brushless DC Motors (PMBLDCM) operating under the various operating conditions ranging from no-load to full load operation.***

***From operating point of view, an operation where the operating point of motor is continuously changing with time and the motor is never operating at a constant speed throughout its operation is termed as non-stationary. Signal processing algorithms such as the Fast Fourier Transform (FFT) cannot be used in non-stationary signals analysis is essentially complicated. This means that under assumptions of near stationary more sophisticated signal processing techniques are needed.***

***In wavelet analysis, a signal is analyzed at different scales or resolutions. To gaze at the approximate stationary of the signal, a large window is used to and a small window is simultaneously used to look for transients. This multi-resolution or multi-scale view of the signal is the core of wavelet analysis. A single prototype function is used to perform wavelet analysis called a wavelet. As measurement of the instantaneous frequency is a significant feature of the anticipated fault-detection algorithm[1]. The Haar wavelet will be chosen for this application.***

***Index Terms— PMBLDCM, over-currents, wavelets and MATLAB.***

## I. PMBLDCM

### *A. Introduction*

With availability of efficient semiconductor switches, mechanical switching on commutator machines is eliminated. This type of permanent magnet machine is called a brushless DC machine. Electronic commutation. PMBLDC motors have many advantages in excess of induction motors and brushed dc Now a day, one of the motor types that rapidly gaining popularity is Permanent Motor Brushless Direct Current Motor (PMBLDCM). Industries such as appliances, automotive, aerospace, consumer, medical, industrial automation equipment and instrumentation use PMBLDCM. As the name implies, brushes are not used for commutation in PMBLDCM; as an alternative, it uses motors. A few of these are: improved speed versus torque characteristics, high dynamic response, high efficiency, extended operating life, quiet operation, higher speed ranges. As well, the ratio of torque delivered to the size of the motor is high; they are useful in applications where weight and space are critical factors [1].

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In significant high performance applications, PMBLDCMs are being used. PMBLDC machine's condition monitoring and fault diagnosis are assuming a novel value. Near the beginning, recognition of faults and asymmetries might allow protective maintenance to be performed and grant enough time for controlled shutdown of the affected process, so the outage time expenses and repairs were reduces. It is essential to be able to identify faults though they are still developing and known as incipient failure detection. This results in a safer operating situation.

### *B. Construction*

PMBLDCMs contain several similarities to brushed DC motors and induction motors in terms of working principles and construction correspondingly. PMBLDCMs also contain a rotor and a stator. PMBLDC motor comes in 1-Ø, 2- Ø and 3- Ø configurations. All the above type, the stator has the same number of windings. Of these, 3-phase motors are the most accepted and widely used. This application note focuses on 3-phase motors.

***Stator:***

Alike Induction AC motor, to carry the windings the PMBLDC motor stator is made up of laminated steel stacked up. In a stator, windings can be positioned in two forms; i.e. a star form (Y) or delta form (Δ). The main variation between the two forms is that the Y form gives high torque at low RPM and the Δ form gives low torque at low RPM.

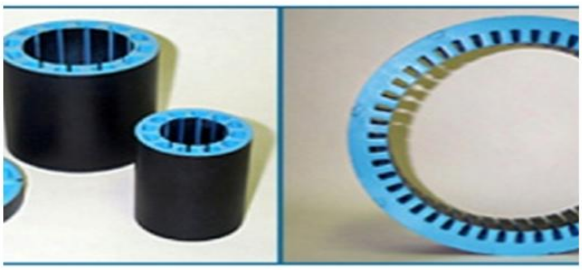


Figure 1: Laminated steel stampings of stator.

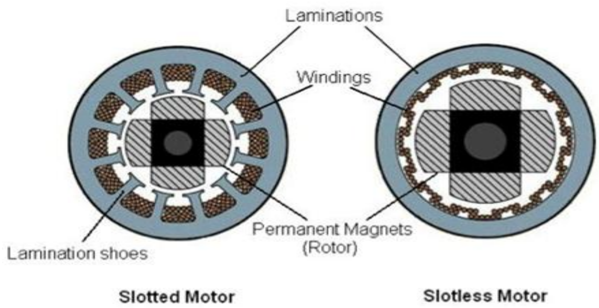



Figure 2:Slotted and slotless motors

Laminated steel stampings of stator as shown in figure 1. Slotted and slotless steel laminations in the stator can be as shown in Figure 2. A slot less core has lesser inductance; hence it can run at very expensive speeds. Requirements for the cogging torque besides go down because of the nonexistence of teeth in the lamination stack; hence making them best fit for low speeds also. Since slotless core requires more winding to compensate for the larger air gap, it is more expensive.

For the construction of stator, proper selection of the windings and the laminated steel are essential to motor performance. Multiple problems arise during production resulting in market delays and increased design costs because of improper selection.

*Rotor:*

A typical PMBLDC motor's rotor is made up of permanent magnets. The number of poles in the rotor may vary, depending upon the application requirements. Better torque can be attained by increasing the number of poles but reduces the maximum possible speed. The material used for the construction of permanent magnet is another rotor parameter that impacts the maximum torque. as the flux density of the material increases, the torque increases 4-pole and 8-pole rotor of PMBLDCM is shown in figure-3

Figure 3: 4-pole and 8-pole PMBLDCM.

### *C. Working Principles and Operation*

The working principle of a PMBLDC motor is same as brushed DC motor; i.e., internal shaft position feedback. Feedback is implemented using brushes and a mechanical commutator, in case of a brushed DC motor. But in case of PMBLDC motor, it can be achieved using multiple feedback sensors such as hall sensors and optical encoders [1]. PMBLDC motor is a kind of synchronous motor. This means the magnetic field generated by both the stator and the rotor rotates at the same frequency.

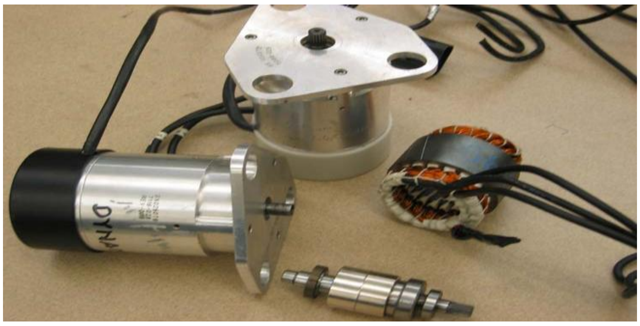


Figure 4: BLDC motor including stator and rotor.

Figure 4 displays PMBLDC motor with a stator and a rotor. This machine produces a trapezoidal back-emf in the stator and has a rectangular air-gap flux density. For an ideal case, back-emf waveforms are shown in Figure 5. When the PMBLDCM excited by six-step switched current waveforms, it develops nearly constant output torque. The stator windings of PMBLDCM are similar to those of an induction or a synchronous motor except that the conductors are uniformly distributed. To increase the width of the trapezoidal back-emf flat terrain region concentrated full-pitched windings are used. The permanent magnets are surface-mounted on the rotor of PMBLDCM that covers 180-degree magnet arcs with non-overlapping phase belts of 60 electrical degrees.

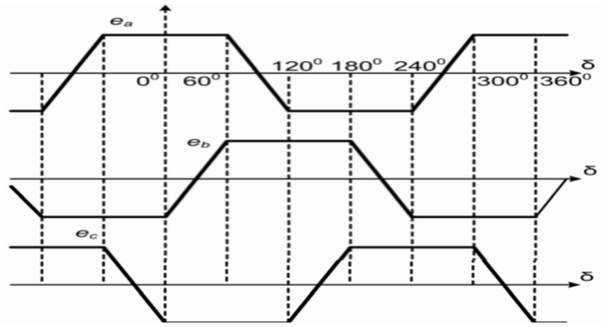



Figure 5: Induced trapezoidal back-emfs.

Figure 5 & figure 6 represents the induced trapezoidal back-emfs and current waveforms respectively

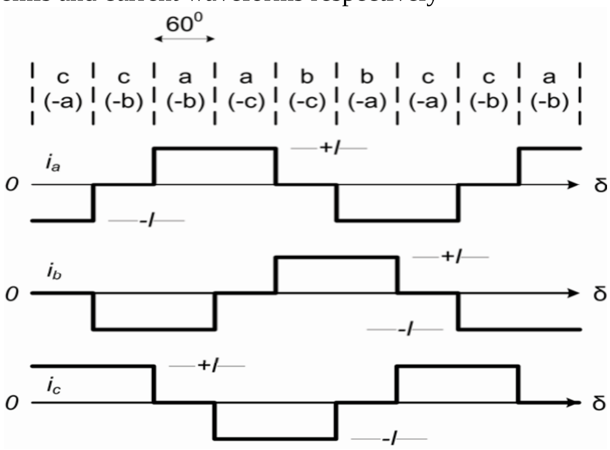



Figure 6: Phase currents for a constant torque in BLDC motor.

## II. FOURIER TRANSFORMS

Fourier analysis is a mathematical procedure for *transforming* the signal to a frequency-based one from a time-based one. For several signals, Fourier analysis is enormously useful because frequency content of the signal is very important.

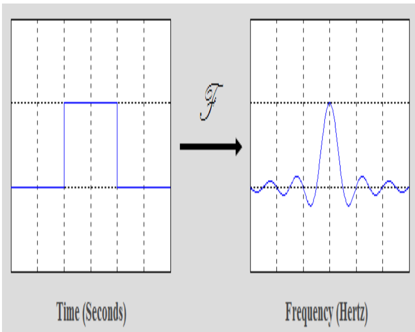
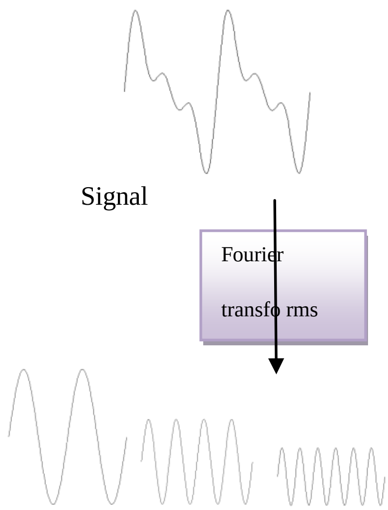



Figure 7: Fourier transform of a signal.

Mathematically, the method of Fourier analysis is represented by the *Fourier transform*: which is a complex exponential multiplied by the sum over all time of the signal *f(t).* The results obtained from the transformation are the *Fourier coefficients*$(\omega)$*;* when these multiplied by a sinusoid of appropriate frequency '$\omega'$' , give up the constituent sinusoidal components of the original signal.




constituent sinusoidal of different frequencies.

Figure 8: Application of Fourier transforms to a signal.

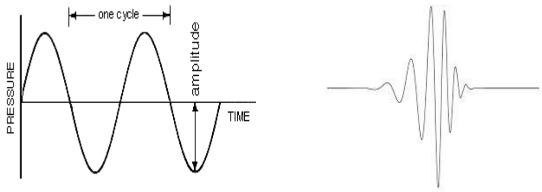
There is a serious drawback Fourier analysis. That is; time information is lost, in transforming to the frequency domain. While looking at a Fourier transform of a signal, it is not possible to notify *when* a particular event took place. In case of a *stationary* signal that is a signal doesn't change much over time, but this drawback is not very important. In practice, the majority interesting signals have numerous non-stationary characteristics: trends, drift, beginnings and ends of events, and abrupt changes. These characteristics are most important part of the signal, and Fourier analysis is not suitable for identifying them.

## III. WAVELET TRANSFORMS

In 1982, Jean morlet introduced the proposal of the wavelet transform and given a novel mathematical tool for seismic wave analysis. Morlet first considered a single function called 'mother wavelet' as a family of functions constructed from translations and dilations.
The wavelet transform is defined as

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{\overline{t-b}}{a}\right) \qquad a, b \in R, a \neq 0 \qquad \text{.... ( 1)}$$

If $|a| < 1$, then the wavelet in (1) is the compressed version of the mother wavelet and corresponds to higher frequencies. If $|a| > 1$, then the in (1) is the dilation version of the mother wavelet and corresponds to lower frequencies. Wavelet analysis represents the next logical step: a windowing method with variable-sized regions. Wavelet analysis allows the make use of and shorter time intervals where we desire high frequency information, lengthy time intervals where we desire more accurate low frequency information [6].
Wavelet means "small wave". In brief, a wavelet is an oscillation that decays rapidly and is shown in figure 9. A wavelet is a waveform of efficiently limited duration that have a zero average value. Fourier analysis is the basis for wavelets compared to sine waves. Sinusoids don't have limited duration, they expand from minus infinity to plus infinity. Sinusoids are smooth and conventional, where as wavelets are likely to be asymmetric and irregular.




Sine wave wavelet

Figure 9: Sine wave and wavelet

Breaking up a signal into sine waves of various frequencies is known as Fourier analysis likewise, breaking up of a signal into shifted and scaled versions of the *mother* (or original) wavelet is known as wavelet analysis. By observing the pictures of sine waves and wavelets, you can notice spontaneously that signals with sharp changes may be analyzed better with an irregular wavelet than with a smooth sinusoid. Eg: just like some foods are better handled with a fork than a spoon.
Wavelet transform is able of providing the frequency and time information at the same time, thus giving a time-frequency representation of the signal.

Wavelet's equivalent mathematical conditions are:
1. Admissibility condition

$$\int_0^\infty \frac{|\widehat{\psi(w)}|}{w}\, dw < \infty \text{... (2)}$$

2. $\int_{-\infty}^{+\infty} \psi(t)dt = 0$ ...(3)
3. $\int_{-\infty}^{+\infty} |\psi(t)^2|\ dt = 1$...(4)

Where $\widehat{\psi(w)}$ is Fourier transform of $\psi(t)$

Wavelet transform is divided into two sub transforms
1. Continuous Wavelet Transforms (CWT).
2. Discrete wavelet Transforms (DWT).

In this paper, mainly concentrated on Discrete Wavelet Transforms (DWT)

## IV.DISCRETE WAVELET TRANSFORM

The Discrete Wavelet Transform (DWT) based on sub-band coding is found to give up a fast computation of Wavelet Transform. It is simple to reduce the computation time and implement and resources required. In the case of DWT, by using digital filtering techniques, a time-scale representation of the digital signal is obtained. The signal, which need to be analyze is approved through filters with different cutoff frequencies at different scales. The DWT family consists of several wavelets such as Haar, Daubechies, symlet, coiflet, biorthogonal spline, reverse biorthogonal spline, battle lemarie, meyer Shannon,CDF. Haar wavelet is chosen for this protection scheme.

## V.HAAR WAVELET

Haar functions have been used from 1910 when they were introduced by the Hungarian mathematician Alfred Haar. The Haar function is an odd rectangular pulse pair and it is the oldest orthonormal and simplest wavelet with squashed support.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In mathematics, the Haar wavelet is a series of rescaled "square-shaped" functions which jointly form a wavelet family basis. Wavelet analysis is similar to Fourier analysis in that it allows a target function over an interval to be represented in terms of an orthonormal function basis[8].
The Haar wavelet is also the simplest possible wavelet. The Haar wavelet is not continuous, and not differentiable. This property is an advantage for the study of signals with sudden transitions. for instance, monitoring of tool failure in machines.

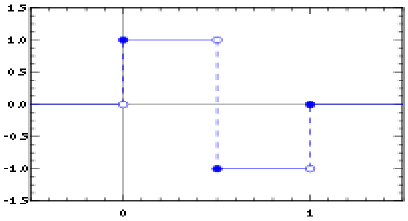

Figure 10: The Haar wavelet

The Haar wavelet's mother wavelet function $\psi(t)$ can be described as

$$\psi(t) = \begin{cases} +1 & 0 \leq t < \frac{1}{2} \\ -1 & {}^{1}/_{2} \leq t < 1 \\ 0 & \text{otherwise} \end{cases} \quad \ldots\ldots\ldots\ldots(5)$$

Its scaling function $\phi(t)$ can be described as

$$\text{Ø}(t) = \begin{cases} 1 & 0 \leq t < 1 \\ 0 & \text{otherwise} \end{cases} \quad \ldots\ldots\ldots(6)$$

*Advantages:* Haar is used for the analysis of signals with sudden transitions, such as monitoring of tool failure in machines.

## VI. OVERCURRENTS

In electricity supply, overcurrent or excess current is a condition where a larger than intended electric current exists through a conductor, leading to excessive generation of heat, and the risk of fire or damage to equipment. Possible causes for overcurrent comprise short circuits, ground faults, failure of mechanical components, reduction in flux, failure of one of the phase of supply, failure of insulation excessive load, and incorrect design.

## VII. BLOCK DIAGRAM AND DESCRIPTION

*Ratings of PMBLDCM.*

| | |
|---|---|
| power | 1kW |
| voltage | 500 Vdc |
| speed | 3000 rpm |
| Number of poles | 8 |

The below PMBLDC is fed by a six step voltage inverter. The DC bus voltage is controlled by usinga speed regulator. The inverter gates signals are created by decoding the Hall effect signals of the motor. The 3-Ø outputs of the inverter are applied to stator windings of the PMSM block. The load torque applied to the shaft of machine from 0 to its nominal value in steps.
The gate signals are developed, according to the hall sensors obtained, Similarly the current output given to wavelet & control block and this block produces the gate signals according to the logic written in that block. The below scheme is simulated in SIMULINK/MATLAB.

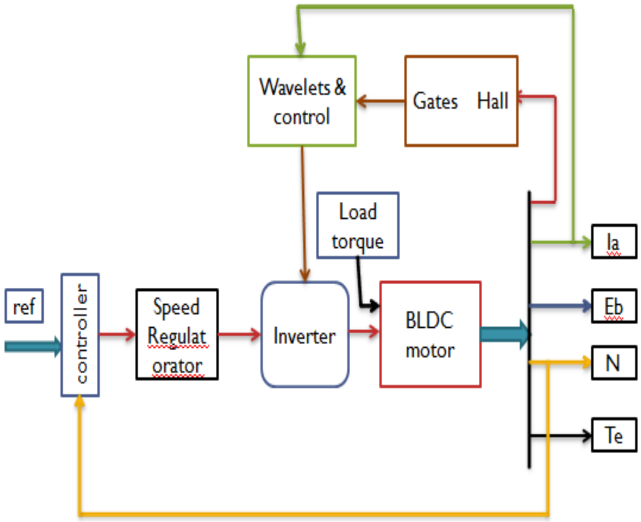


Figure 11:Overcurrent protection scheme for PMBLDCM

## VIII .RESULTS

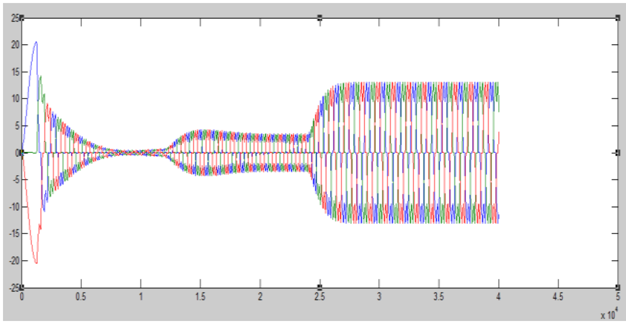

Figure 12: figure represents the motor's 3-Ø overcurrent components under abnormal condition with out protection.

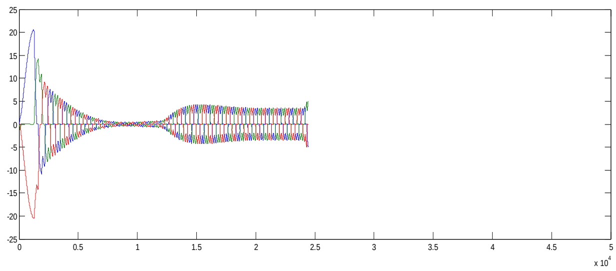

Figure 13: figure represents the motor 3-Ø overcurrent components under abnormal condition with protection .

Initially, at time t=0sec the 3- Ø load currents to the PMBLDCM was 0.5A,the load was increased gradually to 3.5A at t=0.06sec and similarly, at t=0.12sec the load reached to 15A . That currents taken as references to the to protect the PMBLDCM and applied wavelets to that current wave forms. As a result, got two components i.e approximation coefficients and detail coefficients. Finally, protection scheme was developed using these coefficients. Whenever the current exceeds the normal full load value, the maximum value of the approximation coefficient increases. The motor gets paused when this value greater than the value specified in the program.

## IX.CONCLUSION

In this paper, the construction, working principle and operation of PMBLDCM, wavelets are explained. With the increase in load torque, overcurrents are experienced. Approximation and detail coefficients of obtained overcurrents are calculated by using discrete wavelets. When the maximum of the approximation value exceeds the specified value than the PMDCM gets stopped. Figure 11 is simulated in SIMULINK/MATLAB and observed the waveforms shown in figure 12 and figure 13.

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