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Research paper

Bearing Fault Analysis in Induction Motor Drives Using Finite Element Method

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Abstract

Diagnosis of faults in induction motor is an indispensable process in industries to improve the reliability of the machine and reduce the financial loss. Among the various faults occurring in induction motors (IM), bearing fault is the predominant one which covers nearly 60% of faults. In this paper, a study of the electromagnetic field of an induction motor with bearing fault fed from both the mains and a three phase voltage source PWM inverter in open loop is carried out using Finite element method (FEM). Electromagnetic field parameters like flux lines distribution, flux density distribution and radial air gapflux density are analyzed. The presence of bearing fault can be detected from the spatial FFT spectrum of radial air gap flux density. From the FFT spectrum, it is seen that the amplitude of fundamental component of radial air gap flux density decreases and those around 100 mm distance increases with the severity of fault.

Keywords: *Induction motor, bearing fault, Finite element analysis, PWM inverter, radial air gap flux density.*

1. Introduction

In recent times the significance of conditional monitoring of electrical machines and drives is gaining popularity as it avoids the unwanted breakdown time and prevent the machines from catastrophic failure. It will improve the efficiency and reduce the cost of the investment in replacement and repair of electrical machine i.e., repair cost and production shut down. The majority of electrical drives in industry constitute of variable and critical speed applications. In such cases asynchronous machines play a leading role, in fact almost 85% of rotating machines in industries is comprised of induction machine because of their robustness, rugged construction, insensitive to operating .environment, low operating and maintenance cost. These qualities make this machine superior over other machines to be preferred as prime mover for critical applications. Electrical drives using induction motor are broadly classified into two types based on their source and application Inverter fed induction motor drive will be used in variable speed applications and Line fed induction motor will be used in constant speed applications.

As industry heavily depends on the reliable and safe operation of induction motor drive, fault diagnosis will help to prevent the subsequent failure of machine. As per the survey report, [10] bearing faults are the predominant faults in induction machine, depending on the size and type of the machine it varies about 40-90% from large scale to small scale followed by stator faults (38%),rotor related faults (10%) and miscellaneous faults (12%).

Bearing is a critical component in the machines subjected to lot of wear and tear. The quality of bearing will degrade over a period of time, increasing the friction of the machine which may leads to torque and speed oscillation. In general, roller and ball bearing are the prevailing type used in electrical machines, consisting of inner ring, outer ring, race way and cage. Due to wear and tear it may be subjected to fatigue lead to deterioration, if the stresses prolong. The following condition will lead to bearing faults in induction motor, namely poor lubrication, contamination, rubbing, corrosion and electrical pitting which occur especially in inverter fed machines. In case of inverter fed drives, rapid switching of semiconductor switches in the inverter will lead to harmonic rich current component, shaft voltage and bearing current in machine and may cause damage by circulating current.

In [1], bearing abnormality index is used as a quantitative metric containing information about the bearing defect& spectral magnitude is used to identify the bearing fault, [2],[5] proposes sparse deep neural network, Empirical Mode Decomposition (EMD)and auto regressive method to process the non-stationary signal component to identify the presence of abnormalities in the motor and advanced signal processing methods like variational mode decomposition, EMD, empirical wavelet transform and discrete wavelet transform is used to identify the bearing fault in induction motor. In [3], support vector machine to classify the abnormality by analysing the frequency component of load current is proposed and [4], proposes a generalised and localised defects of bearing using artificial neural network to classify the pattern obtained from machine components.

The multidiscipline correlation (Electric, Electromagnetic and mechanical domains) in the electric machines make the drive system coupled with nonlinear components. These nonlinearities will get intensified if the system get subjected to dynamic condition. So accounting of non-linearity effects in the modelling will improve the reliability of the analysis. The implication of

finite element method is considered to include the effect of non-linearity and to analyse the electromagnetic fields of induction machine, it stands superior over the analytical method.
In [6],[7], FEM is used to analyse the stator phase short circuit & inter turn fault in IM based on radial air gap flux density. The magnetic noise in the radial air gap flux density is used to analyse the broken rotor bar fault in IM [8].
FEM is a general tool accustomed for electric machine electromagnetic field problems, it conceives the machine model more precisely by accounting the type of winding, winding material, magnetic saturation level and effect of spatial harmonics in the air gap.
In this paper, ANSYS Maxwell 2D and Simplorer FEA tool is used to analyse the performance of induction motor drive during normal and bearing fault condition. The analysis is carried out in two cases IM directly fed from grid and the machine fed through a voltage source inverter in open loop condition.

2. Modelling of Induction Motor with Bearing Fault Using Finite Element Method

The three phase induction motor is modelled using ANSYS Rmxprt which is a template based on electric machine design tool and is imported to ANSYS Maxwell to carry out the analysis.
A simulation study is carried out on three phase, 380V, 1440rpm, 50Hz, 7.5kW induction motor, the model developed in ANSYS is shown in Fig. 1.The details of the motor used is

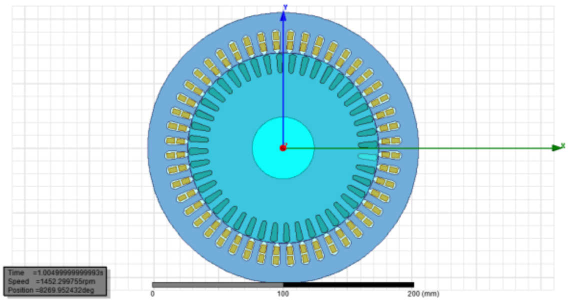


Fig. 1: Induction motor model in ANSYS

given in appendixThe IM in ANSYS Maxwell is co simulated with ANSYS Simplorer to feed the IM from mains and a 3 phase voltage source inverter. The bearing is modelled as a damping friction coefficient attached to the motor shaft in ANSYS Simplorer. The healthy bearing has a friction co efficient of 0.009 Nms/rad. The wear and tear of the bearing increases due to poor lubrication, contamination, corrosion and electrical pitting. The wear & tear is modelled by increasing the frictional co efficient attached to the motor shaft to significant values like 0.1, 0.2, and 0.3 Nms/rad based on the severity of the fault.

3. Transient Analysis of Line Fed Induction Machine

The induction machine is directly connected to the three phase supply from line. Machine is started on no load and at time 0.7s, rated load of 49 Nm is applied to the machine. Fig.2. & Fig. 3.shows the electromagnetic torque, line current and mechanical speed of the machine under healthy bearing (0.009 Nms/rad) and faulty bearing condition(0.3 Nms/rad) respectively. For the healthy bearing condition, the peak value of phase current is 24.87 A.As the bearing condition deteriorates, friction coefficients increase to 0.1, 0.2, and 0.3 Nms/rad and their corresponding peak value of phase current increases to 30.92 A. 34.94 A & 45.97 A.

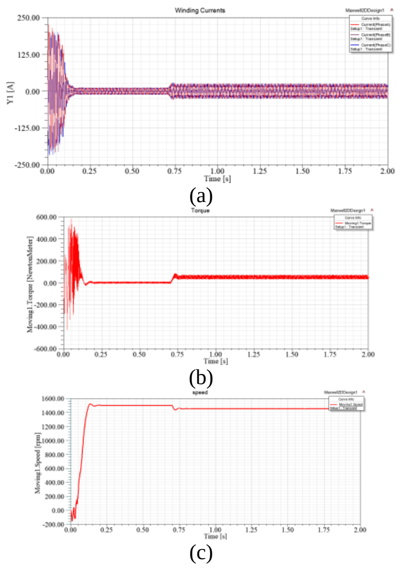


Fig. 2: Analytical parameter of line fed induction machine (with bearing friction 0.009 Nms/rad). (a) Line current. (b) Electomagnetic torque. (c) Speed

The variation in phase current induces oscillation in torque which increases the ripple to 40%and reduces the average torque. Similarly the average speed of the machine decreases from the steady state speed of 1450 rpm to 1405 rpm with added ripple of 11% when the bearing coefficient is varied from 0.009 Nms/rad to 0.3 Nms/rad. Fig. 4. shows the magnetic flux line distribution in the machine during normal and abnormal bearing condition at full load. The flux lines are symmetrically distributed for healthy machine whereas it can be clearly seen from Fig. 4(b), that the flux line distribution is asymmetrical for faulty bearing. The sinusoidal distribution of radial air gap flux density for healthy 4 pole induction machine at full load is shown in Fig. 5(a). Under faulty condition the bearing friction coefficient increases and the radial air gap flux density loses its symmetry which can be seen from Fig. 5(b).The spatial FFT spectrum of radial air gap flux density for healthy and faulty machine is shown in Fig. 6. From the FFT spectrum it can be seen that the amplitude of fundamental component under faulty condition decreases and the amplitude of harmonics at 100 mm distance increases compared to the healthy condition which can be seen from Table I. The amplitude of fundamental component decreases further and amplitude at 100 mm distance increases further based on the severity of the bearing fault.

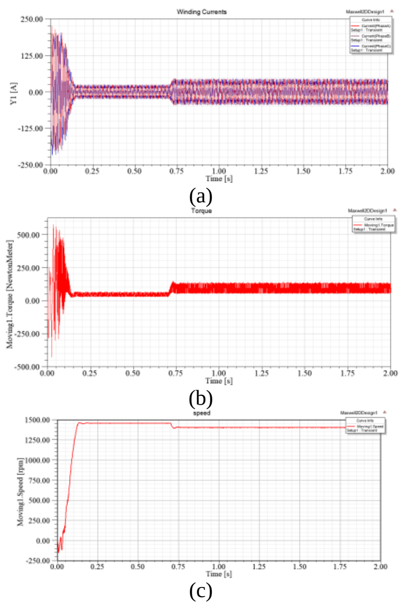
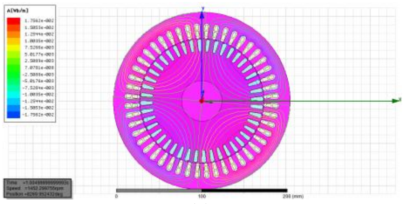


Fig. 3: Analytical parameters of fault in line fed induction machine (with bearing friction 0.3 Nms/rad): (a) Line current; (b)Electomagnetic torque; (c) Speed



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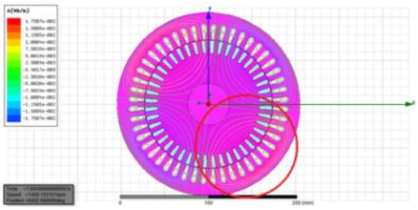

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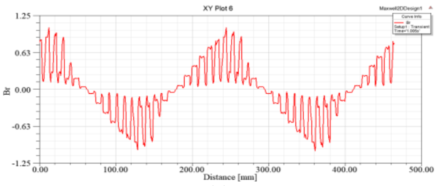
Fig. 4: Flux lines distribution in line fed induction machine

(a) Healthybearing condition (@ 0.009 Nms/rad), (b) Faulty bearing condition (0.3 Nms/rad)



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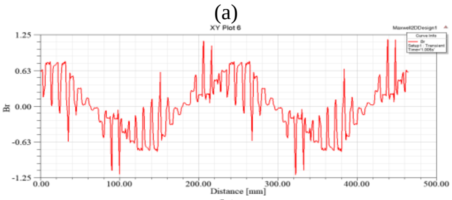
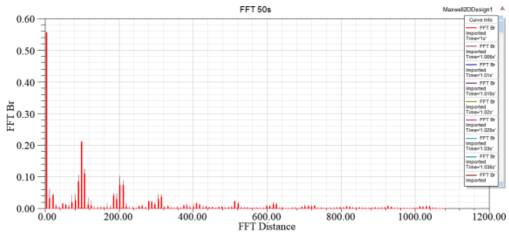


(b)

Fig. 5: Radial air gap flux density in line fed induction machine (a)Healthy bearing condition (@ 0.009 Nms/rad). (b) Faulty bearing condition (@ 0.3 Nms/rad)



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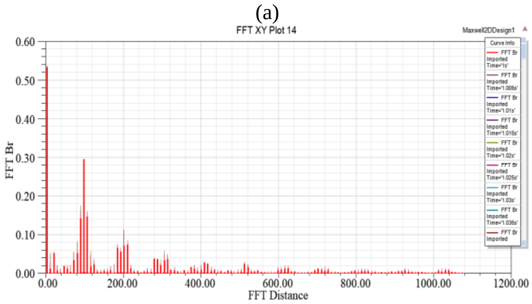


(b)

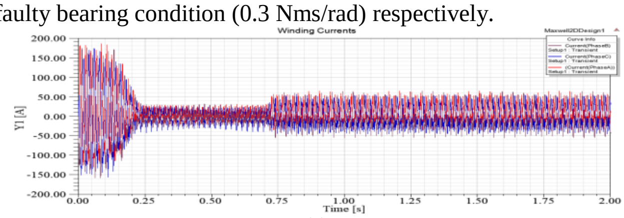
Fig. 6: FFT of Radial air gap Flux density distribution in line fed induction machine: (a) Healthybearing condition (@ 0.009 Nms/rad).(b) Faulty bearing condition (@ 0.3 Nms/rad)

Table I: Magnitude of Spatial FFT Spectrum of Radial Air Gap Flux Density

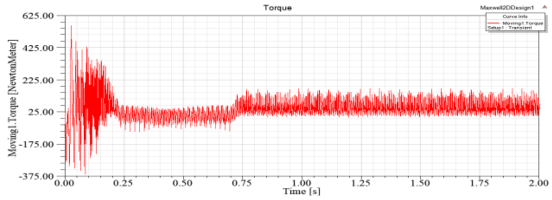
S.NO	Bearing coefficient rad s/m	Line FED IM	
		Fundamental	100 mm
1.	0.009	0.5580	0.2128
2.	0.1	0.5515	0.2370
3.	0.2	0.5440	0.2659
4.	0.3	0.5344	0.2952

4. Transient Analysis of Inverter Fed Induction Motor

The induction machine is fed through inverter under open loop condition and sine PWM is considered as control strategy with switching frequency of 2 kHz. This leads to distortion in line voltage and line current due to switching action of semiconductor devices which will increase the spatial harmonics in the air gap and noise in the machine. The wide range of harmonic spectrum makes the Machine current signature analysis (MCSA) technique not enough for inverter fed condition. Fig. 7.and Fig. 8.shows the variation of electromagnetic torque, speed and line current of the machine under healthy bearing condition (0.009 Nms/rad) and faulty bearing condition (0.3 Nms/rad) respectively.



(a)



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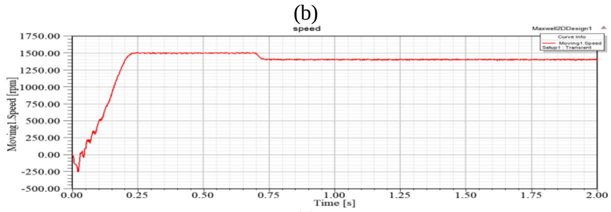

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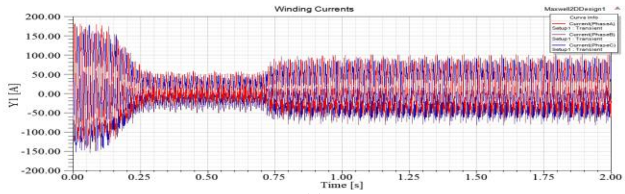
Fig. 7: Analytical performance of Inverter fed induction machine (with bearing friction 0.009 rad s/m) (a)Line current.(b) Electomagnetic torque.(c) Speed



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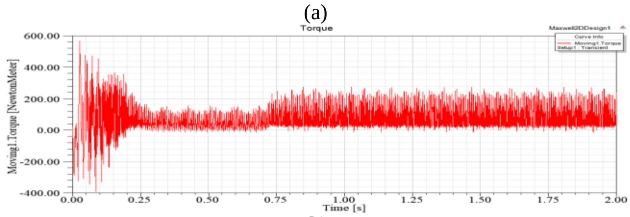

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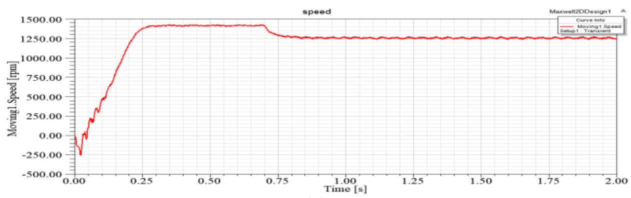
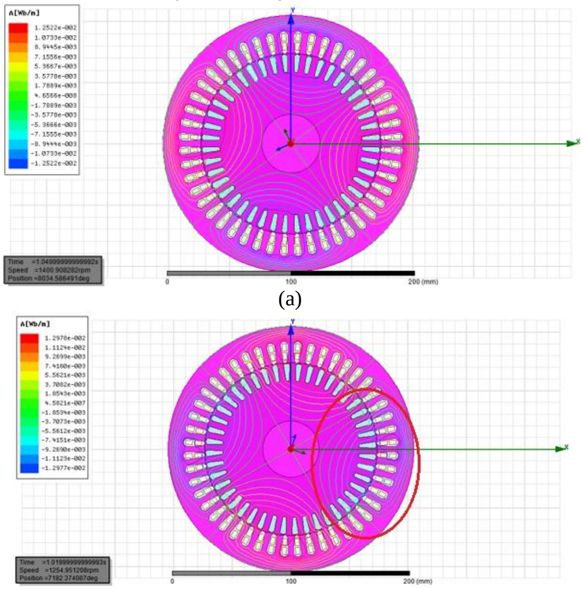


(c)

Fig. 8: Analytical performance of Inverter fed induction machine (with bearing friction 0.3 Nms/rad) (a)Line current. (b) Electomagnetic torque.(c) Speed

It is clearly seen from Fig. 7 that increase in bearing friction coefficient correspondingly increases the peak of the phase current which will cause heating of stator winding. Moreover distortion in. line current leads to oscillation in the torque of the machine and increase of ripple content at the worst bearing condition. This leads to oscillation in the speed of the machine and decrease in average shaft speed of the machine. The average speed is reduced to 1257 rpm from the steady state speed of 1450 rpm at bearing friction coefficient of 0.3 Nms/rad thus seen a decrease in average shaft speed. Flux line distribution of the machine is symmetrical under healthy condition and as the effect of bearing friction increases, distribution becomes asymmetrical as seen Fig. 9. Increase in fault severity correspondingly increases the distortion in flux lines. Fig. 10 indicates the sinusoidal radial air gap flux density of a 4 pole induction machine at full load condition in both normal and abnormalbearing friction coefficient conditions. The presence of sharp peaks in positive and negative cycle of radial air gap flux density is due to the high switching frequency of inverter. Under faulty condition the radial flux density distribution is highly distorted and uneven compared to the healthy condition. Fig. 11 shows the spatial FFT spectrum of radial air gap flux density at full load under healthy and faulty condition.

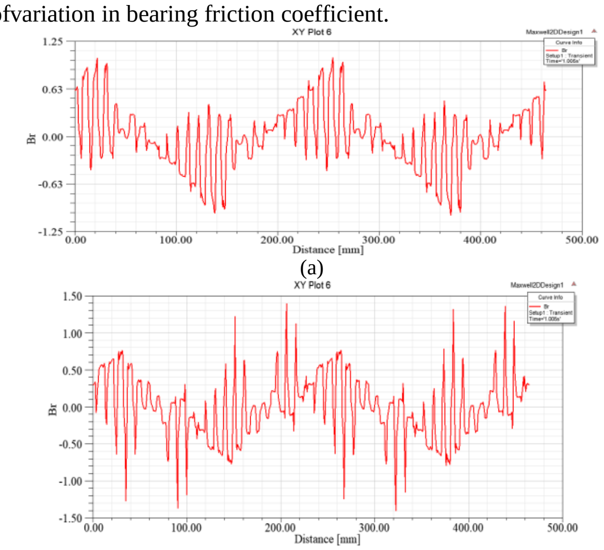


(a)

(b)

Fig. 9: Flux lines distribution in induction machine (a) Healthy bearing condition (@ 0.009 Nms/rad).(b) Faulty bearing condition (0.3 Nms/rad)

It is evident from the spectrum that the magnitude of the fundamental and 100 mm component is varying as a consequence ofvariation in bearing friction coefficient.



(a)

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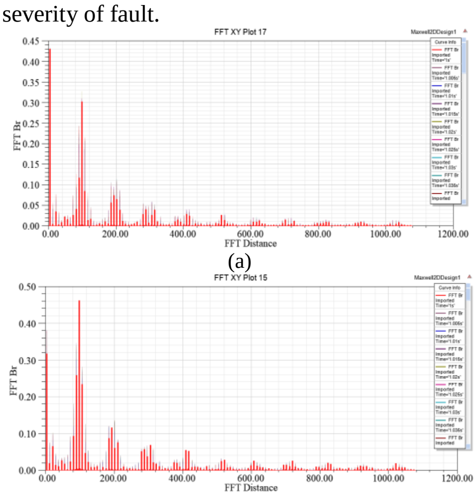
Fig. 10: Radial air gap Flux density distribution in inverter fed induction machine (a) At normal condition (@ 0.009 Nms/rad). ii) At abnormal condition (@ 0.3 Nms/rad)

It is evident from Table II., the magnitude of fundamental component is decreasing and 100 mm component is increasing with the severity of fault.



(a)

(b)

Fig. 11: FFT of Radial air gap Flux density distribution in inverter fed induction machine (a) Healthy bearing condition (@ 0.009 Nms/rad). ii) At abnormal condition (@ 0.3 Nms/rad)

Table II: Magnitude of Spatial FFT Spectrum of Radial Air Gap Flux Density

S.NO	Bearing coefficient rad s/m	Inverter FED	
		Fundamental	100mm
1.	0.009	0.4300	0.3433
2.	0.1	0.4175	0.3875
3.	0.2	0.3998	0.4241
4.	0.3	0.3818	0.4610

5. Conclusion

In this paper electromagnetic analysis of mains fed and inverter fed induction motor drive during normal and abnormal bearing condition is analyzed using FEM. The wear and tear of bearing fault is incorporated by increasing friction coefficient attached to motor shaft in FEM. When the wear and tear in the bearing increases, the current ripple increases which leads to torque ripple and decrease in average speed.

It also leads to asymmetry in the flux lines distribution of the machine and distortion in the radial air gap flux density. The FFT spectrum of radial air gap flux density shows decrease in the amplitude of fundamental component and increase in amplitude at a radial distance of 100 mm.

Appendix

A. Three Phase Induction Motor Data in ANSYS Maxwell
1. General data
Given Output Power(kW):7.5
Rated Voltage(V):380
Number of poles: 4
Speed (rpm): 1450 rpm
Frequency(Hz): 50
2. Stator data
Number of stator slots: 48
Outer diameter of stator (mm):210
Inner diameter of stator (mm):148
Length of Stator Core(mm):250
TypeofSteel:M19 24G
NumberofParallelBranches:2
NumberofConductorsperSlot:30
Number of wires per conductor:2
3.Rotor data
NumberofRotorSlots:44
Air Gap(mm):0.35

Inner Diameter of Rotor(mm):48
Length of Rotor(mm):250
TypeofSteel:M19 24G

References

[1] Kang M, Kim J, Jeong IK, Kim JM & Pecht M, "A massively parallel approach to real-time bearing fault detection using sub-band analysis on an FPGA-based multicore system", *IEEE Transactions on Industrial Electronics*, Vol.63, No.10, (2016), pp.6325-6335.
[2] Qi Y, You W, Shen C, Jiang X, Huang W & Zhu Z, "Hierarchical diagnosis network based on sparse deep neural networks and its application in bearing fault diagnosis", *Prognostics and System Health Management Conference (PHM-Harbin)*, (2017), pp.1-7.
[3] Pandarakone SE, Akahori K, Matsumura T, Mizuno Y & Nakamura H, "Development of a methodology for bearing fault scrutiny and diagnosis using SVM", *IEEE International Conference on Industrial Technology (ICIT)*, (2017), pp.282-287.
[4] Zhao H & Li L, "Fault diagnosis of wind turbine bearing based on variational mode decomposition and Teager energy operator", *Journal on Renewable Power Generation*, Vol.11, (2017), pp. 453-460.
[5] Prieto MD, Espinosa AG & Henao H, "Bearing Fault Detection by a Novel Condition-Monitoring Scheme Based on Statistical-Time Features and Neural Networks", *IEEE Transactions on Industrial Electronics*, Vol.30, (2013), pp.3398-3407.
[6] Praveen Kumar N & Isha TB, "Electromagnetic Field Analysis of 3 Phase Induction Motor Drive under Broken Rotor Bar Fault Condition Using FEM", *IEEE International Conference on Power Electronics Drives and Energy Systems*, (2016).
[7] Praveen Kumar N, Isha TB & Balakrishnan P, "Radial Electromagnetic Field Analysis of Induction motor Under Faulty Condition using FEM", *Biennial International Conference on Power and Energy Systems: Towards Sustainable Energy*, (2016).
[8] Prasob K, Praveen Kumar N & Isha TB, "Inter-Turn Short Circuit Fault Analysis of PWM Inverter Fed Three-Phase Induction Motor Using Finite Element Method", *International Conference on Circuit ,Power and Computing Technologies*, (2017).
[9] Thorsen OV & Dalva M, "A survey of faults on induction motors in offshore oil industry, petrochemical industry, gas terminals and oil refineries", *Petroleum and Chemical Industry Conference*, (2002).