# Parks-Hilbert Transform based Fault classification of Induction Motor

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***Abstract***: It is well know that stator winding faults and Bearing defects are the most frequent source of breakdown in Induction motors. Small inter turn short faults and normal bearing defects detect early to reduce damage and repair cost. So, this paper describes to analyse the different faults occurring in three phase induction motor such as inter-turn short circuit and bearing faults. This paper proposes Parks Transform and Parks-Hilbert Transform to detect inter turn short circuit as well as bearing faults. This method effectively distinguishes inter-turn short circuit condition in stator as well as inner race and outer race defects in the bearing. The Parks-Hilbert approach is depends on the spectral analysis through FFT. The theoretical background of the Parks Transform and Parks-Hilbert Transform present and acquisition of currents and voltages of special 2 KW three phase Induction motor to propose method on the basis of amplitude of $\mathrm{PSVM}_{P-H}$ in different condition. ANN is used to classify the listed faults. It produces excellent capabilities in fault classification process.

***KeyWords:*** *Three phase Induction motor, inter turn short circuit faults (10-T), bearing defects (Inner race & outer race), Parks Transform, Parks-Hilbert Transform, ANN (Artificial Neural Network).*

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## I. INTRODUCTION

The 3 ø induction motor has wide application in industries. Induction motors play a very important role in the safe and running of industrial processes. In industry, it is necessary to run drive continuously without any break down. But, different loading conditions and duty cycles can lead to the frequent occurrence of faults, such as inter turn, short circuit and bearing faults[1],[2].Failure of 3 ø induction motor may further goes towards major economical loss. Main reason for this loss can be a turn to turn insulation failure and bearing faults. It is necessary to detect faults at initial stage which can prevent from an increase of severe loss and also avoid repairing cost and breakdown hours. Many papers used different methods to analyse inter turn and bearing faults. For example,[1] shows analysis of inter turn faults by parks – Hilbert transformation and shown that inter turn faults causes grow of harmonics.[2],gives method to detect bearing fault using stator current. Method implements by filtering unwanted frequency component in stator current which are not necessary in detection of bearing faults. In general look of failures [3] have reported that 40% of the motor Failures were because of bearing related failures, 38% faults by stator insulation failures, l2% by rotor related failures and l0 % by other failures. Obviously, most often faults are inter turn and bearing faults.

## I. PROPOSED FAULT

**A. Bearing Fault:** The large race that goes in the bore is called the outer race and the some race that the shaft rides in it called as inner race. A cage is part of bearing which holds the balls together. This fault characterized into distributed and localized defects. Single-point defects are localized defects and can be classified according to its effect on different element such as [6][9],

- Outer raceway defect
- Inner raceway defect

**B. Turn to turn insulation Failure:** The stator is goes under various stresses such as, thermal, electrical mechanical and environmental which severely affects the stator status grow towards faults [4].
The stator faults can be broadly classified into the following two categories.

**A) End winding portion**: local damage to insulation, fretting of insulation, contamination of insulation by moisture, oil or dirt, damage to connectors, cracking of insulation, discharge erosion of insulation, displacement of conductors, turn to turn faults.

**B) Slot portion** : fretting of insulation, displacement of conductors[5].
It is obvious that, effect of inter turn fault is MMF because of stator winding changes. It further causes change of flux density [1]

## II. PROPOSED METHOD

A. Parks Transform
B. Parks-Hilbert Transform

**Parks Transform:** It is simple approach to analysis to detect inter turn short circuit fault, by spectral analysis of parks vector modulus [1] [7] [4]. (PVM), stated as,

$$\text{PSV} = \sqrt{i_d^2 + i_q^2}$$

Where $i_d$ & $i_q$ are the parks vector component which are calculated using three phase currents as follows.

$$i_d(t) = \sqrt{\frac{2}{3}}\, i_A(t) - \sqrt{\frac{1}{6}}\, i_B(t) - \sqrt{\frac{1}{6}}\, i_C(t)$$

$$i_q(t) = \sqrt{\frac{1}{2}}\, i_B(t) - \sqrt{\frac{1}{2}}\, i_C(t)$$

The stator winding faults can be easily detects by successfully implemented parks vector modulus. It can be done by only knowing spectral component at twice of supply frequency.

**Parks-Hilbert Transform:**

The step by step approach for Parks-Hilbert is as follows [1].

1) The data acquisition system acquisition of 3-phase currents $I_A, I_B, I_C$ at different conditions such as healthy, inter turn short circuit (10-T, 20-T, 30-T) and bearing defects (inner & outer race).

2) In Hilbert approach computation of three analytical signals ($\bar{I_A}, \bar{I_B}, \bar{I_C}$) using,

$$y\,(t) = \text{HT}\; x\,(t) = \frac{1}{\pi t} \times x\,(t)$$

3) IA of each analytical signal ($|\bar{I_A}|, |\bar{I_B}|, |\bar{I_C}|$) is to be determined by using,

$$\bar{x}(t) = x\,(t) + j\,y\,(t) = a(t)e^{j\theta(t)}$$

With

$$a(t) = \sqrt{|x^2(t) + y^2(t)|} \quad \text{and}$$

$$\theta(t) = arc\ tan\left(\frac{x\,(t)}{y\,(t)}\right)$$

Where $a(t)$ the instantaneous amplitude of the $\bar{x}(t)$ and $\theta(t)$ is the instantaneous phase of the $\bar{x}(t)$.

4) The Parks-Hilbert components calculation is as follows,

$$i_{d(P-H)}(t) = \sqrt{\frac{2}{3}}\, |\bar{I_A}\,(t)| - \sqrt{\frac{1}{6}}\, |\bar{I_B}\,(t)| - \sqrt{\frac{1}{6}}\, |\bar{I_C}\,(t)|$$

$$i_{q(P-H)}(t) = \sqrt{\frac{1}{2}}\, |\bar{i_B}\,(t)| - \sqrt{\frac{1}{2}}\, |\bar{i_C}\,(t)|$$

5) Calculation of PSVMP-H by using,

$$\text{PSVM}_{P-H} = i^2_{d\,(P-H)} + i^2_{q\,(P-H)}$$

6) Analysis, of the $PSVM_{P-H}$ by using Fast Fourier Transform (FFT).

## III. ARCHITECTURE OF ANN

The Neural networks are combination of various layers and layers made of number of interconnected nodes. The hidden layers then link with out- put layers and final answers is out-put as shown in figure 1.

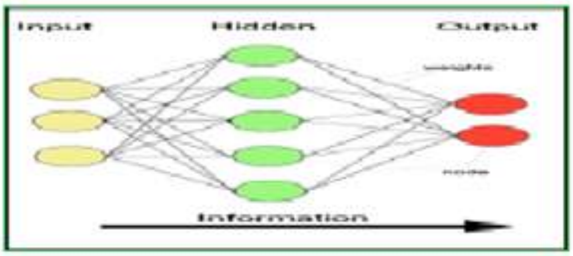


Figure1: ANN Architecture

## IV. EXPERIMENTAL SET UP

The fault of Induction motor diagnose at high accuracy level, a modern laboratory test bench set up as shown in figure 2.

Fig. 2: Experimental set up

The experimental set up used to acquisition of various data sheet at different condition. 2 HP, three phase, 50 Hz squirrel cage Induction motor with electrical loading used for experimental purpose.

The Induction motor coupled with D.C shunt generator with resistive load arrangement is used for the electrical loading to analysis inter-turn short faults (10-T,) and bearing defects (Inner race and outer race).. The three phase stator current signals IA, IB and IC captured with voltage VA the ADLINK data card, with 1 KHz sampling were used to capture the current. The main purpose of experimentation is to capture the motor current signals IA, IB and IC under healthy and faulty condition.

## V. EXPERIMENTAL RESULT OF PARKS TRANSFORM

**A) Time domain analysis:**

The capture current signals from stator winding of 3 phase Induction motor at No load in healthy condition, Inner race defects, Outer race defects and 10-T inter turn short circuit shows in figure 6a, 6b, 6c and 6d respectively.

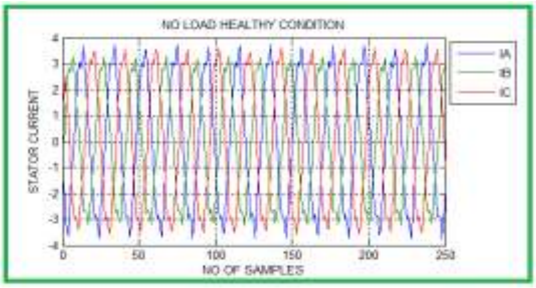


Fig 6a: Stator current signals

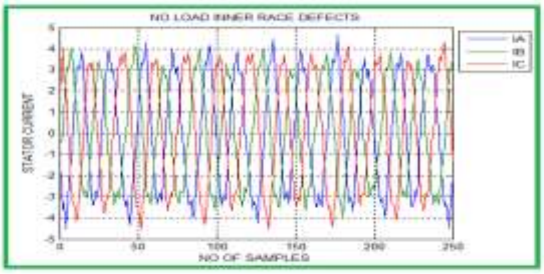


Fig. 6b: Stator current signals.

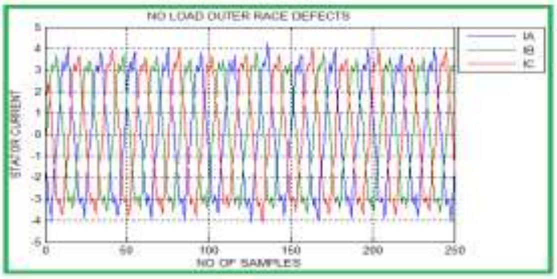


Fig. 6c: Stator current signals.

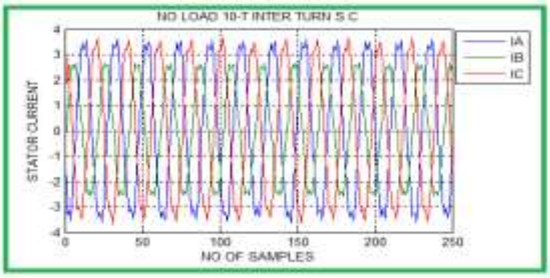


Fig. 6d: Stator current signals.

The time domain analysis is quit inconvenient in this case so, instead of this method Frequency domain analysis is preferred.

**B) Frequency domain analysis:** The spectrum of Parks Transform at No load is analyzed by Fast Fourier Transform (FFT).

PSV = $\sqrt{i_d^2 + i_q^2}$

The spectrum for healthy condition, Inner race defects, Outer race defects and 10-T Inter turn short circuit at no load shows in figure 7a, 7b, 7c and 7d respectively.

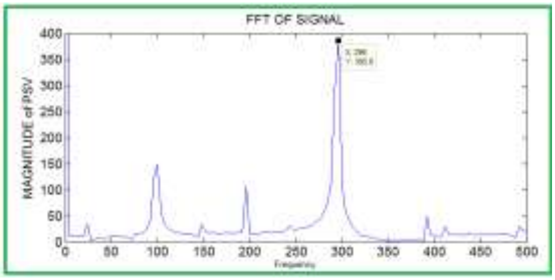


Figure 7a: PSV Spectrum at no load (Healthy)

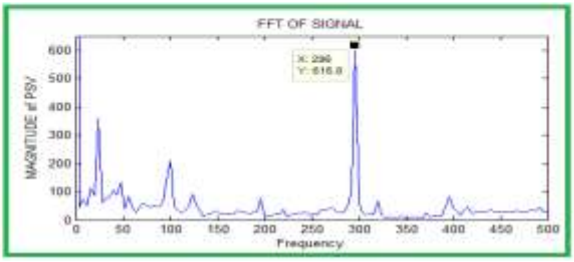


Figure 7b: PSV Spectrum at no load (Inner race defect)

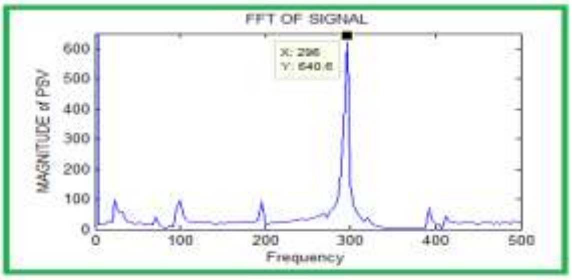


Figure 7c: PSV Spectrum at no load (Outer race defects).

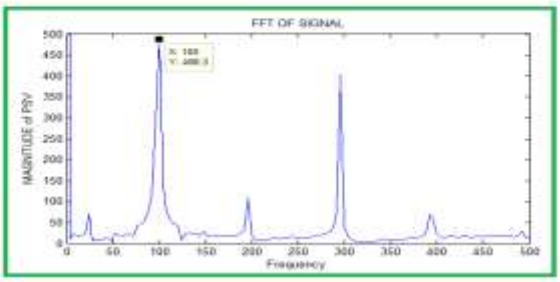


Figure 7c: PSV Spectrum at no load (10-T Inter turn S.C).

The magnitude of PSV and its frequency shown in following table 1 at Healthy, inner race defects, outer race defects and 10-T inter turn S.C condition.

| S N | Faults/ Defects | Magnitude of PSV | Frequency |
|---|---|---|---|
| 1 | Healthy | 385.8 | 296 |
| 2 | Inner Race | 616.8 | 296 |

| | | | |
|---|---|---|---|
| 3 | Outer Race | 640.6 | 296 |
| 4 | 10-T inter turn S.C | 486.3 | 100 |

Table1: Classification of PSV Vs frequency.

### C. ANN BASED FAULT CLASSIFICATION OF PARKS TRANSFORM.

The artificial neural network techniques are rather easy to develop and to perform. Stator currents captured from motor terminals under healthy, faulty bearing and inter turn short circuit, at various loading condition are transformed in to frequency domain. Fourteen statistical parameters computed such as Minimum, Maximum, Mean, Median, Sum, Absolute sum, RMS value, Energy, Kurtosis, Crest factor, Shape factor, standard deviation, Variance and Skewness of transformed signals are fed as input to ANN for classification of Healthy, Bearing and Inter turn short circuit defects transformed signals are fed as input to ANN for classification of Healthy, Bearing and Inter turn short circuit defects [8].

Generalized feed forward ANN with transfer function TanhAxon and learning rule used is momentum, step size is 0.1000, momentum 0.700000 and maximum epochs are 1000 used to train the network. The percentage of training is 75% and percentage of testing is 25% with different combination of hidden layers, processing elements, performance of network is evaluated.

The fourteen statistical parameters computed using parks Transformation given to ANN network classifies Healthy, Bearing defect and inter turn short circuit giving following % classification accuracy in table 2. Figure 8a and figure 8b shows the graph of % accuracy Vs number of PEs and MSE Vs number of PEs respectively.

| Sr.No | No of Inputs | No of PE | MSE | % Accuracy Result | | |
|---|---|---|---|---|---|---|
| | | | | H | B | IT(S.C) |
| 1 | 14 | 1 | 0.11 | 100 | 60 | 100 |
| 2 | | 2 | 0.11 | 100 | 66.6 | 100 |
| 3 | | 3 | 0..06 | 0 | 80 | 71.4 |
| 4 | | 4 | 0.06 | 66.6 | 75 | 100 |
| 5 | | 5 | 0.06 | 0 | 50 | 100 |
| 6 | | 6 | 0.02 | 100 | 57.1 | 100 |
| 7 | | 7 | 0.03 | 100 | 80 | 100 |
| 8 | | 8 | 0.04 | 66.6 | 100 | 100 |

Table 2: Classification of % Accuracy

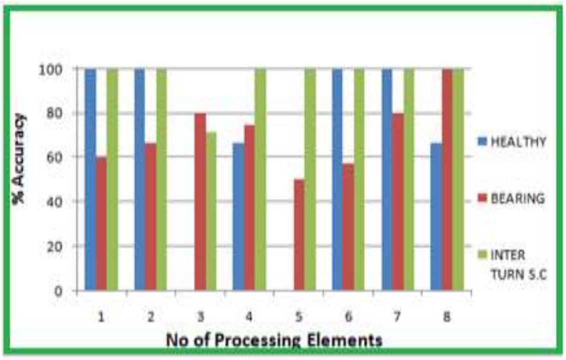


Figure 8a: % Accuracy Vs No of PEs.

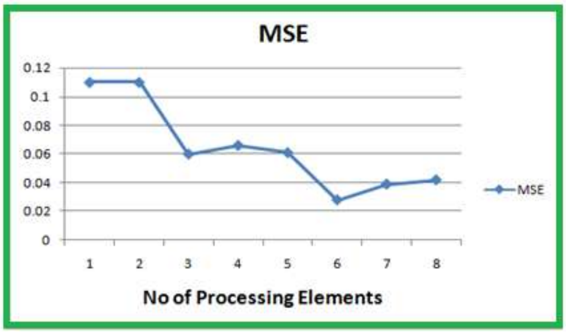


Figure 8b: % MSE Vs No of PEs.

## VI. EXPERIMENTAL RESULT OF PARKS-HILBERT TRANSFORM

### A) Time domain analysis:

The capture current signals from stator winding of 3 phase Induction motor at No load in healthy condition, Inner race defects, Outer race defects and 10-T inter turn short circuit shows in figure 9a, 9b, 9c and 9d respectively.

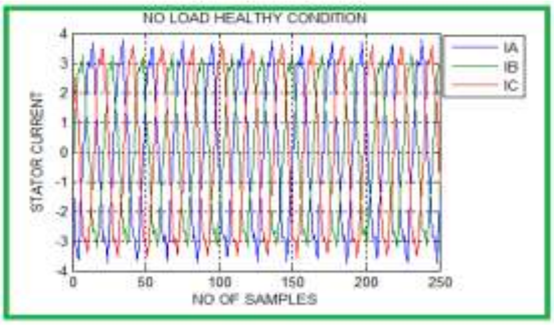


Fig. 9a: Stator current signals.

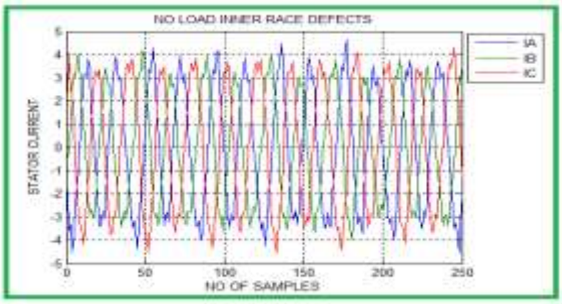


Fig. 9b: Stator current signals.

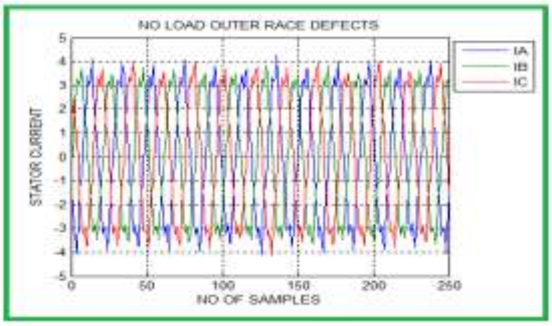


Fig. 9c: Stator current signals.

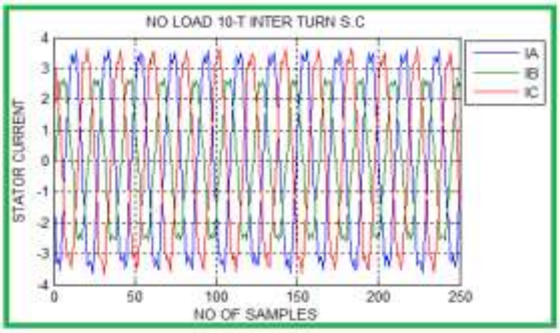


Fig. 9c: Stator current signals.

The time domain analysis is quit inconvenient in this case so, instead of this method Frequency domain analysis is preferred.

**B) Frequency domain analysis:** The Parks Square Vector Modulus ($PSVM_{P-H}$) spectrum of Parks-Hilbert Transform at No load is analyzed by Fast Fourier Transform (FFT).

$$PSVM_{P-H} = i^2_{d(P-H)} + i^2_{q(P-H)}$$

The spectrum for healthy condition, Inner race defects, Outer race defects and 10-T Inter turn short circuit at no load shows in figure 10a, 10b, 10c and 10d respectively.

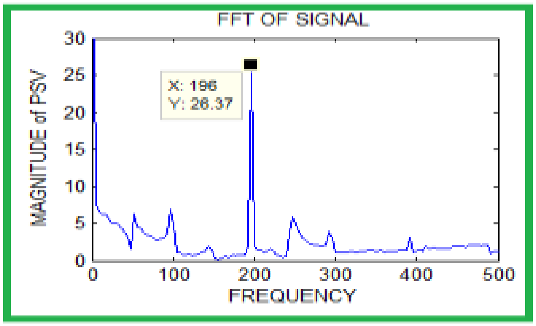


Figure 10a: $PSVM_{P-H}$ Spectrum at no load (Healthy)

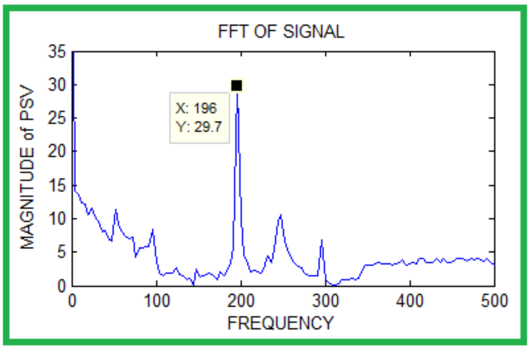


Figure 10b: $PSVM_{P-H}$ Spectrum at no load (Inner Race)

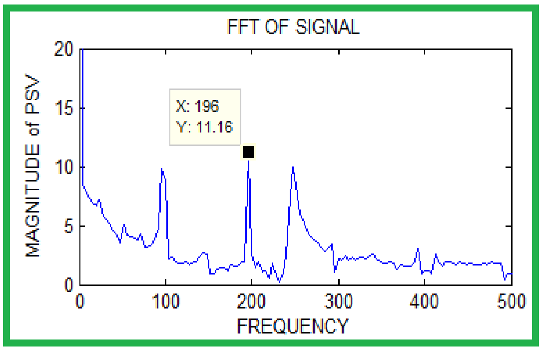


Figure 10c: $PSVM_{P-H}$ Spectrum at no load (Outer Race)

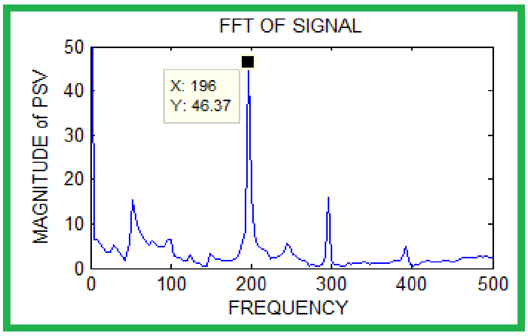


Figure 10c: $PSVM_{P-H}$ Spectrum at no load (10-T Inter Turn)

The magnitude of $PSVM_{P-H}$ and its frequency shows in table 3 at Healthy, inner race defects, outer race defects and 10-T inter turn S.C condition.

| Sr.No | Faults/Defects | Magnitude of $PSVM_{P-H}$ | Frequency |
|---|---|---|---|
| 1 | Healthy | 26.37 | 196 |
| 2 | Inner Race | 29.7 | 196 |
| 3 | Outer Race | 11.16 | 196 |
| 4 | 10-T inter turn S.C | 46.37 | 196 |

Table3: Classification of PSV Vs frequency

ISSN: 2321-8169
028– 033

### C. ANN BASED FAULT CLASSIFICATION OF PARKS-HILBERT TRANSFORM.

The fourteen statistical parameters computed using Parks-Hilbert Transformation given to ANN network classifies Healthy, Bearing defect and inter turn short circuit giving following % classification accuracy in table 4. Figure 11a and figure 11b shows the graph of % accuracy Vs number of PEs and MSE Vs number of PEs respectively.

| **Sr .No** | **No of Inputs** | **No of PE** | **MSE** | **% Accuracy Result** | | |
|---|---|---|---|---|---|---|
| | | | | **H** | **B** | **IT(S.C)** |
| 1 | 14 | 1 | 0.092 | 100 | 42.8 | 100 |
| 2 | | 2 | 0.080 | 66.6 | 40 | 83.3 |
| 3 | | 3 | 0.093 | 100 | 71.4 | 100 |
| 4 | | 4 | 0.096 | 100 | 60 | 100 |
| 5 | | 5 | 0.039 | 66.6 | 60 | 100 |
| 6 | | 6 | 0.061 | 0 | 100 | 100 |
| 7 | | 7 | 0.071 | 100 | 75 | 88.8 |
| 8 | | **8** | **0.079** | **100** | **100** | **100** |

Table 4: Classification of % Accuracy

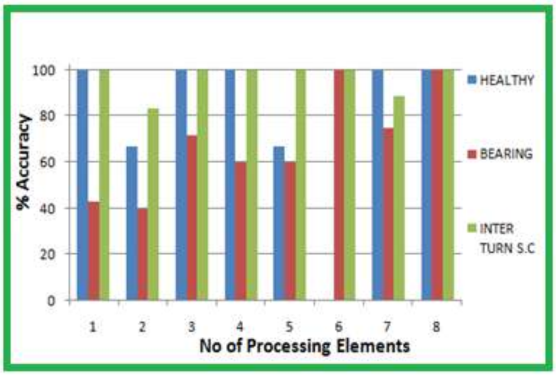


Figure 11a: % Accuracy Vs No of PEs.

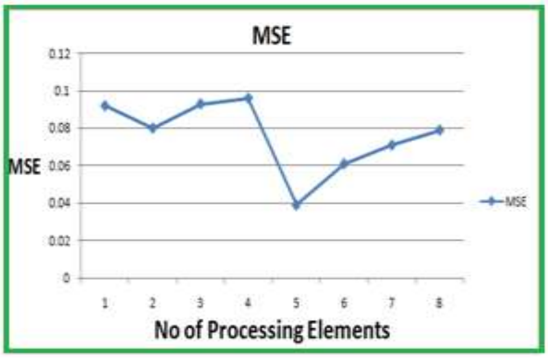


Figure 11b: % MSE Vs No of PEs.

## VII. CONCLUSIONS

This paper has presented Parks Transform and Parks-Hilbert Transform method for detection and diagnosis of Induction motor fault, which is based on the spectral analysis, via the FFT, of the PSV and $PSVM_{P-H}$ computed. Results obtained by using parks transform and Parks-Hilbert Transform clear that Parks-Hilbert Transform is best method to detect and diagnosis the Induction motor faults. Parks-Hilbert transform gives different magnitude of $PSVM_{P-H}$ at frequency 196 Hz.

ANN gives fault classification result by considering different combination of statistical parameters which are input of ANN. Parks-Hilbert based fault classification achieving 100% accuracy at 0.079 minimum mean squared error (MSE).

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