Stator Faults Diagnosis and Protection in 3-Phase Induction Motor Based on Wavelet Theory

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ABSTRACT

Induction motor faces various stresses during operation conditions. The conditions of monitoring, diagnosis of faults and protection become needful in order to avert tragic failures. The stator winding faults are usually related with insulation failures which are generally known inter turn, line-to-ground, line-to-line and loss phase faults. Discrete and packet wavelet transforms can be employed to extract certain features for induction motor line currents to diagnosis between the healthy and faulty conditions and detect the type of fault. This paper proposes a current signature from the second level of decomposition (ad^2) and (dd^2). The mother wavelet is chosen according to mean square error (MSR) technique, while the optimal level of resolution is chosen according to non-normalized Shannon entropy criterion. The Matlab-simulation results reflect that the proposed signature method has the ability to detect and discriminate the fault within quarter cycle (using Laptop computer,Windows_7,Matlab_R2010a).
Keywords: wavelet packet transform, induction motor protection, Shannon entropy, MSR.

تشخيص وحماية أعطال الجزء الثابت للمحرك الحثي الثلاثي الطور اعتماداً على نظرية المويجه

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الخلاصة

يواجه المحرك الحثي شتى انواع الاجهاد خلال ظروفه التشغيليه. لذلك فأن الرصد والتشخيص لاعطاله وحمايته منها قد اصبح من الاحتياجات المهمة وذلك من اجل تجنب الاعطال الكارثية. تحدث اعطال ملفات الجزء الثابت عادة نتيجه تلف عوازلها والتي تعرف انواع اعطابها (داخل ملف الطور الواحد ، ملف طورمع الارضي ، ملفات طورمع ملفات طور اخر، فقدان احد اطوار مصدر التغذية) .ان التحويلات المقطعة والحزمه للمويجه يمكن استخدامها لاستخراج ميزات تيارات خطوط المحرك الكهربائي من اجل التشخيص بين ظروف التشغيل الطبيعية وظروف العطل مع امكانية تحديد نوع ذلك العطل. ان الغرض من ذلك البحث هو استنباط بصمه من قيم المعاملات (ad^2) و(dd^2) لتيار العطب عند تحليله حتى المستوى الثاني. تم اختيار المويجه الام وفقاً لتقنية مربع متوسط الخطأ (MSR) ، بينما تم اختيار افضل مستوى تحليل وفقاً لمعيار قانون شانون انتروبي الاول . تعكس البصمه المقترحه من خلال نتائج برنامج المحاكاه الماتلاب ان لديها القدرة على كشف وتمييز الخطأ للمحرك الحثي ضمن ربع دورة.
الكلمات الرئيسية : تحويله حزمه المويجه ، حماية المحرك الحثي ، شانون انتروبي ، مربع متوسط الخطأ

1. INTRODUCTION

Induction motor is commonly used in industries application for many causes; it is simple construction, solid and high reliability like compressors, low maintenance requirement, such as fans, pumps and other applications. The harmonics which are included in induction motor currents are used as indication of various faults. The Squirrel cage induction motor is an important type as it can operate during fault conditions until the fault becomes rise**, Hamma, 2014, Gaeid,** and **Ping, 2011, Jawadekar, et al., 2014.**

Many various techniques are applied to fault detection that focus on the stator faults to non-invasive properties. The tools of signal processing contain discrete Fourier transform (DFT), fast Fourier transform (FFT) are useful tools for non stationary signal analysis**,Yang, et al., 2003, Coifman,** and **Meyer, 1992.** The techniques of FFT signal processing which are depend on the stator current fundamental frequency, motor speed and load are enough for faults diagnosis but sometimes they cannot be applied for high sharp signals with nonlinear systems**, Hamma, 2014.**

The wavelet technique is capable to get information in frequency and time domains in additional to it have a high sensitive for diagnosis faults compared with classical signals processing techniques such as DFT and FFT, **Pons-Llinares, et al., 2015.** The wavelet becomes one of the most important tools which are used for analyzing the frequency and time domains. It has multi-resolution analysis and perfect time localization which produces very attractive researchers in faults diagnosis **Zhang, et al., 2015.**

A research has been done to enhance and perform reliable technique to monitor, protection and diagnostic faults of electrical machines. These techniques are based on applying tools for digital signal processing on stator currents of induction motors**, Liang, et al., 2002.** Another technique, Fuzzy logic is applied in induction motor faults detection**, Mini, et al., 2010, Agrawal , et al., 2015,** besides the wavelet technique. The last is used in transformer protection**, Saleh,** and **Rahman, 2005, Saleh, 2003,** to discriminate inrush and normal current from faulted current. The wavelet is also used for permanent magnet motor faults protection**, Kafiey, 2006, Pons-Llinares, et. al., 2015.** The technique uses the detail coefficients form the second level to find a signature for line current which is used for faults diagnosis.

In this paper, the WPT is used to construct an extraction features from the second level details and approximation coefficients. For this purpose, the paper includes collection of data from a 3-phase induction motor for different faults for no load and different loading conditions, chosen of the optimized mother wavelet and optimized levels number for resolution used off-line testing for data collected by Matlab_R2010a environments.

2. WAVELET PACKET TRANSFORM (WPT)

The wavelet packet transforms are alternative base; it forms the linear-collections wavelet components. They get property like time-frequency location of their identical wavelet components. A wavelet packet component is composed of three indices (j), (k) and (n), as shown in Eq.(1)**, Coifman,** and **Meyer, 1992, Kafiey, 2006, Mohd Tumari, et al., 2013, Khan,** and **Rahman, 2008.**

$$w_{j,k}^{n} = 2^{j/2}\, w^{n}(\, 2^{j}t - k) \qquad (1)$$

The wavelet packet transform allows to make multi-resolution analysis of signals as they are possible to have similarity of the connected scaling function and smooth wavelet with consolidated support. Any resolution level (j) in wavelet packet transform contains (2^j) cases which they are formed through low pass filter (LPF) and high pass filter (HPF) tree. The process up to 2^{nd} level of resolution as shown in **Fig. 1**.

The original signal x(n) that has the length (N) is decomposed in the first level. The decomposition tree creates two-frequency sub-bands, the LPF (G) which is the approximation coefficient (a^1) with length (N/2) and HPF (H) which is the detail coefficient (d^1) with the length (N/2). The 2nd decomposition level creates four-frequency sub-bands represented the same group filters in the first level of resolution, (aa^2), (ad^2), (da^2), (dd^2) with length (N/4) for each one. These operations are repeated while the original signals are become as sampled to a sure level of frequency in Hertz which represent highest-rate frequency that signal could restrain.

3. SIMULATION SETUP AND DATACOLLECTION

The initial and important step in this work is to setup the protected induction motor with all the necessary blocks to accurately collect the needed data. The needed data consists mainly of three phase normal currents (unloaded, loaded) and fault currents Line to Ground unloaded and loaded fault, Line to Line unloaded and loaded fault, multi-ratio turn to turn unloaded and loaded fault, phase loss unloaded and loaded fault. The collected data is employed for choosing both the optimized mother wavelet and number of level of decomposition. A 3-ph induction motor of 10hp, 380V, 4-poles, 1440 rpm, 50Hz is used in this simulation.

The sampling frequency of 12.8 kHz (256 samples /cycle) is applied in the proposed simulation. The fault signatures are the research requirement from the model simulation of induction motor.

3.1 Modeling of Healthy Induction Motor

The stator and rotor equations for flux, voltage, and torque in dq axis theory are shown in Eq.(2-5)**, Gerhard, 2002, Djalal,** and **Aissa, 2009, Obed, 2010.**

$$\frac{d\Psi_{d1}}{dt} = v_{d1} - i_{d1}.R_1 + \omega_1.\Psi_{q1} \quad (2)$$

$$\frac{d\Psi_{q1}}{dt} = v_{q1} - i_{q1}.R_1 - \omega_1.\Psi_{d1} \quad (3)$$

$$\frac{d\Psi'_{d2}}{dt} = -i'_{d2}.R'_2 - (\omega - \omega_1)\Psi'_{q2} \quad (4)$$

$$\frac{d\Psi'_{q2}}{dt} = -i'_{q2}.R'_2 + (\omega - \omega_1)\Psi'_{d2} \quad (5)$$

The current equations result from the flux linkages equations as shown in Eq.(6-9).

$$i_{d1} = \frac{1}{L_s}[\Psi_{d1} - L_m.i'_{d2}] \quad (6)$$

$$i_{q1} = \frac{1}{L_s}[\Psi_{q1} - L_m.i'_{q2}] \quad (7)$$

$$i'_{d2} = \frac{1}{L_r}[\Psi'_{d2} - L_m.i_{d1}] \quad (8)$$

$$i'_{q2} = \frac{1}{L_r}[\Psi'_{q2} - L_m.i_{q1}] \quad (9)$$

The dynamic equation as shown in Eq.(10).

$$\frac{d\omega}{dt} = \frac{p}{J}.[p.\left(\Psi_{d1}.i_{d1} - \Psi_{q1}.i_{d1}\right) - M_w \quad (10)$$

3.2 Stator Faults Modeling of Induction Motor

In this section, it is representative a simulation model for squirrel-cage induction motor under multi-stator faults conditions. A model takes the effects of shorting for one or more circuits of stator phase winding as turn-to-turn phase fault, line-to- line fault, line-to-ground fault and loss-phase.

The stator faults are defined by two parameters:

– A real angle represents between stator phase axis (i.e. phase A) and turn-to-turn stator winding which is a localization parameter(θ_{cc}). It allows the faulty winding that occurs in specific localization (0, 2π/3, or 4π/3) corresponding respectively to a short circuit on the stator phases A, B or C.

– The ratio of number of turns short circuit winding to total number winding in same phase as shown in Eq.(11). This detection parameter (η_{cc}) allows measure the unbalance value of short circuit winding**, Smail, et al., 2006, Jesper,** and **Carsten, 2006, Khan, et al., 2007.**

$$\eta cc = \frac{ncc}{ns} \tag{11}$$

The short circuit currents as shown in Eq.(12-15):

$$i_{cck} = \frac{2.\eta_{cck}}{3.R_1}.P(-\theta).Q(\theta_{ccK}).P(\theta).u_{dq1} \tag{12}$$

$$P(\theta) = \begin{bmatrix} cos(\theta) & cos(\theta + \frac{\pi}{2}) \\ sin(\theta) & sin(\theta + \frac{\pi}{2}) \end{bmatrix} \tag{13}$$

$$Q(\theta_{cc}) = \begin{bmatrix} \cos(\theta_{cc})^2 & \cos(\theta_{cc}).\sin(\theta_{cc}) \\ \cos(\theta_{cc}).\sin(\theta_{cc}) & \sin(\theta_{cc})^2 \end{bmatrix} \tag{14}$$

The resultant dq stator currents became as shown in Eq.(15)

$$i_{dq1} = i'_{dq1} + \sum_{i=1}^{3} i_{ccK} \tag{15}$$

3.3 Data Collection for Various Operating Conditions

Each stator winding is characterized by its faulty parameters (η_{cck} ,θ_{cck}). The desired simulation results include different fault currents. **Fig. 2** shows the 25% turn to turn (phase B) fault condition case. **Fig. 3** shows the full phase B to ground fault condition case of induction motor. **Fig. 4** shows the phase to phase (10% turn phase A with 25% turn phase B) fault condition case of induction motor. **Fig. 5** shows the loss phase (phase-A) fault condition case.

4. SELECTION OF OPTIMAL MOTHER WAVELET FUNCTION AND LEVEL NUMBER OF DECOMPOSTION

The collected data are mainly used for simulation test and for applying the mean square error (MSR) technique criterion in the MATLAB environment. It is also applied to choose the optimal mother wavelet filter. The non normalized Shannon entropy based criterions are used for determining the optimize decomposition level numbers. Mother wavelets have many types that used for analysis such as, Daubechies (db.), Coiflets, Symlets, Haar, etc. The simulated data is used for choosing of the mother wavelet filter.

4.1 Selection of Mother Wavelet Filter

There are a number of wavelet families which can be applied for electrical power system transient application. The variable orthogonal and non-orthogonal wavelets of the Matlab wavelet toolbox could be tested by the mean square error (MSR) technique criterion for the optimal mother wavelet selection. The candidate mother wavelets with different length of filters for this work are:

1. Orthogonal Wavelet Families which contain Daubechies (db3, db4), Coiflet (coif1, coif3), and Symlet (sym5).
2. Biorthogonal Wavelet Families which contain (Dmey).

MSR technique is used for selection the optimal mother wavelet. The MSR index could be determined for the original signal x(n) and the reconstructed signal $\hat{x}(n)$**, Saleh, 2003 ,Kafiey, 2006, Mohd Tumari, et al., 2013** as shown in Eq.(16):

$$\varepsilon = ||x - \hat{x}|| = (\sum_{n=0}^{N-1} |x - \hat{x}|^2)^{0.5} \tag{16}$$

The results of the mean square error indices for healthy and multi-types of fault signals are given in **Table 1**:

The Daubechies family (**db3**) is selected as a mother wavelet because it has the smallest MSR indices as a dominate of all the candidate mother wavelets. As a result, '**db3**' can be employed to carry out a MRA with the highest degree of similarity between the approximations and the original signal.

4.2 Selection of Optimal Level of Decomposition

The resolution levels number of the WPT chooses the resolution of an original signal in expression of its time and frequency with great time resolution. So, a signal decomposes into many different levels. But the compulsion of high memory requirements and complex calculations in real time applications, the optimum resolution levels number is the least number of decomposition levels, wherever the decomposed signal could be reconstructed into the original signal without any loss of its information.

In this section, the optimal levels number of resolution is determined by the non normalized Shannon entropy criterion using the chosen optimal mother wavelet 'db3'. The entropy values H(x) of any subspace of wavelet packet tree as shown in Eq.(17), **Obed, et al., 2011.**

$$H(x) = -\sum_{n=0}^{N-1} |x(n)|^2 * \log |x(n)|^2 \tag{17}$$

The entropy of a parent sub-space compares with its children sub-spaces to find optimal out level of resolution by the equation as shown in Eq.(18), **Hassan, et al., 2016**:

$$H(x)_j \geq H(x)_j - 1 \tag{18}$$

Fig. 6 shows the entropy values of each subspace of wavelet packet tree up to the 3rd level of resolution in case of normal no-load current of the induction motor.

Here, according to Eq.(18) the children subspaces can be kept in the tree because the entropy values of each children subspace are lower than these of their parent's substance consented. As a result, the decomposition signal up to the third level of resolution is not enough to represent its properties.

Fig. 7 gives the entropy values of each subspace of wavelet packet trees up to the third level of decomposition for the phase to phase stator winding fault current of the induction motor. Here, the entropy values of high frequency details of the first level are lower than its combined children subspaces. A according to Eq.(18) the entropy values of each children subspace are higher than these of their parent's substance consented which its children can be omitted from the tree.

So, the optimal resolution level is the second level which is enough calculation to use with the wavelet packet transform algorithm. It is based on the protection requirements of fault current disturbance in induction motors.

5. PROPOSED DISTURBANCE AND CLASSIFIER DETECTOR

The modern approaches for induction motor protection are mainly based on the mathematical modeling of the motor according to the disturbances. These approaches monitor currents waveforms of the faulted motor in order to detect and diagnose faults in induction motor drive. The algorithm is used on WPT analysis of fault currents.

5.1 Colour Strip of the WPT-Coefficient for Different Fault Currents

In this section, a proposed signatures analysis criterion is used for the feature extraction. **Figs. 8-11** show time location color diagrams of the coefficients of wavelet packet transform ($\boldsymbol{ad^2}$),($\boldsymbol{dd^2}$) of line currents of (unloaded–loaded) normal and fault conditions. When a disturbance occurred as in **Figs. 10-12** the details ($\boldsymbol{dd^2}$) shows a high density of color strips between the faulted regions which are compared with these of healthy current (load and unload) of **Figs. 8-9, Khan and Rahman, 2010.**

5.2 WPT Proposed Algorithm for Tripping Signal

The evaluation of the Wavelet Packet Transform coefficient could be down by filtering the signal with filters created by the optimal mother wavelet ($\boldsymbol{db}$**3**). **Fig. 12** shows the realized procedure as in Flowchart.

The proposed wavelet packet transform algorithm for protection the three phase induction motors checks the highest frequency sub band values for the resolution 2nd level (optimal level of resolution) of the wavelet packet transform. It determines whether those values are greater than the threshold value or not. The thresholds are set by minimum of absolute of WPT-coefficient values $\boldsymbol{aa^2}, \boldsymbol{ad^2}$ and $\boldsymbol{da^2}$ of the highest frequency sub band which determined under the normal condition of the induction motors. It is to be noted that because of leakage energy between the low pass filter and high pass filter magnitude response and the effect of induction motor parameters on the magnetic saturation, some highest frequency sub-band components are present at the 2nd level high frequency approximate and detail coefficients for the state under normal operating condition of induction motor.

The required off line test will contain multi-fault currents and healthy operating current as details.**Fig. 13** shows the case of unload-to-load normal (un-faulted) duration condition of the induction motor model, **Fig.14** shows the case of loaded normal (un-faulted) steady state condition. They are clear that the WPT algorithm has responded accurately by keeping the status of the trip signal unchanged. **Figs. 15-23** show the multi-case of un-normal (faulted) duration condition of the induction motor. They are clear that the WPT algorithm has specified the troubles fairly and changed the trip signal case at the first quarter cycle after the fault appearance.

6. CONCLUSIONS

This paper proposes an approach for diagnoses stator fault types from three phase stator currents based on wavelet packet transform. It can conclude the follows:

***** The optimal chosen of mother wavelet and the number of decomposition level evaluate the wavelet packet transform coefficients to help the correct discrimination between healthy and faults conditions. The proposed approach revels accurate, fast and reliable method which could be applied in protection of stator faults of induction motor.

***** The WPT algorithm has changed the status of accurately by keeping the case of the trip signal only for the status of fault current data, and it occurred almost at the first a quarter cycle of the fault (first frame of cycle fault which contain 64 samples) occurrence on a 50Hz system. The response of the WPT algorithm was very fast when it compared with the use of DWT in transformer protection with a different signature approach**, Saleh,** and **Rahman, 2005, Saleh, 2003,** which need half cycle to appear the trip signal after the time of fault occurrence.

***** The Shannon entropy values can be used to show leakage energy between the HP and LP filters magnitude response for in the cases of multi- stator faults operating condition of the induction motors.

***** The important features for fault detection is taken-out based on density of color strips of the WPT coefficients of fault currents, which able to supply reliable and correct diagnostic multi-fault currents. The WPT algorithm depends on the similarity of high frequency components $\boldsymbol{dd^2}$ of line currents of the wavelet packet tree.

NOMENCLATURE

ε = mean square error index (MSR).
n_{cc} = number of inter-turns S.C windings.
n_s = total number of turns S.C windings.
θ_{cc} = short-circuit rotor angular position.
$\Psi(t)$ = wavelet function.
Ψ_{d1}= stator d axis flux linkage.
Ψ_{q1} = stator q axis flux linkage.
Ψ'_{d2} = rotor d axis flux linkage.
Ψ'_{q2} = rotor q axis flux linkage.
ω =rotor speed, rad/sec.
ω_1 =synchronous speed, rad/sec.
G = low pass filter (LPF).
H = high pass filter (HPF).
H(x) = the value of entropy.
i_{cc} = short-circuit currents, A.
i_{d1} = stator d axis currents, A.
i_{q1} = stator q axis currents, A.
i'_{d2} = rotor d axis currents, A.
i'_{q2} = rotor q axis currents, A.
J =moment of inertia of motor, Kg.m^2.
j =scale operations index.
K= number of the stator phase.
k =translation operations index.

L_s =stator self inductance per phase, Henry.
L_r =rotor self inductance per phase, Henry.
L_m =mutual inductance, Henry.
M_w = load torque, N.m.
N = length of signal.
n =modulation parameter index.
P = number of pole pairs.
R_1 = stator resistance per phase, Ohm.
R_2 =rotor resistance per phase, Ohm.
v_{d1} = stator d axis voltages, V.
v_{q1} = stator q axis voltages, V.
x(n) = the original signal.
$\hat{x}(n)$ = the reconstructed signal.
x(t) = continuous signal.
CWT = continuous wavelet transform.
db = Daubechies mother wavelet.
DFT = discrete Fourier transform.
DWT = discrete wavelet transform.
FFT = fast Fourier transform.
MRA = multiresolution analysis.
Sym = symlet mother wavelet.
WPT = wavelet packet transform.

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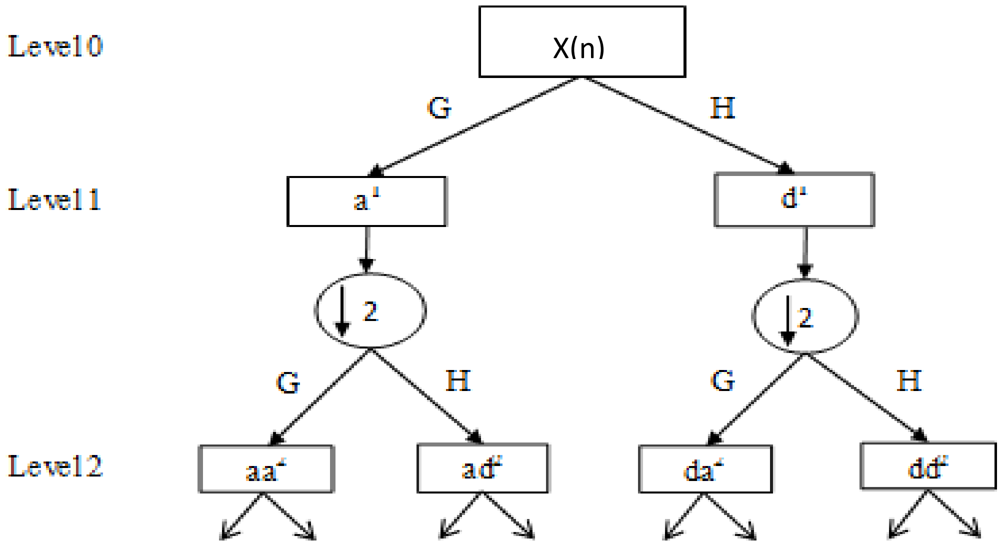

Figure 1. Implementation procedure of WPT

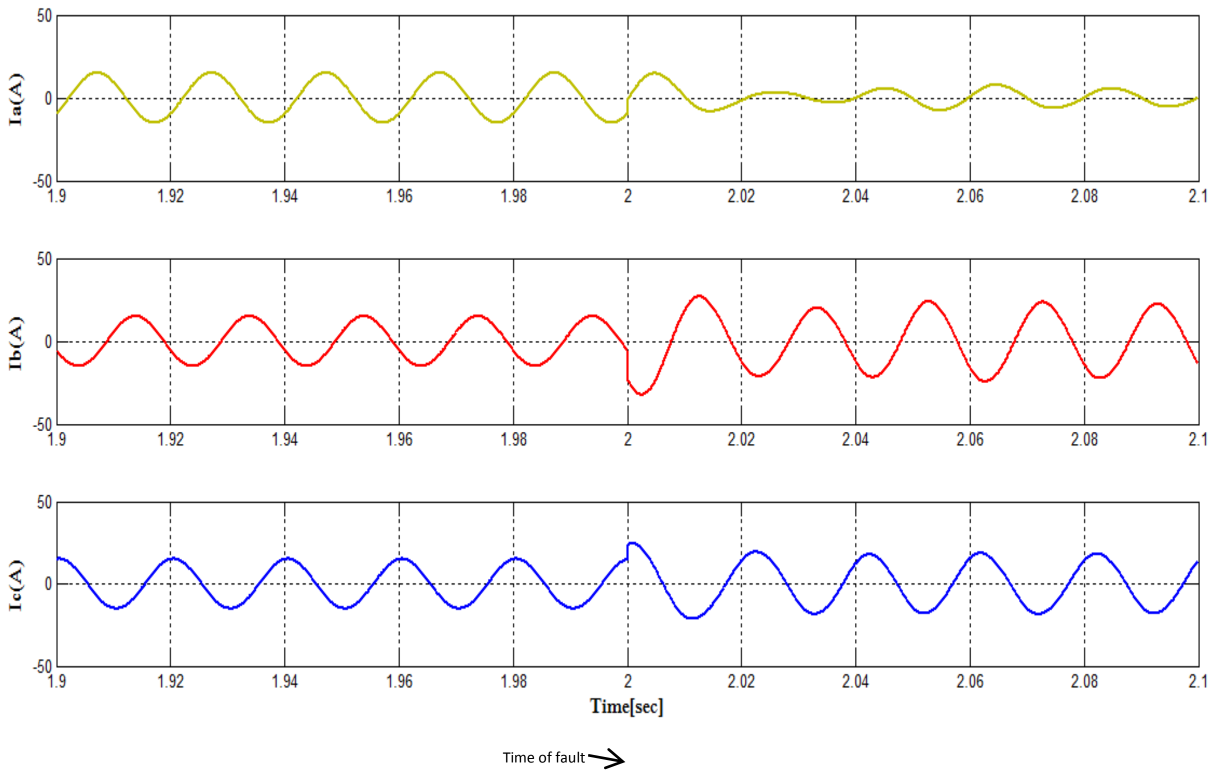

Figure 2. 3-ph currents for the case 0f 25% inter turn to turn (phase B) fault condition.

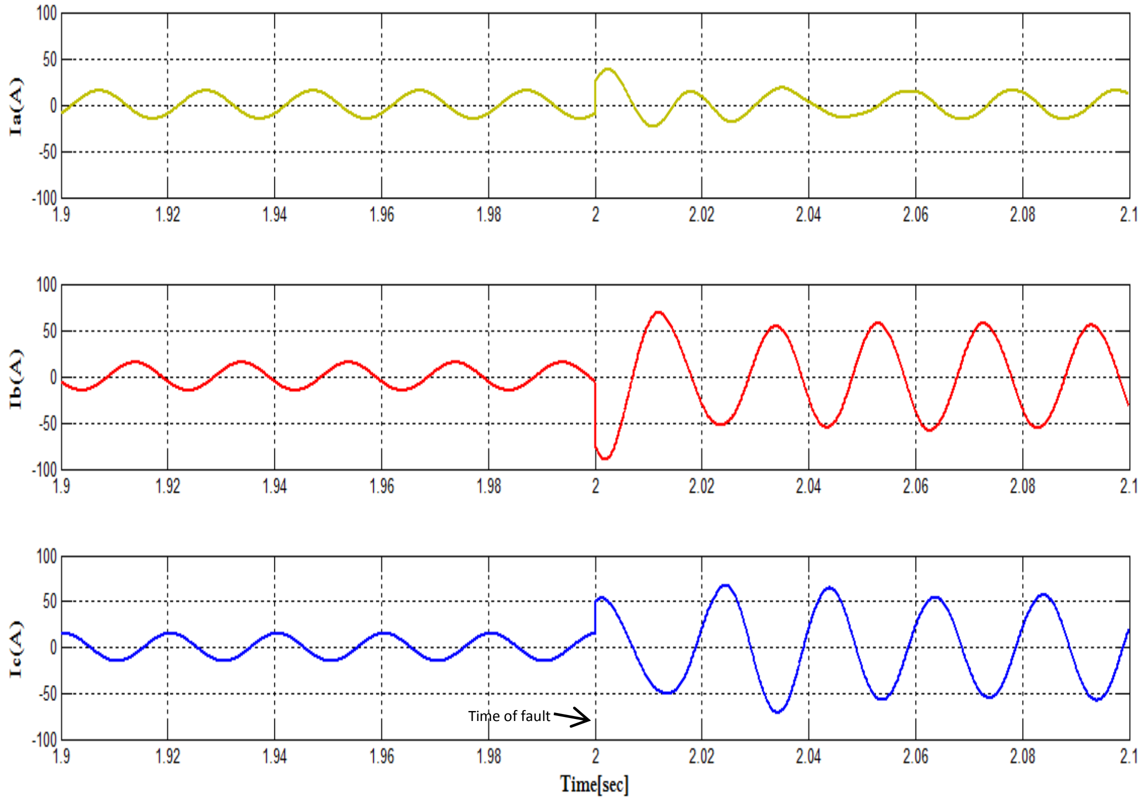

Figure 3. 3-ph currents for the phase to ground (phase B) fault condition case.

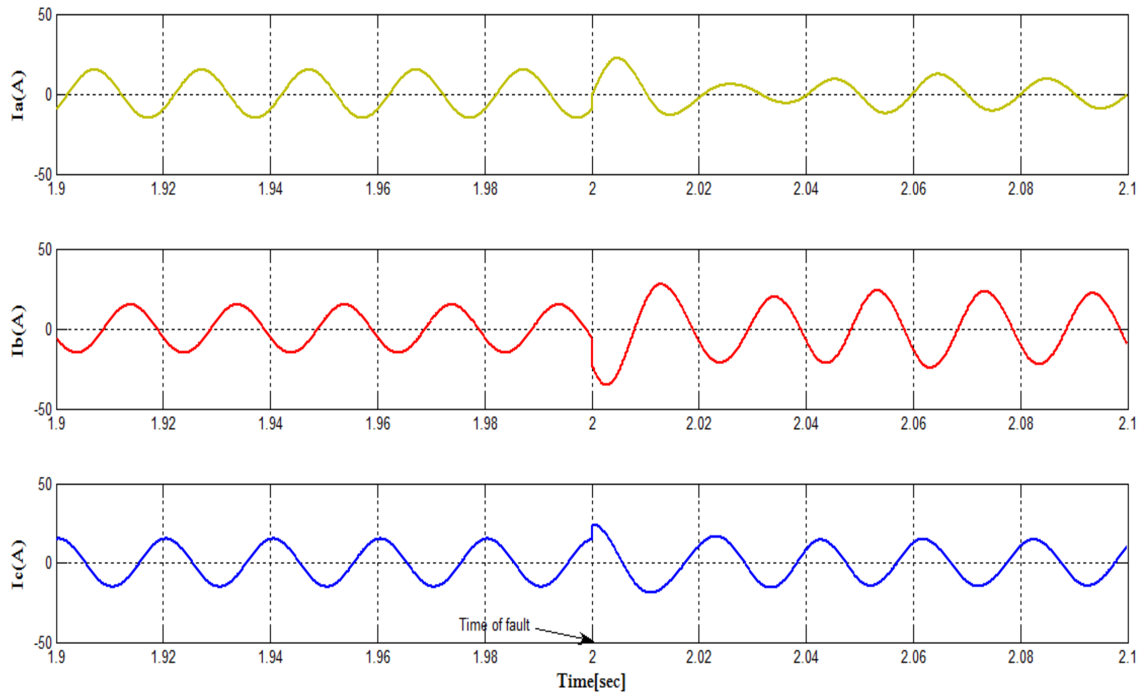

Figure 4. 3-ph currents for the phase to phase (10% Phase A - 25% Phase B) fault condition.

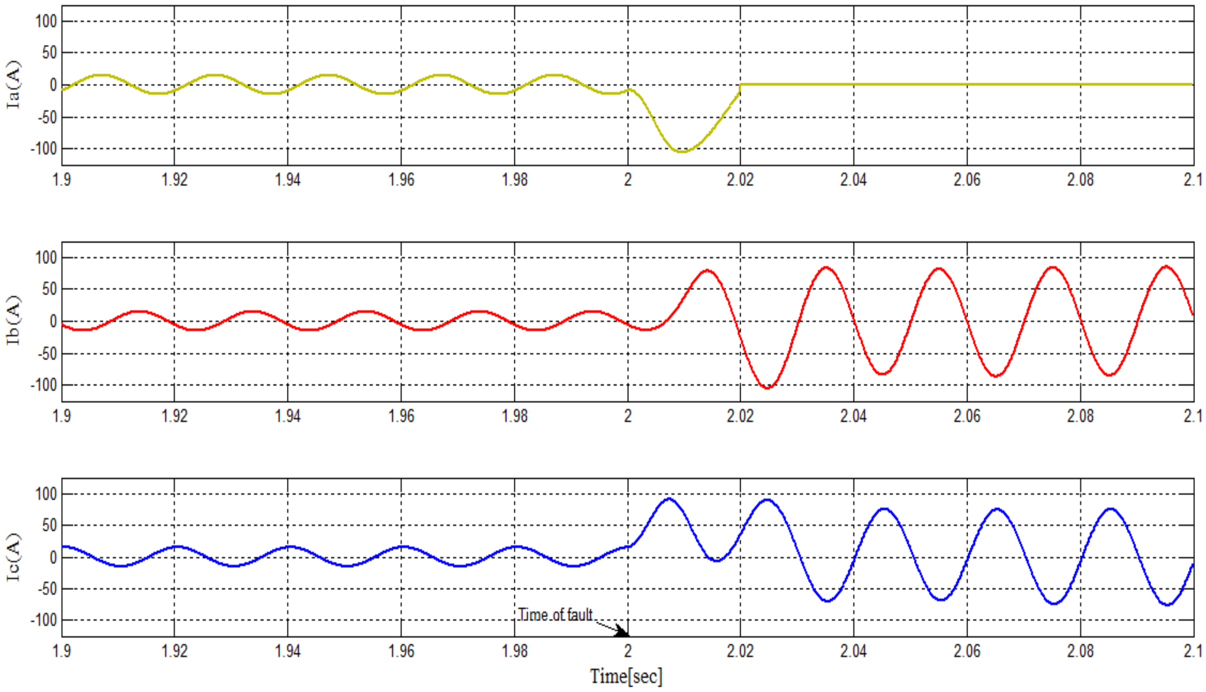

Figure 5. 3-ph currents for the case 0f loss-phase (phase A) fault condition of induction motor.

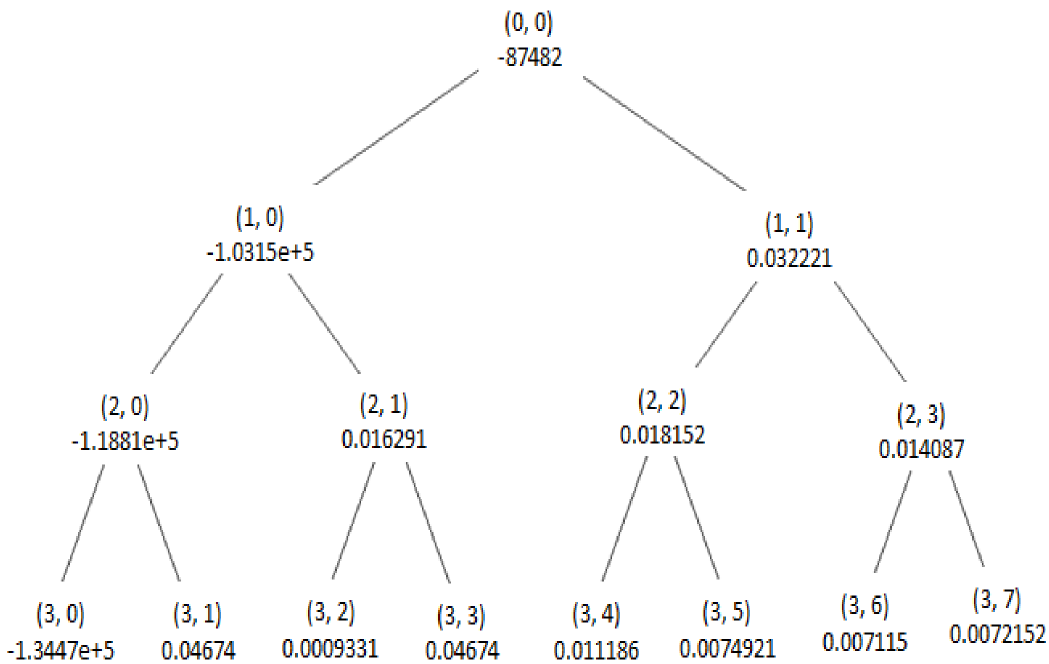

Figure 6. The entropy values of each subspace of wavelet packet tree up to the 3rd level of decomposition for the normal no-load current of the induction motor state.

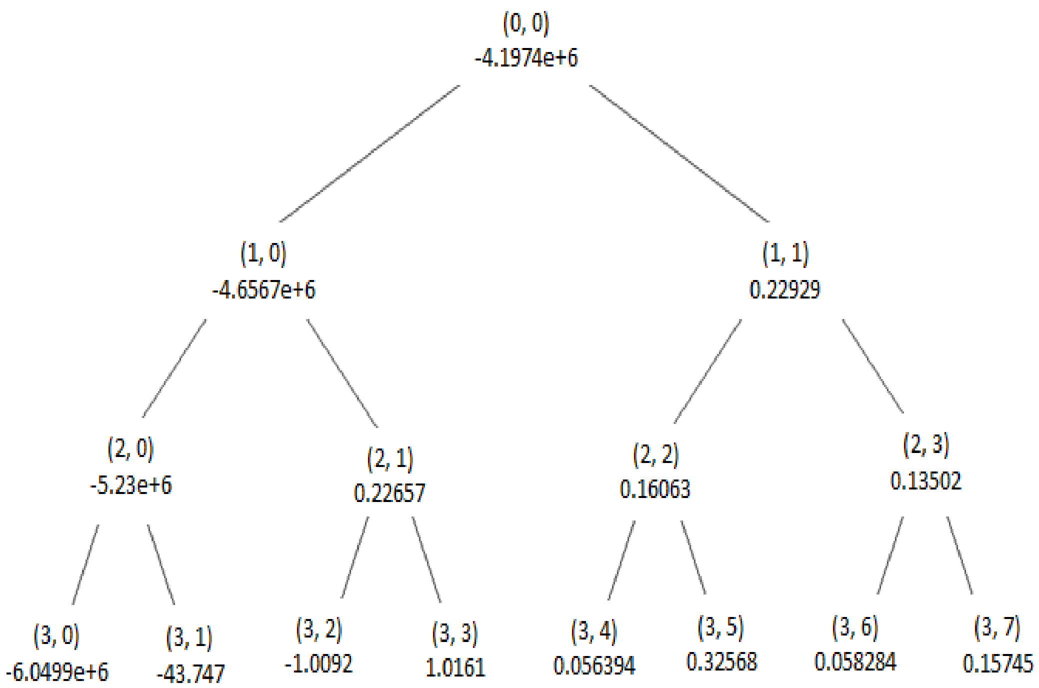

Figure 7. The entropy values of each subspace of wavelet packet tree up to the 3rd level of decomposition for phase to phase load current fault of the induction motor state.

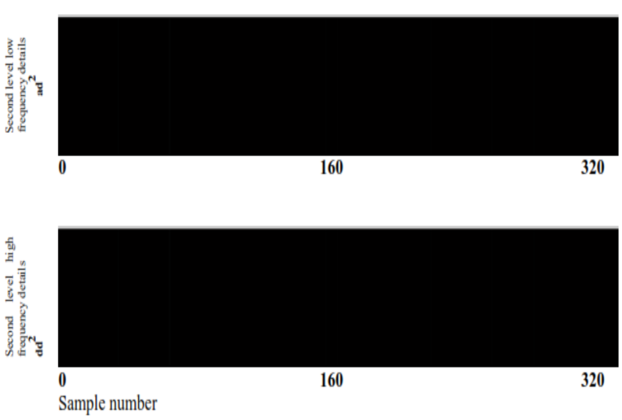

Figure 8. WPT second level approximation $\boldsymbol{ad^2}$ and 2nd level details $\boldsymbol{dd^2}$coefficients of healthy unloaded 3-ph induction motor.

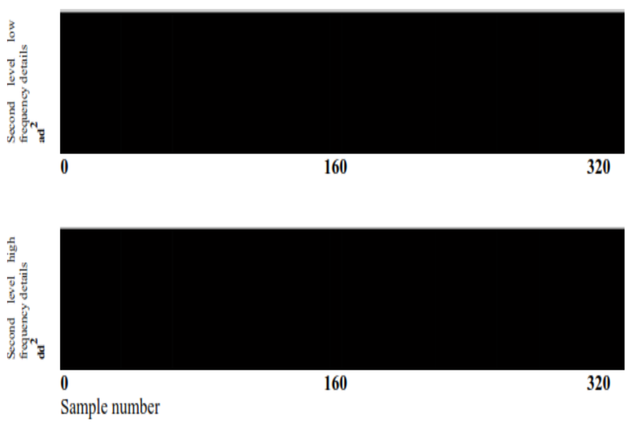

Figure 9. WPT second level approximation $\boldsymbol{ad^2}$and 2nd level details $\boldsymbol{dd^2}$ coefficients of healthy loaded 3-phase induction motor.

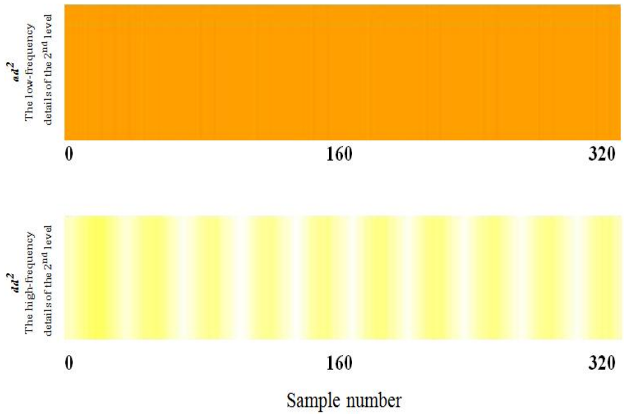

Figure 10. WPT second level approximation ad^2 and 2nd level details dd^2coefficients of 15% turn to turn phase a fault 3-phase induction motor**.**

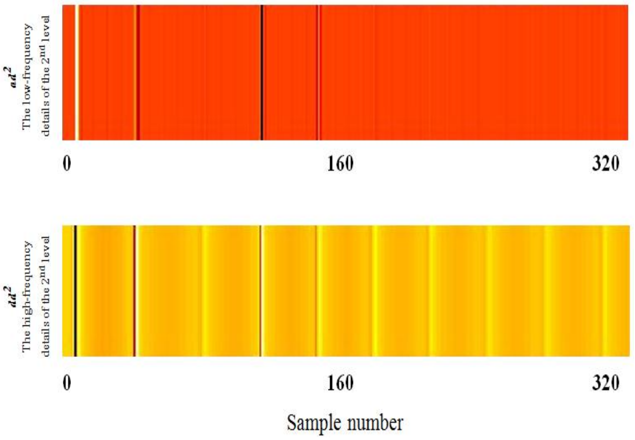

Figure 11. WPT second level approximation ad^2 and 2nd level details dd^2 coefficients of phase to ground fault 3-ph induction motor.

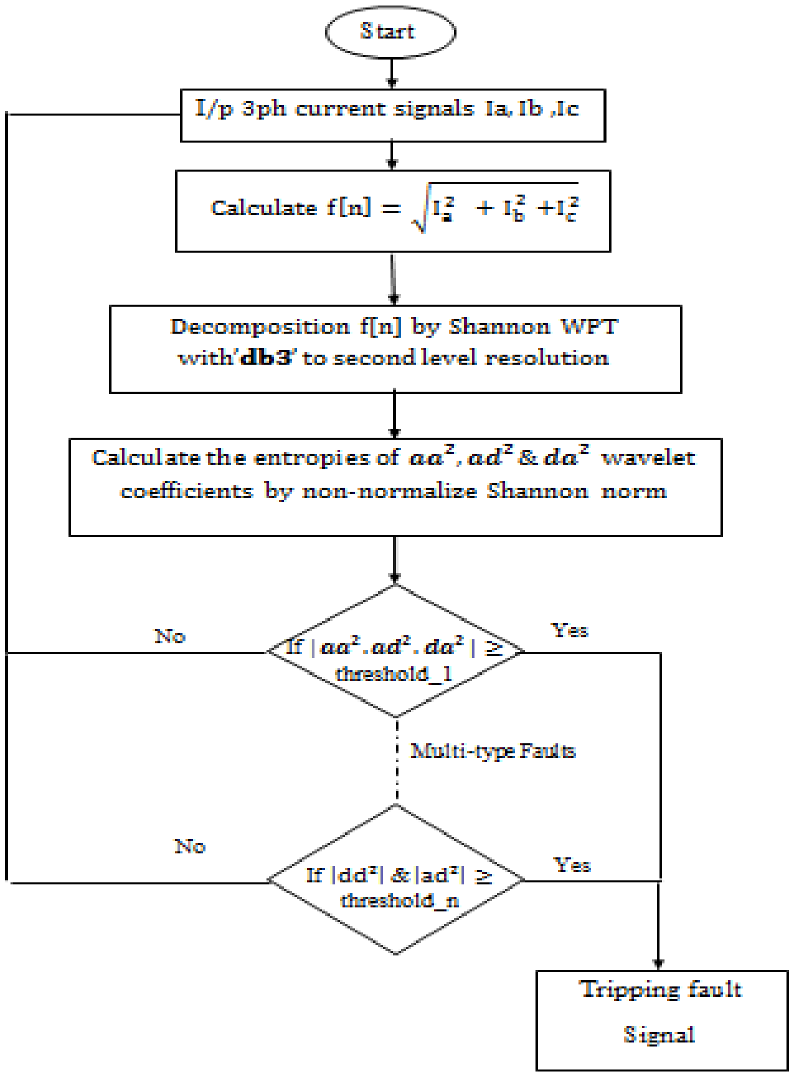

Figure 12. Flowchart of the proposed (WPT) disturbance detector.

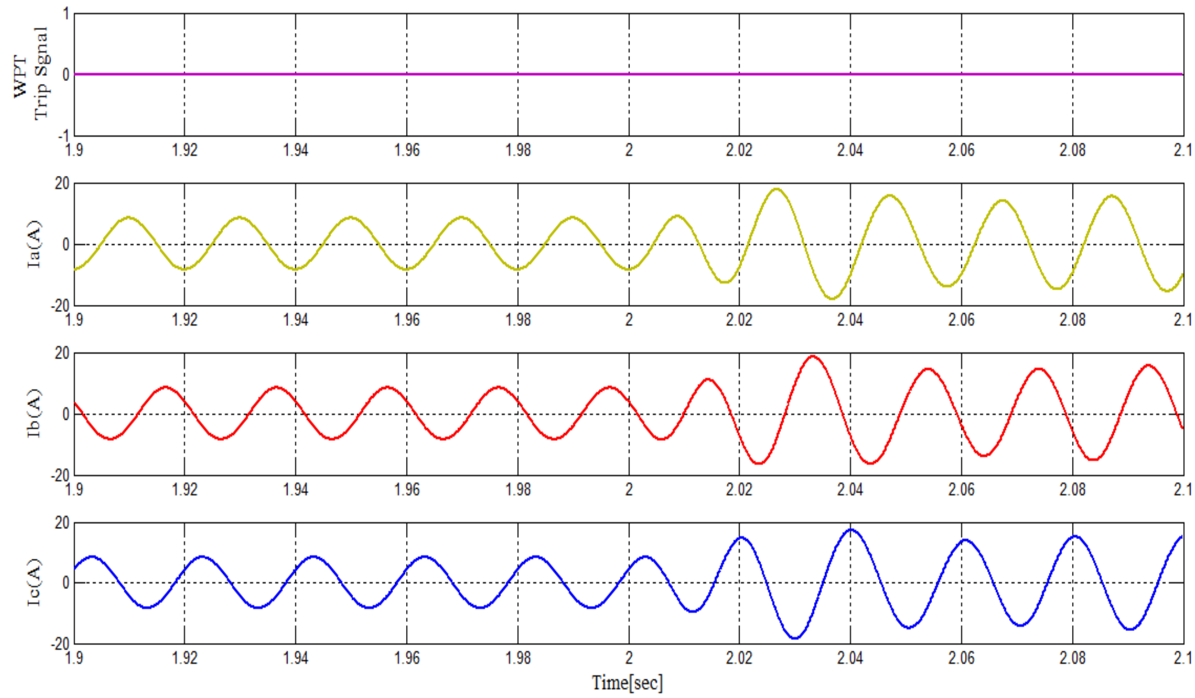

Figure 13. WPT based indicator response and 3-phase stator currents of the healthy (un-faulted) no load-to-load duration condition.

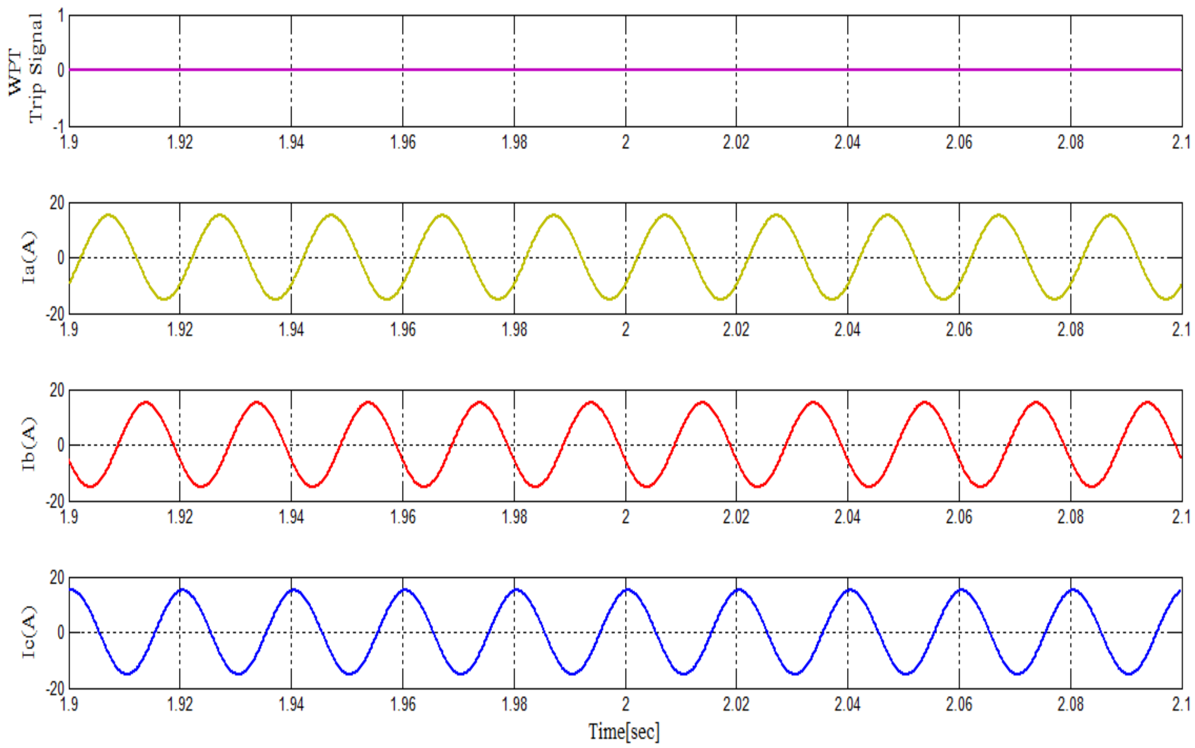

Figure 14. WPT based indicator response and 3-phase stator currents of the normal (un-faulted) loaded condition.

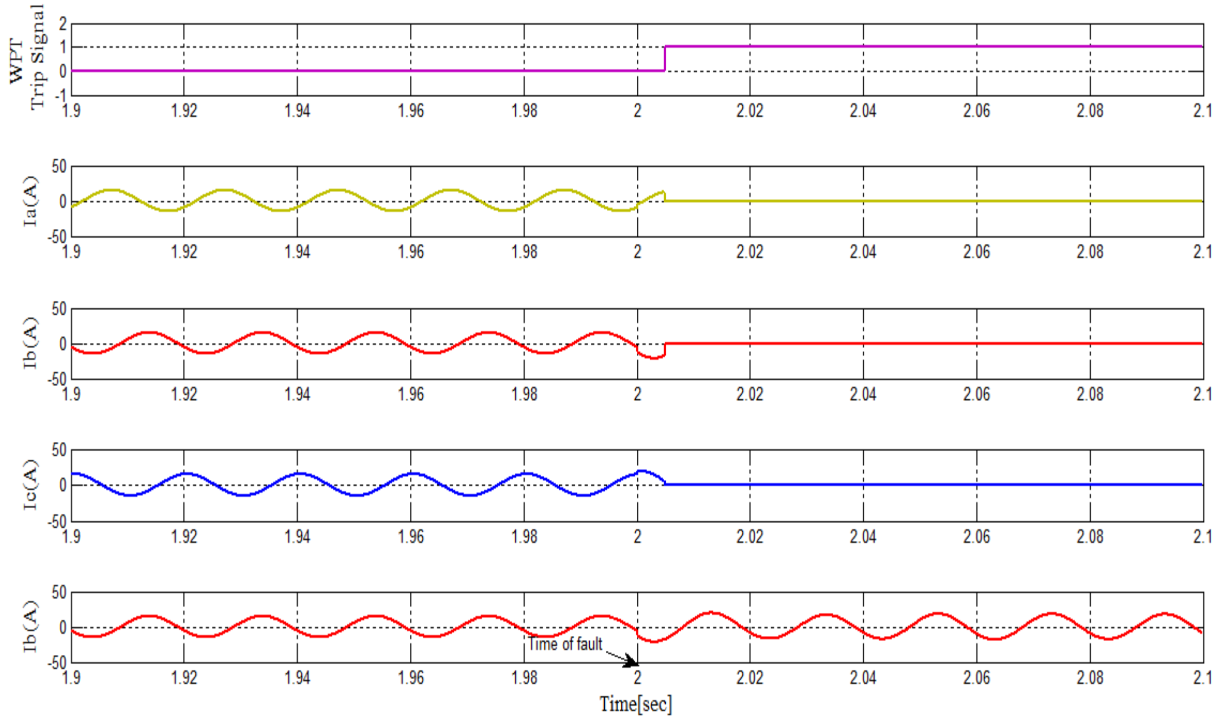

Figure 15. WPT based indicator response and 3-phase stator currents of the 10% turns of phase B fault condition case.

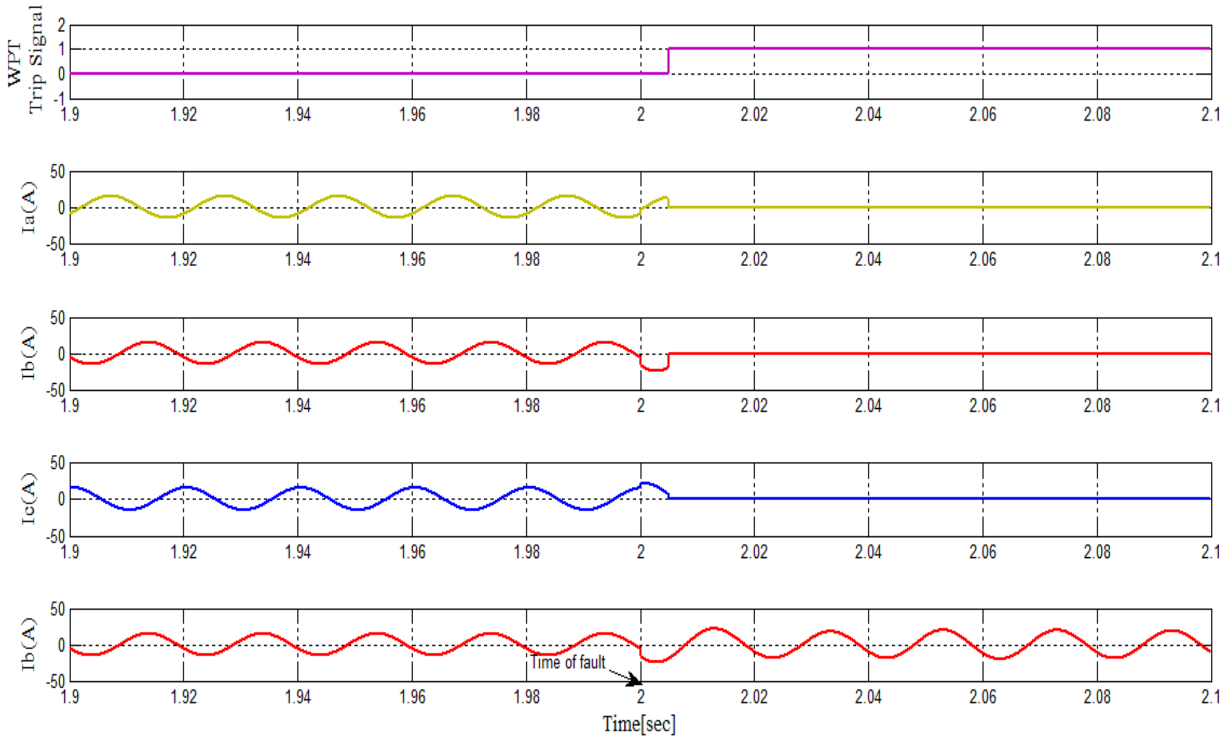

Figure 16. WPT based indicator response and 3-phase stator currents of the 15% turns of phase B fault condition case.

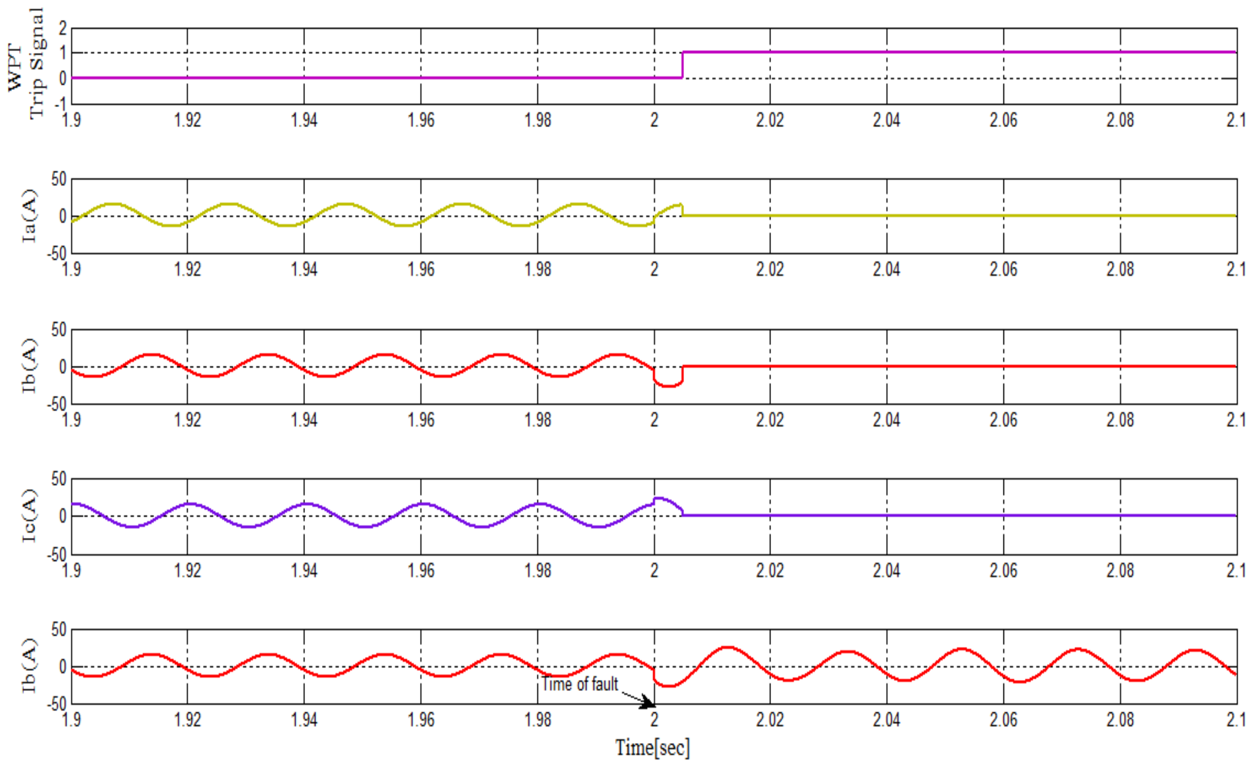

Figure 17. WPT based indicator response and 3-phase stator currents of the 20% turns of phase B fault condition case.

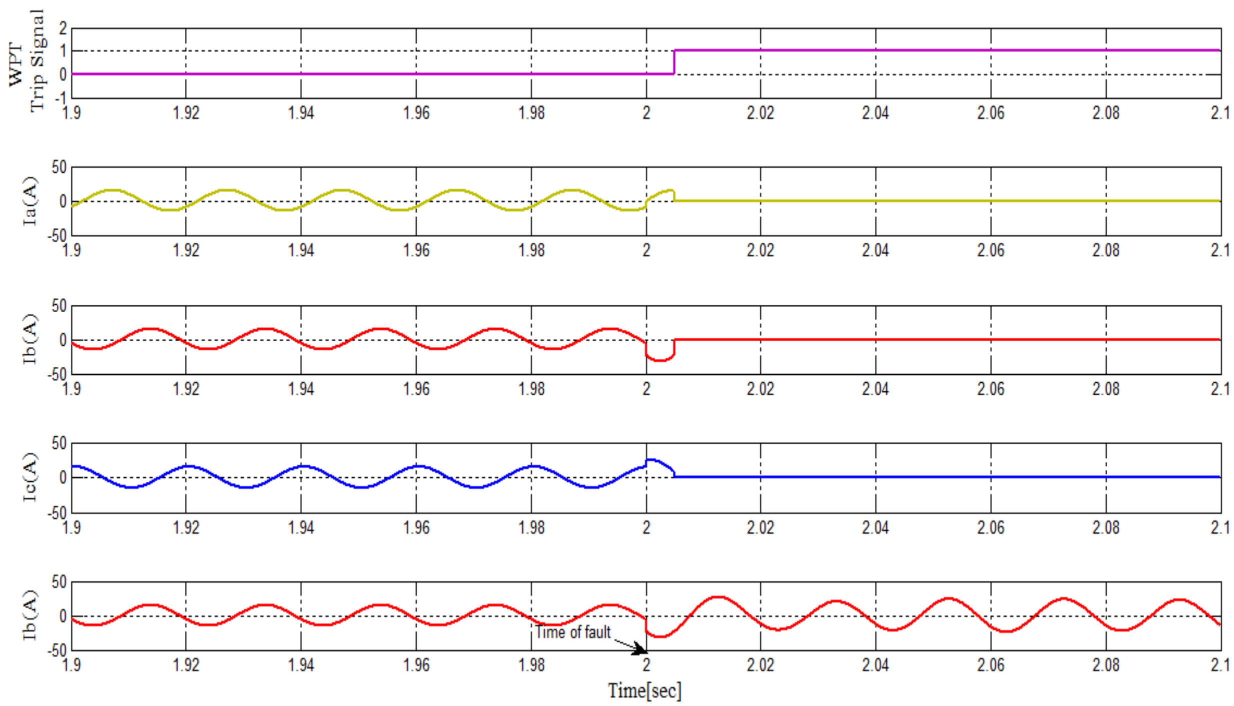

Figure 18. WPT based indicator response and 3-phase stator currents of the 25% turns of phase B fault condition case.

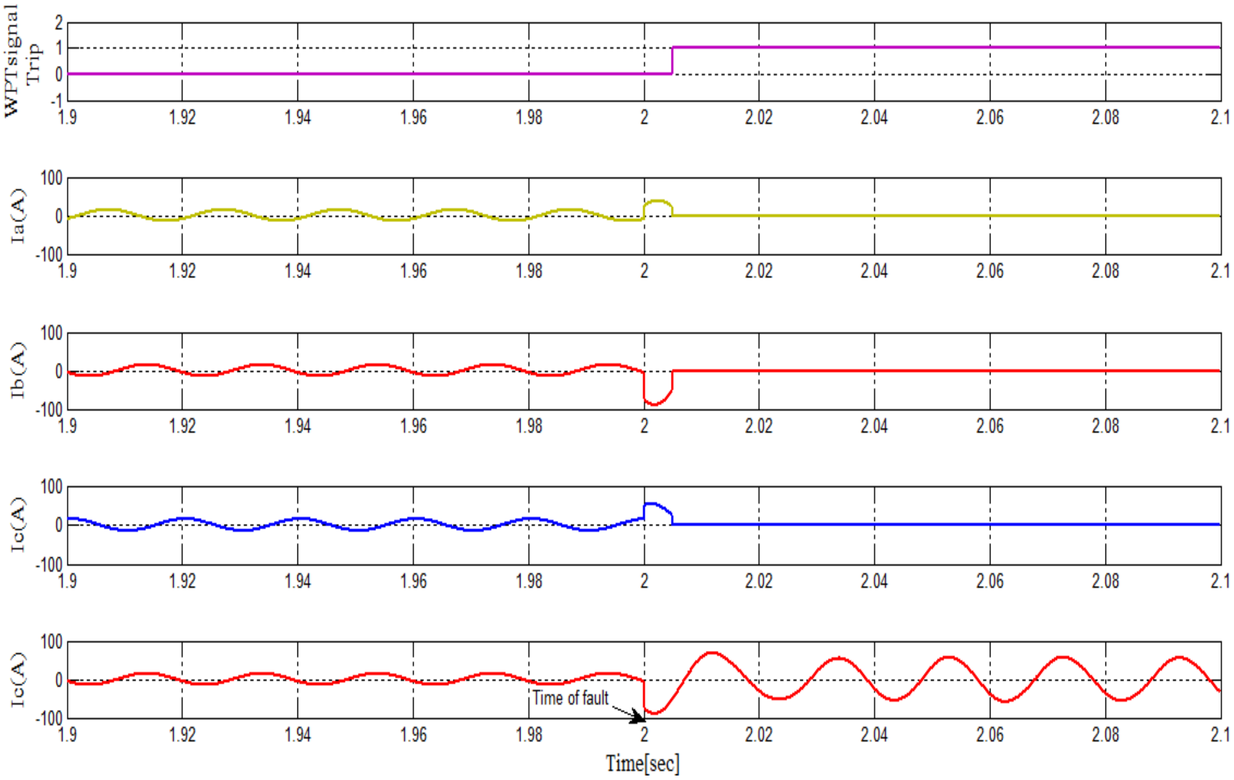

Figure 19. WPT based indicator response and 3-phase stator currents of the phase-to-ground (phase B) fault condition case.

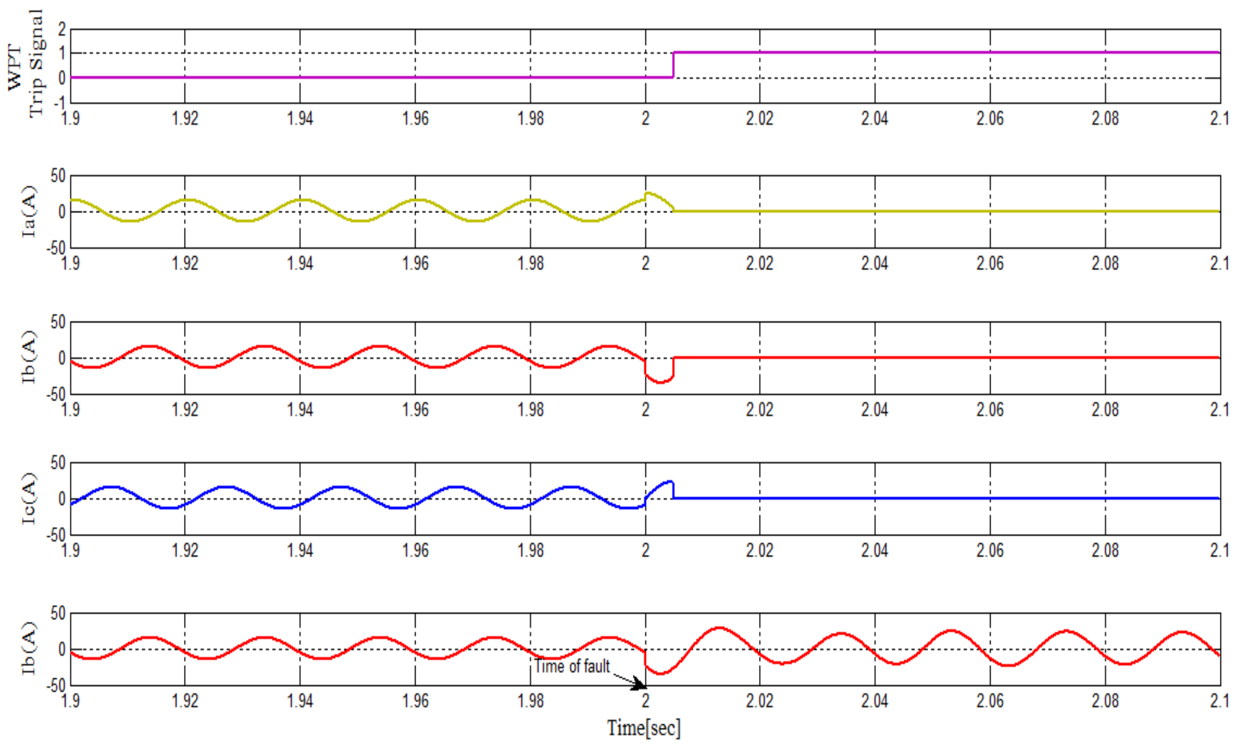

Figure 20. WPT based indicator response and 3-phase stator currents of the 10% turns phase A -to- 25% turns phase B fault condition case.

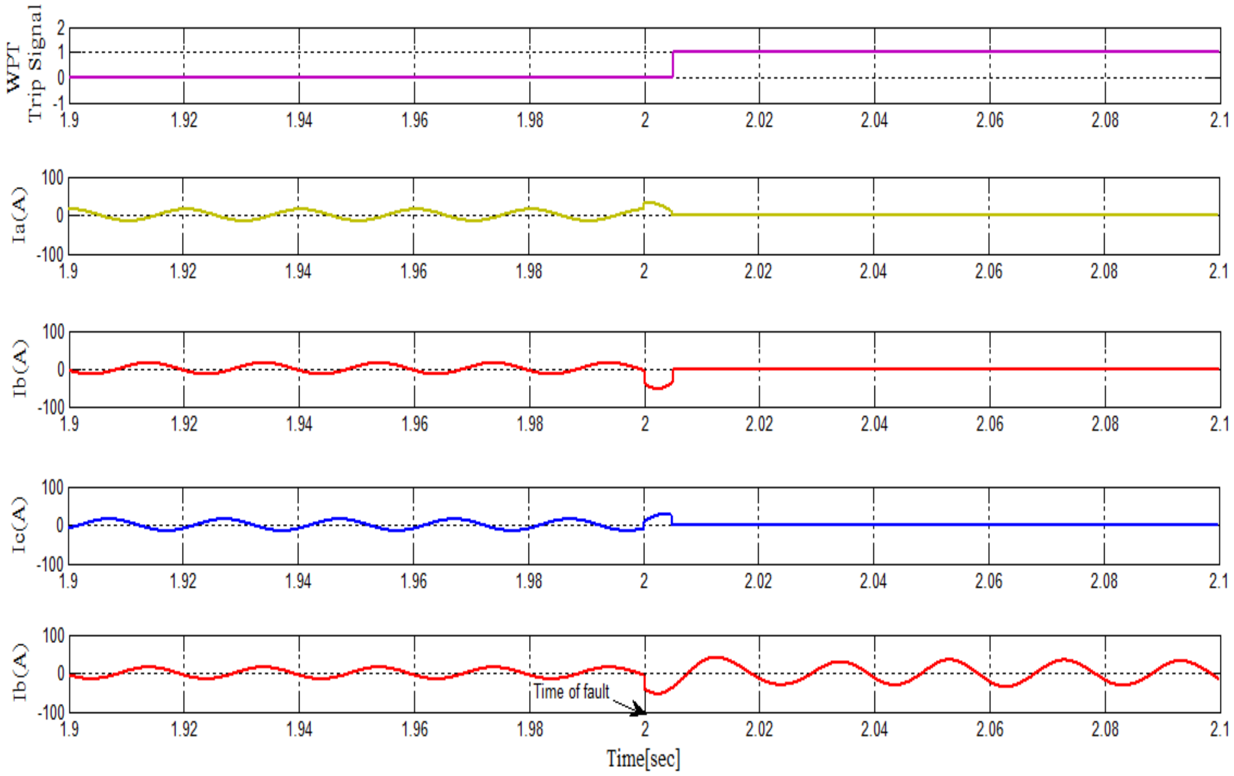

Figure 21. WPT based indicator response and 3-phase stator currents of the 10% turns phase A - to- 50% turns of phase B fault condition.

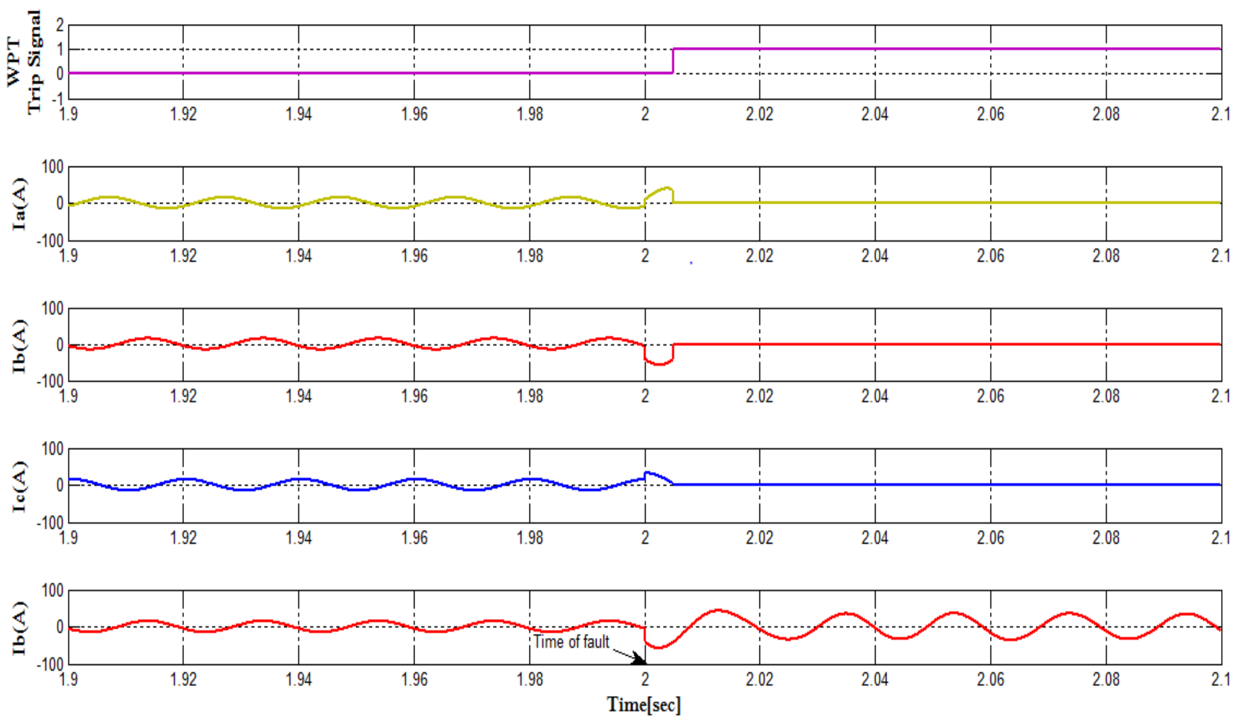

Figure 22. WPT based indicator response and 3-phase stator currents of the 25% turns phase A- to- 50% turns phase B fault condition case.

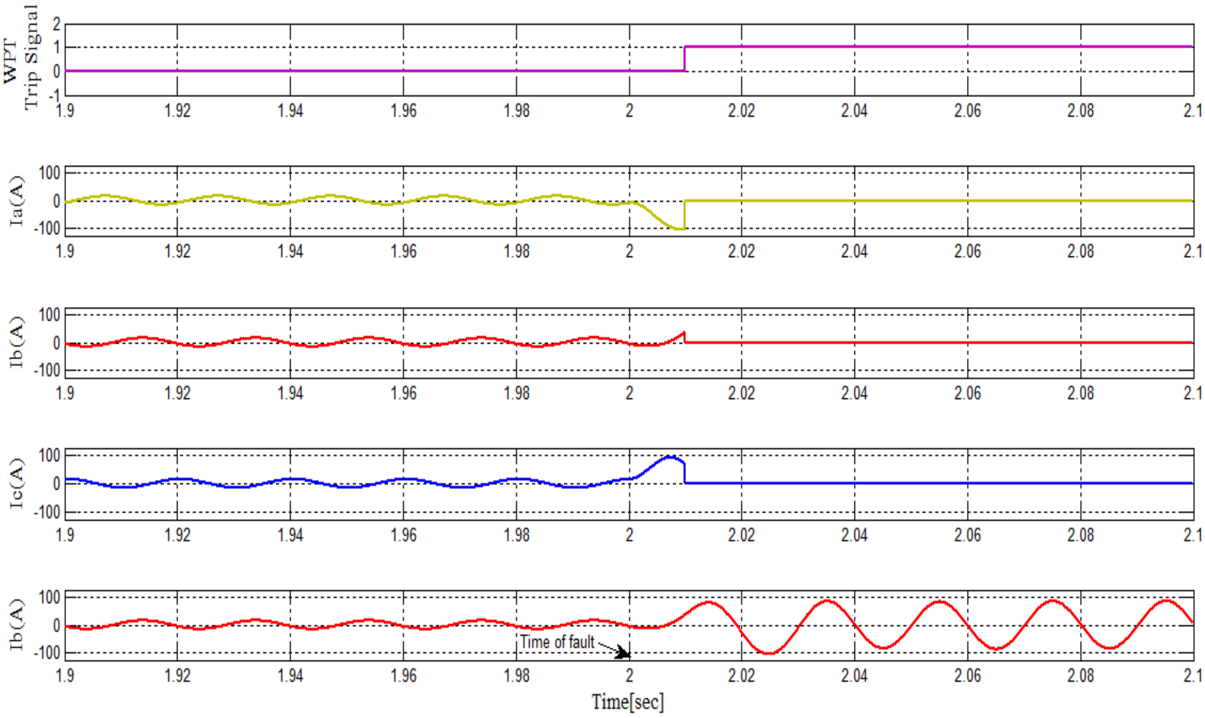

Figure 23. WPT based indicator response and 3-phase stator currents of the loss phase a fault condition case.

Table 1. the Mean Square Error (MSR) indices for multi-types of signals

	dmey	**db3**	**db4**	**db44**	**sym5**	**coif3**
Healthy (load)	7.17 E-05	1.87 E-12	7.02 E-13	1.25 E-03	5.84 E-13	6.10 E-13
Healthy (no-load)	6.32 E-08	2.64 E-13	3.17 E-13	2.14 E-06	3.30 E-13	3.48 E-13
10%Turn (no-load)	2.51 E-04	5.14 E-07	5.63 E-07	1.46 E-03	5.75 E-07	5.90 E-07
Phase loss (No-load)	4.20 E-03	5.30 E-10	2.80 E-10	1.95 E-01	3.88 E-12	1.01 E-11
Line-Ground (load)	3.32 E-03	5.88 E-10	2.97 E-10	1.89 E-01	4.87 E-12	1.88 E-11
Line-Line (load)	1.41 E-03	1.72 E-10	3.44 E-11	6.26 E-02	1.17 E-12	3.69 E-12
Sum (error)	9.26 E-03	5.15 E-07	5.64 E-07	4.49 E-01	5.75 E-07	5.90 E-07