IM FAULT DIAGNOSIS AND DISCRIMINATION OF FAULT AND NON-FAULT CASE USING PRONY ANALYSIS

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Abstract: The fault diagnosis and protection of Induction Motor (IM) is a stimulating task for all technicians and engineers. Surveys shows that, in IM most occurring fault are stator faults on stator side and faults on bearing on rotor side. The early detection of these faults will minimize the sudden stoppage and unpredicted failures of IM. Discrimination of faulty case from non-fault case, Fault diagnosis with continuous monitoring the condition of IM has become a vital task for engineers, technicians and researchers. For future research on continuous monitoring the condition, fault discrimination and fault diagnosis in IM, some prerequisite has to be analyzed. This paper describes various types of faults, techniques for fault diagnosis of IM and discrimination of fault and non-fault case using prony analysis.

***Keywords*— Condition monitoring, Fault, Fault diagnosis, Induction Motor, Prony.**

I. INTRODUCTION

Induction motor is considered as fault lenient motor and it is a most preferable option for industrial applications [1],[2]. It is necessary to know about faults occurring in IM at early stage so as to reduce the failure of IM and as an end result it will not hamper the operation and production of Industries. Less quality material, manufacturing deficiencies and forbearance, operational environment, period of maintenance are the most common factors which are responsible for occurrence of faults and failures in rotating machines [3]. To maintain the induction machine in good condition, various conventional approaches have been taken. One of them is to carry out the maintenance after a decided period of time. This type of inspection and rectification maintenance of the IM will slower down the production cycle in industries. Beside this, corrective maintenance is carried out that simply takes corrective act on the machine failure as soon as it happens [4]. Generally corrective maintenance requires stoppage of IM operation, which may lead to the shutdown of production. Basically online and offline are the two ways of detecting a fault on IM. As discussed earlier, the offline fault detection leads to the disturbance in IM operation whereas online detection method allows to work IM continuously till the detection of fault, hence reduces the outage times [5].

Condition monitoring and diagnosis of fault of IM is become necessary to stop the unpredicted failures and minimize the spontaneous outage. Various techniques in signal processing are available for diagnosis and detection of faults in IM. Various transformation techniques like Fast Fourier, Short Time Fourier, Wavelet transform and Prony's analysis are used. In this paper various faults arising on IM and signal processing techniques for IM fault diagnosis are discussed.

II. IM FAULTS

Faults on IM are happened due to number of factors such as uses of low quality material, manufacturing and installation problems, operational environment, improper operative procedure, scheduled maintenance. IM faults are classified as internal faults and external faults. These faults are broadly classified as Electrical faults and Mechanical faults as shown in fig. 1.

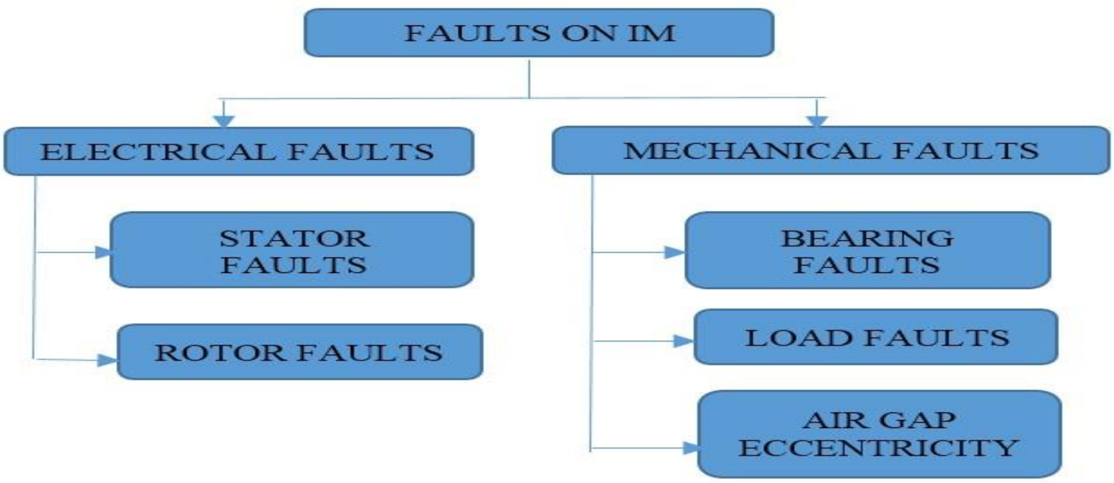

Fig. 1. Classification of Electrical and Mechanical faults on IM

Electrical faults on IM are classified into two types- stator faults and rotor faults. Stator faults are generally due to failure of insulation of stator winding. The variety of stator faults are turn to turn fault, coil to coil fault, open circuit (OC) fault, phase to phase (LL) fault and phase to ground (LG) fault whereas rotor faults includes damaged rotor bars, damaged rotor lamination, cracks in end rings. Mechanical faults are classified into three types- Bearing faults, load faults and Air gap eccentricity. Bearing faults are due to small or large hole, a missing or damaged piece in bearing. [6]. It is also caused due to insufficient lubrication, excessive greasing, use of wrong lubricant, misalignment, shaft overload, vibration, overheating. Load faults are especially related to gear system. Machines are often coupled to load through gear arrangement. Air gap eccentricity is further categorized into three types – Static, Dynamic and Mixed air gap eccentricity. In static air gap eccentricity, steady pull is generated towards one direction. This steady pull then produces Unbalanced Magnetic Pull (UMP). In Dynamic air gap eccentricity, produced UMP, rotates at motor speed and it directly acts on rotor. Mixed eccentricity is the merge of static eccentricity and dynamic eccentricity.

The statistical studies of IM failures are carried out by many institutions such as ABB (ASEA Brown Boveri), IEEE (Institution of Electrical and Electronics Engineers), and EPRI (Electrical Power Research Institute). The survey shows that, commonly occurring faults on IMs are bearing and Stator winding faults [7]. The result of these statistical studies is shown in fig. 2.

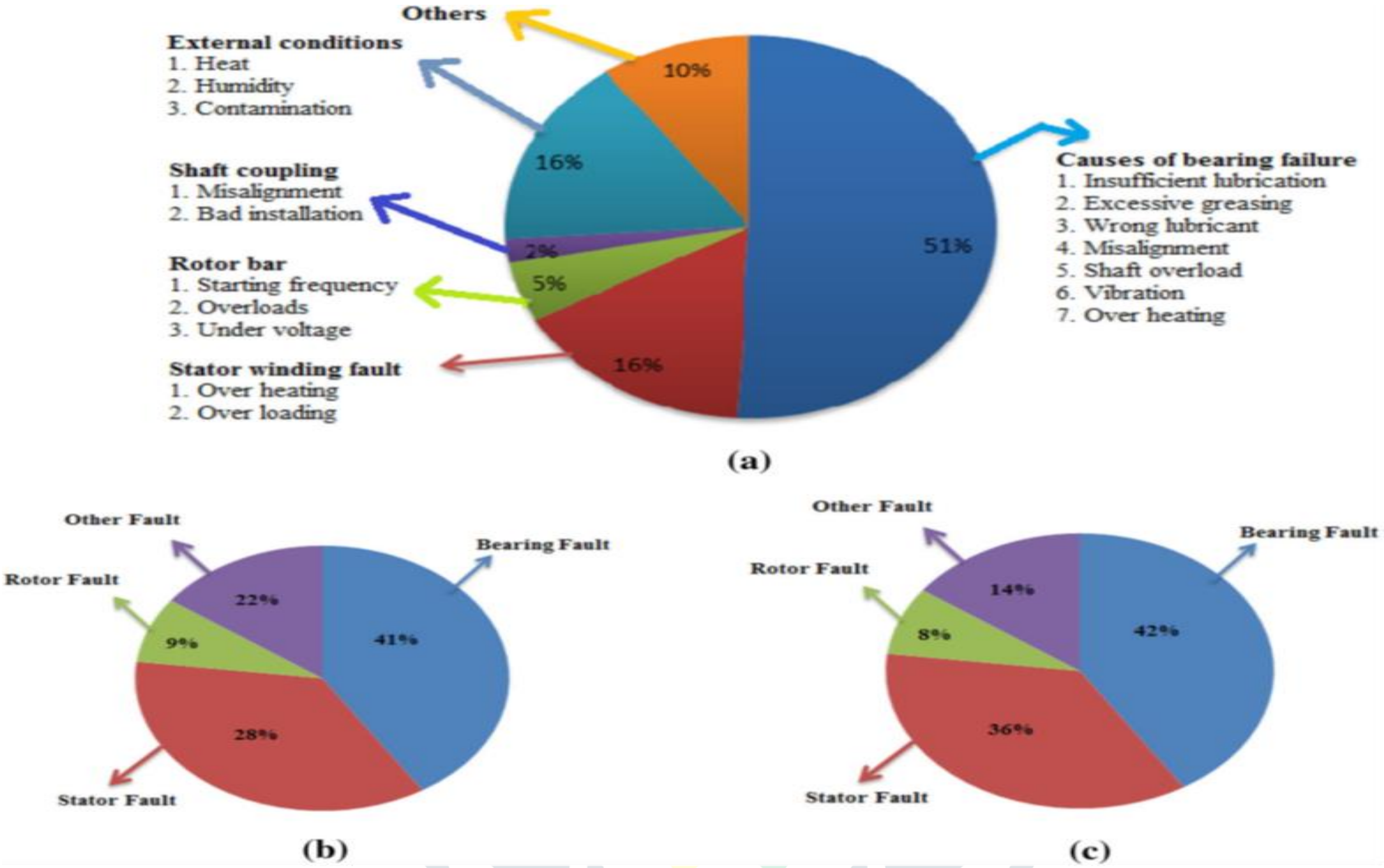

Fig. 2 IM fault's statistical study (a)- ABB, (b)- IEEE, (c)- EPRI

Bearing faults

Bearing is an essential component of electrical rotating machines. According to EPRI and IEEE, the bearing fault occurring during operation in IM is 42% and 41% respectively as shown in Fig. 2b, 2c. The most encounter fault in IM during operation is bearing fault and its occurrence, according to ABB, is about 51% during operation as shown in Fig. 2a.The various areas in which bearing defects occurs are cage of bearing, ball, inner and outer race. Faults on bearing leads to failures, unproductive and noisy operation and sudden stoppage.

Stator faults

Stator faults are the second most encountered fault on IM during operation. According to the survey of IEEE (Institution of Electrical and Electronics Engineers), and EPRI (Electrical Power Research Institute), faults occurs in the IM stator are 28% and 36% respectively as shown in Fig. 2b, 2c. Basically stator faults are categorized as fault in stator windings, fault in stator winding lamination, faults in frame of the stator. Majority of stator faults occur at stator windings. The various stator winding faults are shown in Fig. 3.

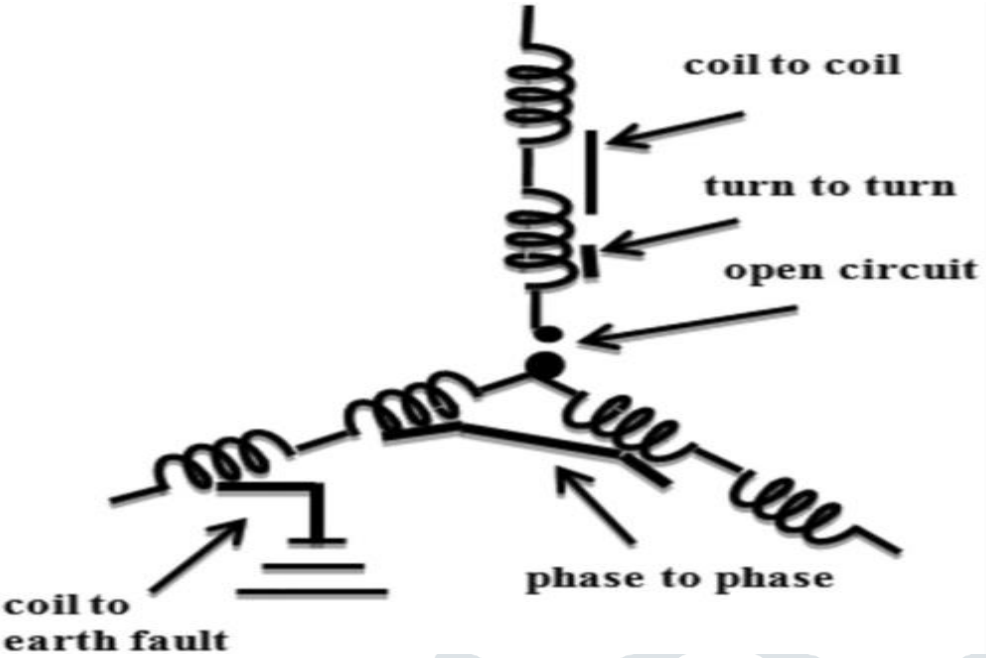

Fig. 3 Types of faults on stator winding

The different faults encountered on stator winding of IM are open circuit fault and short circuit fault. The short circuit faults are - a. turn to turn fault, b. coil to earth fault, c. coil to coil fault and d. phase to phase fault. In three phase IM, stator winding faults can be rapidly detected using an innovative technique which uses an autoregressive model for detection. [8] Higher order spectrum is the base of IM fault diagnosis technique [9].

III. IM FAULT DIAGNOSIS TECHNIQUES

Due to the wide applications and uses of Electrical rotating machines, serious research efforts has been concentrated on the monitoring of IM condition and also on electrical machine fault diagnosis techniques. The basic and foremost requirement for condition monitoring and fault diagnosis is to have an analysis technique which analyze the current signal. From the analysis, valuable information and outcomes can be obtained. The various techniques for fault diagnosis are-

1. Frequency domain analysis-

Fast Fourier Transform (FFT) technique

2. Time – Frequency techniques

The various Time – frequency domain techniques are - Short Time Fourier Transform, Gabor Transform and Cohen class distribution.

Cohen class distribution is further classified as-

a- Wigner Ville Distribution

b- Choi Williams Distribution

c- Cone shaped Distribution

3. Wavelet Transform (WT)

4. Time Series Methods

The various time series methods are- Spectral estimation through ARMA Model, Welch Method, MUSIC method and Periodogram. [10]

5. Prony analysis

FFT is a frequency domain analysis technique. FFT is computationally effective method to compute Discrete Fourier Transform (DFT). FFT is a modified algorithm of DFT. FFT decomposed the considered data into a smaller data series sets. Finally, it workout the DFT of each and every small series data set. FFT algorithm is effective to diagnose and detect various types of machine faults.

Time frequency analysis represents a signal in three dimensional time, amplitude and frequency. This analysis is best suited to specify various transient events in the signal. The STFT is a mathematically linear time frequency distribution. Time frequency distribution also includes quadratic distribution such as Wigner Ville Distribution. The quadratic time frequency distribution offers more frequency resolution than the linear time frequency distribution [10].

Wavelet technique is the representation of signals sparingly. It collects the transient present in signals and perform multiple resolution signal analysis. Wavelet signal processing is having unique properties which makes it different from other signal processing techniques.

Wavelets are finite in length and irregular in shape. Time series analysis such as MUltiple SIgnal Classification (MUSIC) is an algorithm used for frequency estimation and radio direction finding [11].

Prony analysis requires prior processing of signals hence signals are transformed to park's vector at first. The prony's method is an influential tool for detecting oscillation frequency, damping, phase and amplitude in measured data [12]. It is a signal analysis technique. It can also be used as a system identification method. Prony's analysis is most effective in various fields such as power system, radar, sonar, electromechanical oscillations, speech processing, biomedical, geophysical sensing and radioactive decay [13].

IV. FAULT DISCRIMINATION USING PRONY TECHNIQUE

Prony analysis is the advanced tool in power system which discriminates between fault and non-fault condition in induction motor. In power system transient applications, prony method can effectively use to handle damping signals and estimating damped coefficients.

The prony method estimates frequency, phase, amplitude and damping coefficients of the signal.

$$y(t) = \sum_{i=1}^{N} A_i e^{\sigma_i t} \cos(2\pi f_i t + \phi_i)$$

A_i – Amplitude of Component

σ_i – Damping Coefficients of Component i

$Ø_i$ – Phase Of Component i

f_i – Frequency of Component i

N – Total No. of Damped Exponential Component

A. BLOCK DIAGRAM OF PROPOSED ALGORITHM

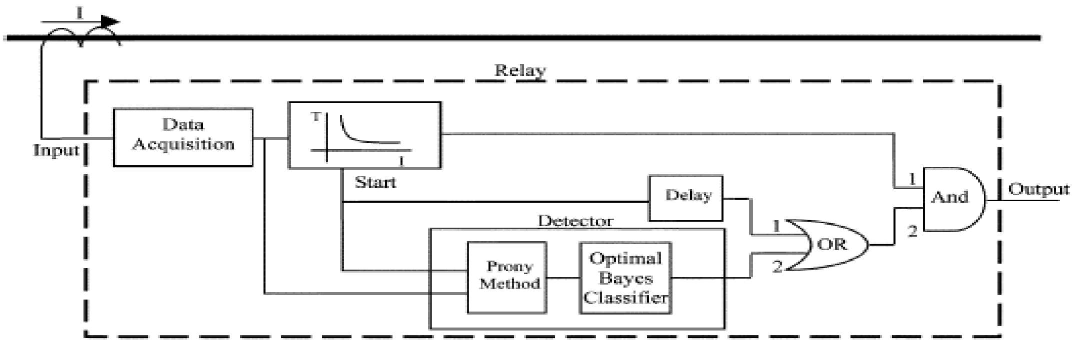

Fig. 4 Block diagram of proposed algorithm.

The block diagram shows the relay model of the proposed prony algorithm. In this relay system, an analog input is converted into digital signal using data acquisition unit and then fed to relay characteristics and detector unit. If the current amplitude is higher than the relay setting then signals is fed to prony unit and optimal bayes classifier for decision making. For faulty case, within 1.5 cycle of the signal, both pin numbers 1 and 2 of the AND gate becomes 1 and trip signal is initiated. During non-fault condition i.e. switching condition, the 2nd pin of AND gate remains zero and trip signal is not initiated. Delay block is provided for prolonged fault case.

B. SIMULATION AND RESULT

Case –I (Switching Event)

A 13 bus, 34.5 KV distribution systems is designed. Different motor starting cases for motors with different ratings have been applied at different parts of the power system. A detailed study of a typical case is presented below. In this case a 2.5–MVA induction motor at bus bar 13 is switched at t=0.75 and currents are measured at bus bar 7. Fig. shows the current of phase A. In this case, the damping of the fundamental harmonic (50 Hz) is 0.82 and the ratio of the 2nd harmonic amplitude to the fundamental harmonic amplitude is 0.02. In this situation, the probability of the case being faulty is 0.00012153and being non faulty is 0.99987, therefore the occurred case is diagnosed as a non-faulty case correctly and the maltrip of the relay is prevented.

In this case, the pickup current of relay sets on 1.3 and time dials setting at 0.2. As seen, induction motor starting leads to the maltrip of the relay at 0.8 s. To overcome this, the pickup current must be increased; however this delays the relay operation when fault occurs. Output of the relay characteristic or pin 1 of the AND gate of Fig. 4 leads to the maltrip at 0.8 s, but pin2 of the AND gate (output of the suggested algorithm) detects the non-fault case shorter than 40 ms (at 0.5338 s) and keeps pin2 of the AND gate equal to zero. Finally, the output of relay becomes zero and prevents the maltrip of the relay.

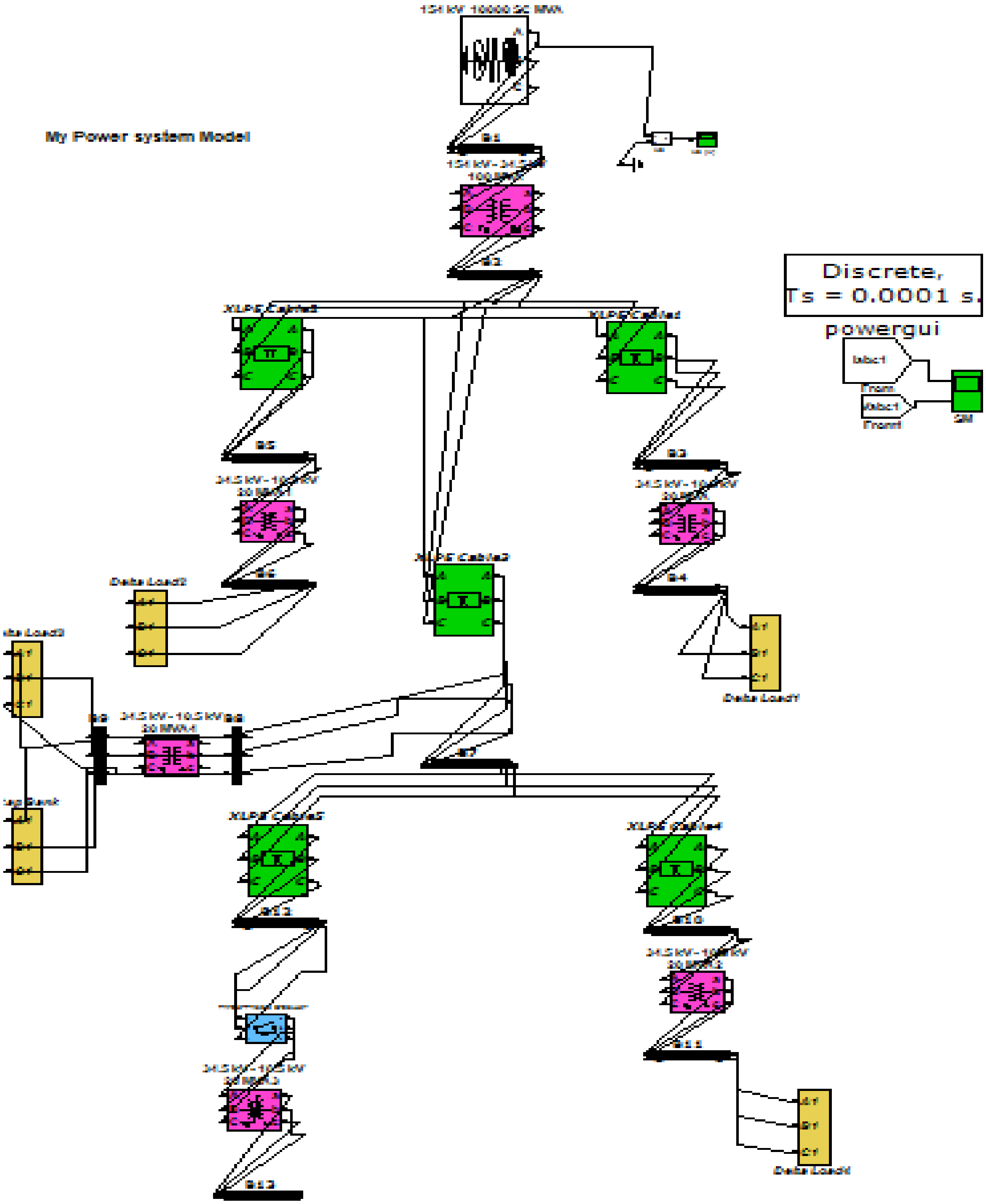

Fig. 5: 34.5 kV, 13 Bus Distribution System model

RESULTS:

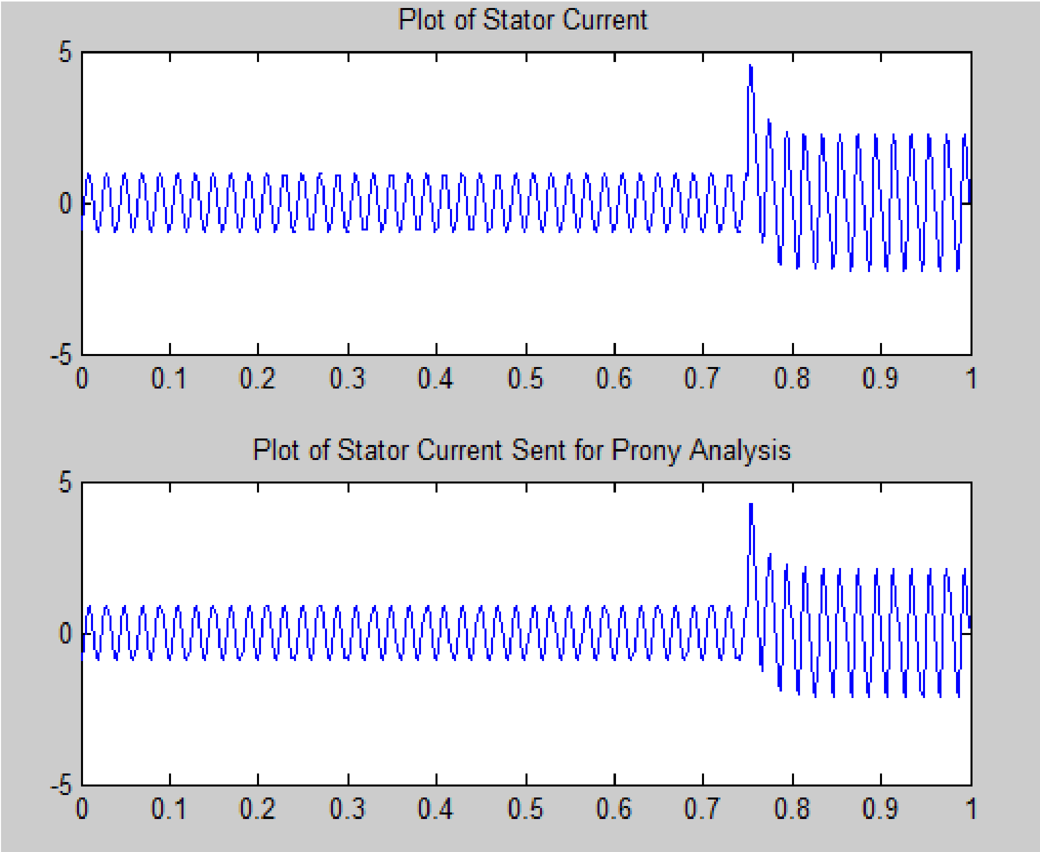

Fig.6: Prony Analysis of Stator Current of Induction Motor

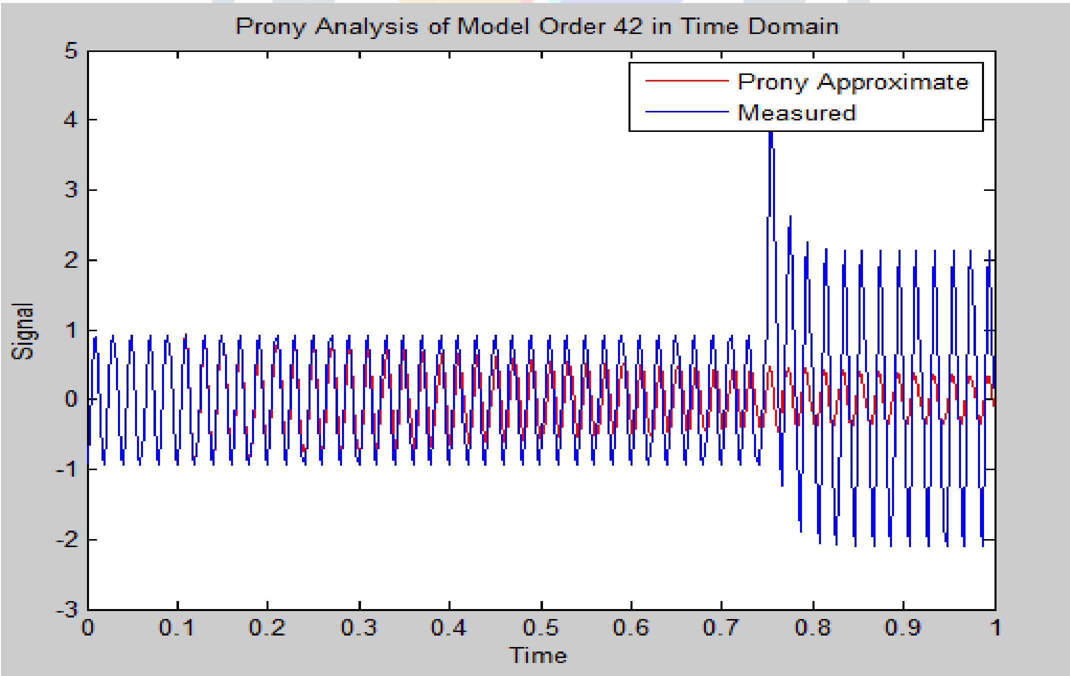

Fig. 7: Current of Phase A Due To Motor Starting

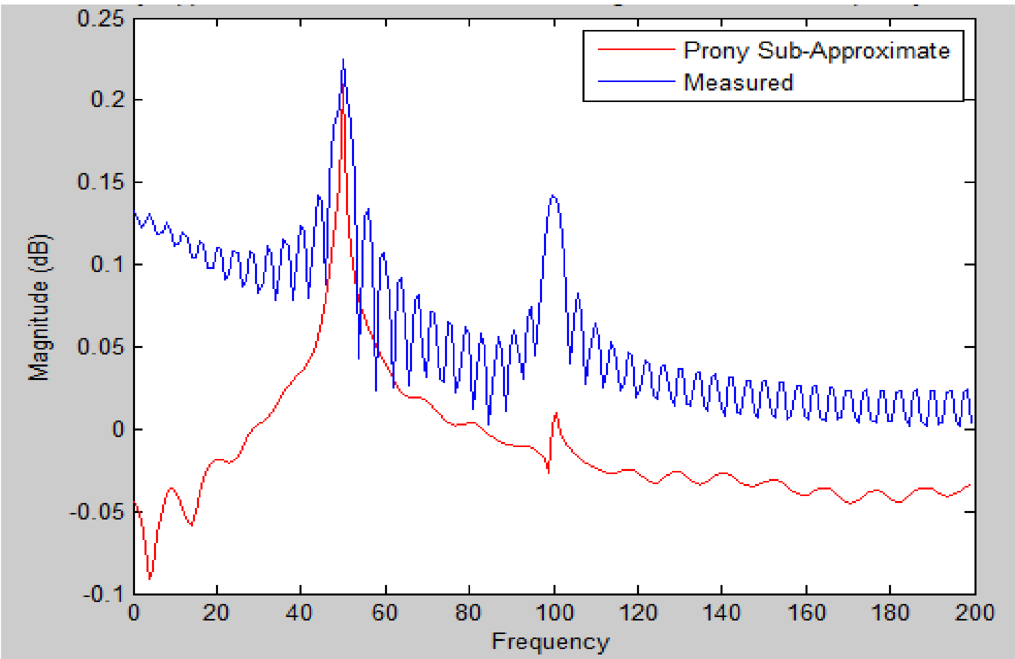

Fig. 8: Frequency and Magnitude Plot of Prony Analysis

From fig. 8,

Fundamental Frequency = 49.8753

2nd Harmonic Frequency = 99.750

Fundamental Amplitude = 0.2091

2nd Harmonic amplitude = 0.0311

Ratio = 2.7848 Ratio = 0.1488

The above ratio are given to the Naïve Bayes classifier for taking decision.

If fault occurs, then output of detector or pin 2 of **AND** gate becomes **1.** In a non-faulty case, output of detector or pin 2 of **AND** gate becomes **0**

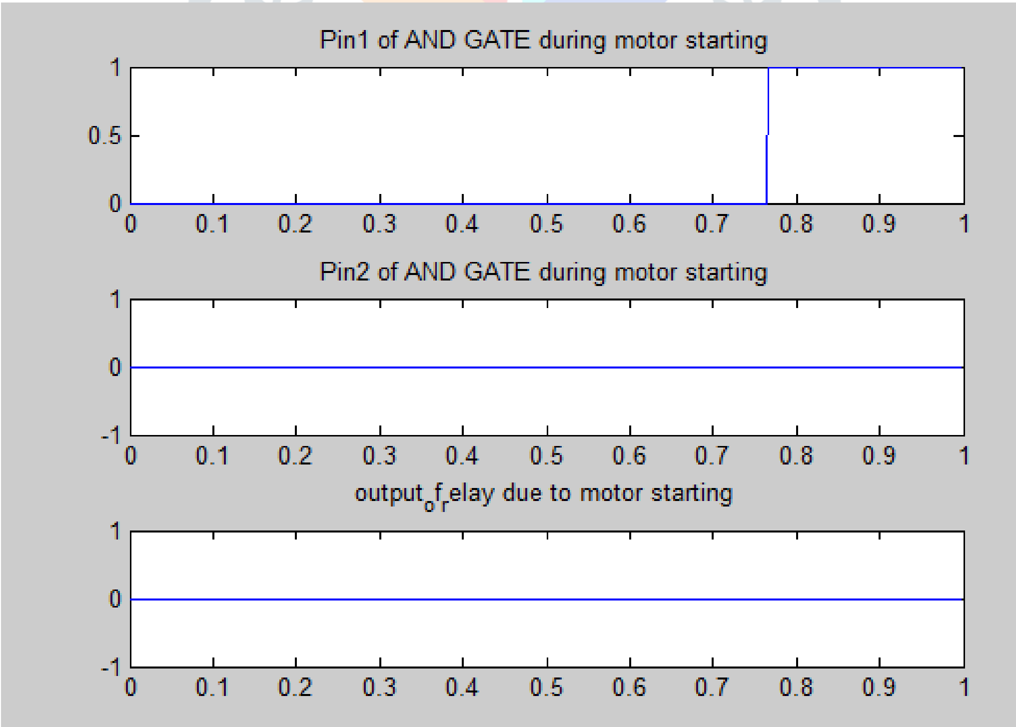

Fig.9: Output of relay due to motor starting

Case-II (Fault Events)

In this case, L-G fault is applied at busbar 13 at t=0 and currents are measured at busbar 7. Fig 12 shows the current of phase A. Considering the relay characteristics, pin 1 of AND gate is 1 and pin 2 of AND gate detects the fault case and it becomes 1.Therefore output of relay or output of AND gate is 1. So the occurred case is diagnosed as a fault case.

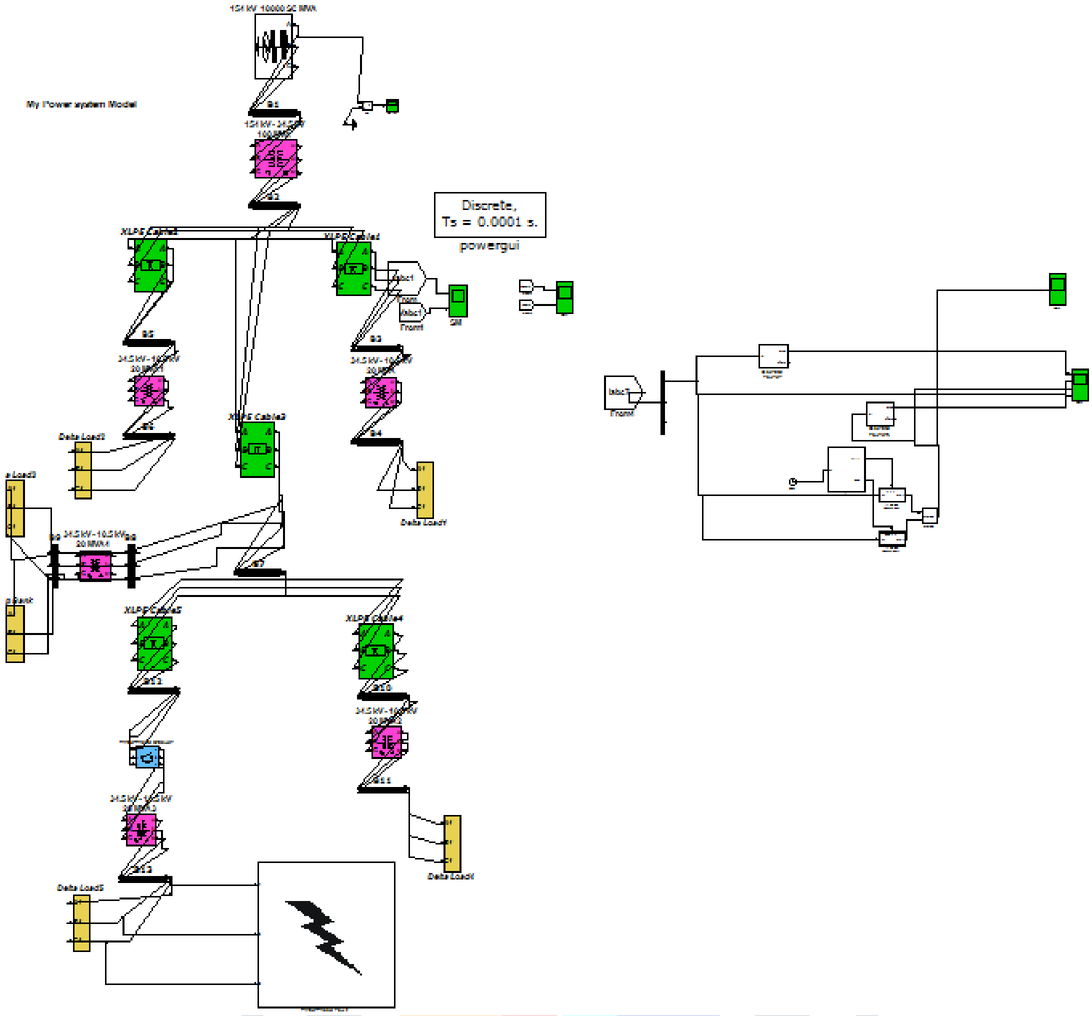

Fig. 10: 34.5 kV, 13 Bus Distribution System model (Fault Event)

RESULTS:

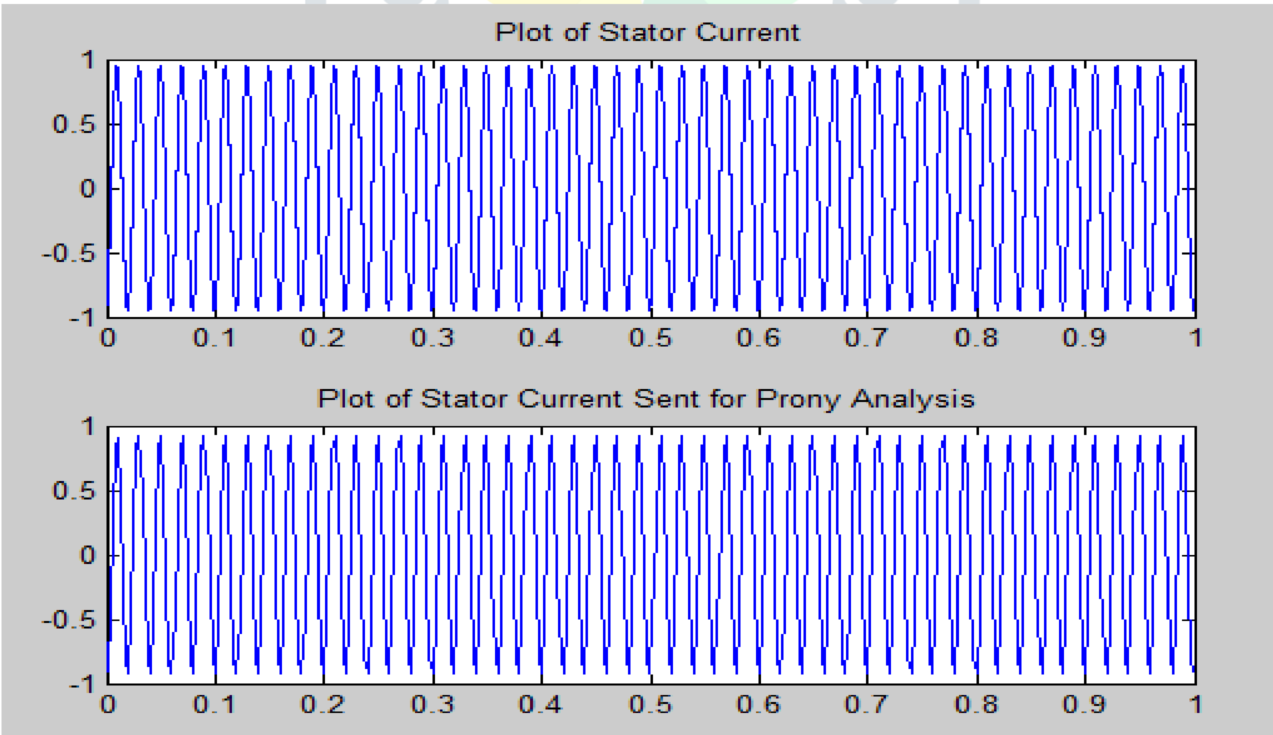

Fig: 11: Prony analysis of stator current of induction motor

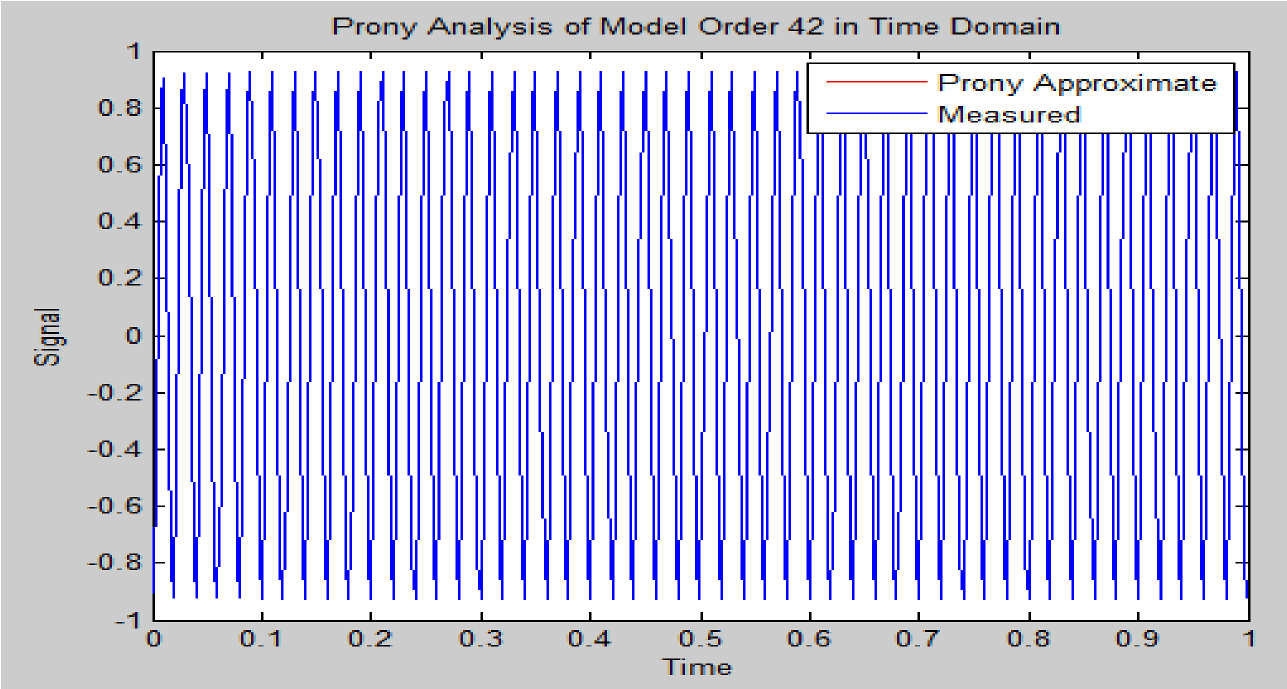

Fig. 12: Current of phase A due L-G fault

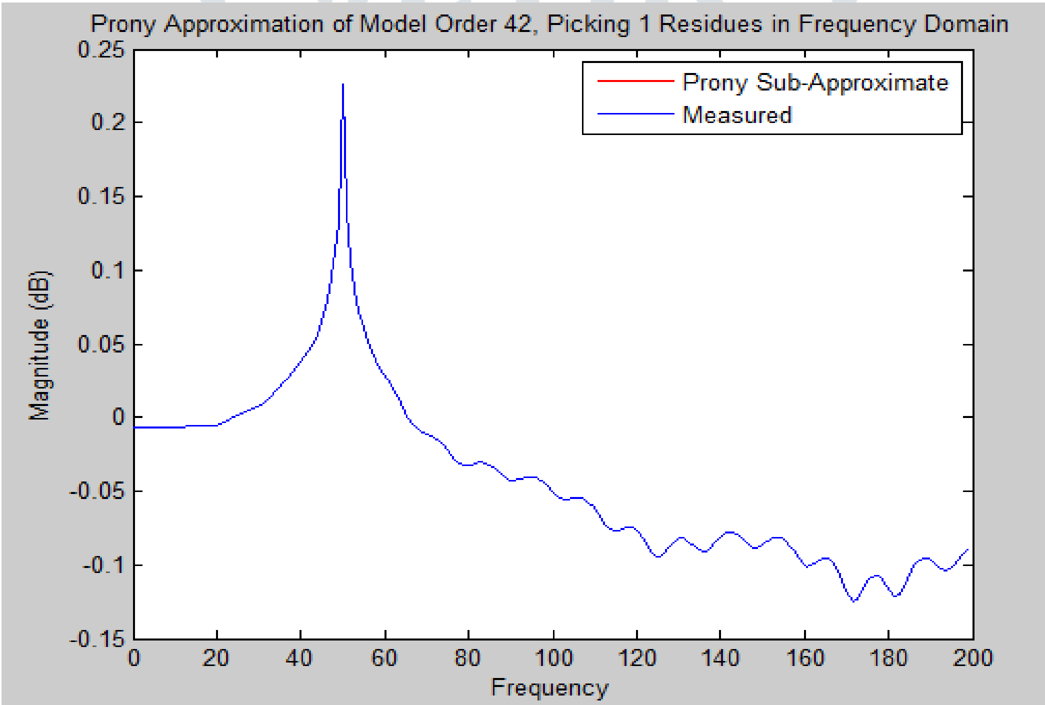

Fig. 13: Frequency and Magnitude Plot of Prony Analysis

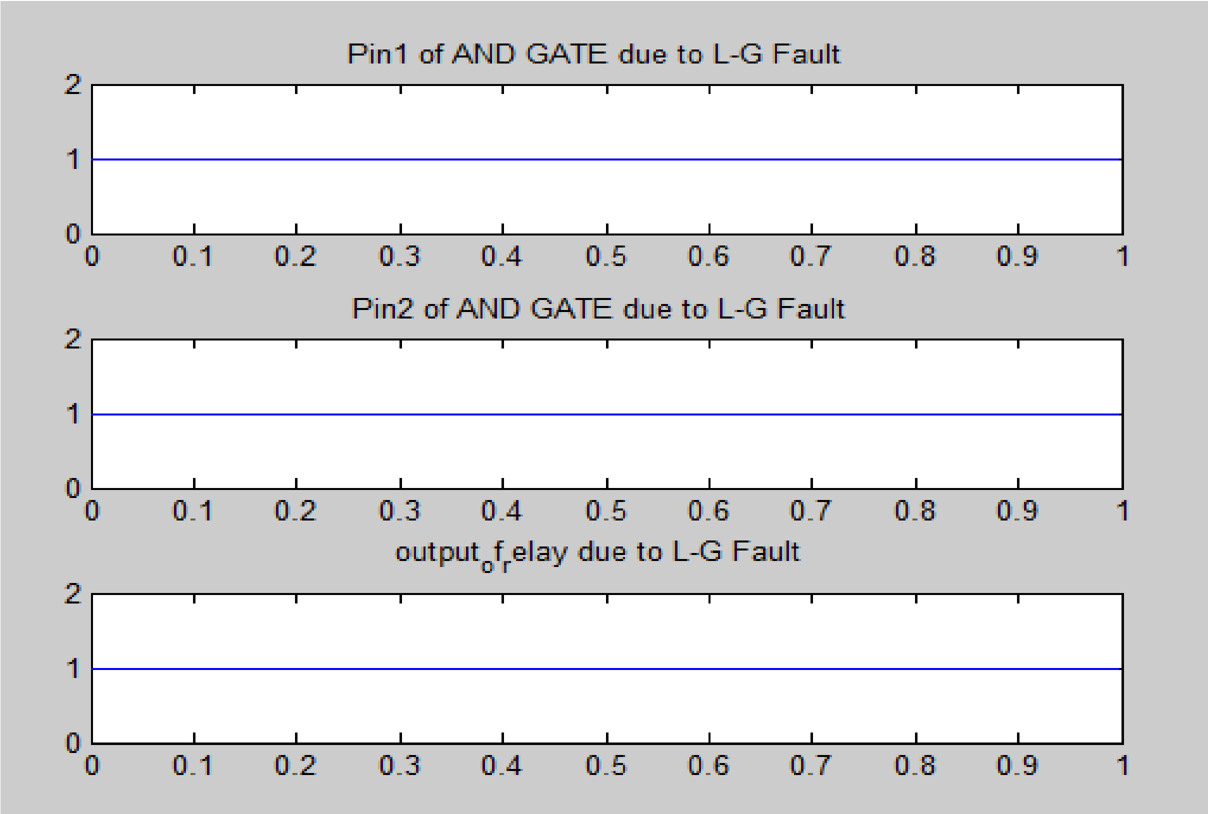

Fig.14: Output of relay due to fault L-G

Table 1: RESULT VERIFICATION

Cases	**Expected Result**			**Simulated Result**		
	Pin 1 AND Gate	**Pin 2 AND Gate**	**Output of Relay (AND Gate)**	**Pin 1 AND Gate**	**Pin 2 AND Gate**	**Output of Relay (AND Gate)**
Non Fault	**1**	**0**	**0**	**1**	**0**	**0**
L- G Fault	**1**	**1**	**1**	**1**	**1**	**1**
L-L- G Fault	**1**	**1**	**1**	**1**	**1**	**1**
L-L Fault	**1**	**1**	**1**	**1**	**1**	**1**

CONCLUSION

A variety of fault can occur within three phase IM while performing its normal operation. If the faults are not detected at early stage, it can cause a damaging failure to IM. To avoid the sudden failure situation and to maintain a good health of Induction motor, a variety of continuous condition monitoring methods and fault diagnosis techniques have been employed for the analysis of abnormal condition. For fault diagnosis, continuous monitoring purpose and discriminating purpose, Prony based Signal processing techniques are very effective. Due to continuous advancement of signal processing techniques and related instruments, early fault detection, discrimination and online condition monitoring of electrical machines became very reliable and effective.

References

[1] Hayri Arabac, Osman Bilgin, "Automatic detection and classification of rotor cage faults in squirrel cage induction motor", Neural Computer & Application (2010),Springer-Verlag London Limited 2009,19:713–723, Received: 11 March 2009 / Accepted: 15 December 2009 / Published online: 31 December 2009.

[2] N. Bessous, S. E. Zouzou, W. Bentrah, S. Sbaa, M. Sahraoui, "Diagnosis of bearing defects in induction motors using discrete wavelet transform", International Journal System Assur. Engg. Manag. (April 2018),The Society for Reliability Engineering, Quality and Operations Management (SREQOM), India and The Division of Operation and Maintenance, Lulea University of Technology, Sweden 2016, 9(2):335–343, Received: 1 September 2015 / Revised: 5 November 2015 / Published online: 3 May 2016.

[3] Xuefeng CHEN, Shibin WANG, Baijie QIAO, Qiang CHEN, “Basic research on machinery fault diagnostics: Past, present, and future trends”, Front. Mech. Eng. 2018, This article is published with open access at link.springer.com and journal.hep.com.cn,13(2): 264–291.

[4] “Detection and Classification of Induction Motor Faults Using Motor Current Signature Analysis and Multilayer Perceptron”, 2014 IEEE 8th International Power Engineering and Optimization Conference (PEOCO2014), Langkawi, The Jewel of Kedah,Malaysia. 24-25 March 2014 – page 35 -40.

[5] Vanessa fernandez-cavero1, Daniel morinigo-sotelo, Oscar duque-perez1, and Joan pons-llinares, “A Comparison of Techniques for Fault Detection in Inverter-Fed Induction Motors in Transient Regime”, IEEE Access, Received March 27, 2017, accepted April 25, 2017, date of publication May 9, 2017, date of current version June 7, 2017, Vol. 5,2017, pages 8048 -8063.

[6] Zhiqiang huo, Yu zhang, Pierre francq, lei shu, and Jianfeng huang, “Incipient Fault Diagnosis of Roller Bearing Using Optimized Wavelet Transform Based Multi-Speed Vibration Signatures”, Received December 11, 2016, accepted January 15, 2017, date of publication March 8, 2017, date of current version October 12, 2017. Vol. 5,2017 , IEEE Access , page 19452-19456.

[7] Anurag Choudhary, Deepam Goyal, Sudha Letha Shimi1, Aparna Akula, “Condition Monitoring and Fault Diagnosis of Induction Motors: A Review”, Archives of Computational Methods in Engineering, CIMNE, Barcelona, Spain 2018, Received: 4 January 2018 / Accepted: 1 September 2018.

[8] FranciscoM. Garcia-Guevara, Francisco J. Villalobos-Piña, Ricardo Alvarez-Salas, Eduardo Cabal-Yepez, and Mario A. Gonzalez-Garcia, “Stator Fault Detection in Induction Motors by Autoregressive Modeling”, Hindawi Publishing Corporation Mathematical Problems in Engineering, Volume 2016, Article ID 3409756, 7 pages.

[9] Juggrapong Treetrong, “Fault Detection and Diagnosis of Induction Motors Based on Higher-Order Spectrum”, Proceedings of the international Multi conference of Engineers and computer IMECS 2010, March 17 – 19, 2010, Hong Kong.

[10]Neelam Mehala, “Time- Frequency Techniques for Fault Identification of Induction Motor”, International Journal of Electronic Networks, Devices and Fields, ISSN 0974-2182, Volume 8, Number 1 (2016), pp. 13-17.

[11]Pan-Pan Wang, Xiao-Xiao Chen, Yong Zhang, Yong-Jun Hu and Chang-Xin Miao, “IBPSO-Based MUSIC Algorithm for Broken Rotor Bars Fault Detection of Induction Motors”, Chinese Journal of Mechanical Engineering, Wang et al. Chin. J. Mech. Eng. (2018) 31:80.

[12]Jawad Faiz, Saeed Lotfi-fard, and Saied Haidarian Shahri, “Prony-Based Optimal Bayes Fault Classification of Overcurrent Protection”, IEEE transactions on power delivery, vol. 22, no. 3, july 2007 – pages 1326-1334.

[13]A. Fernández Rodríguez, L. de Santiago Rodrigo, E. López Guillén, J. M. Rodríguez Ascariz, J. M. Miguel Jiménez and Luciano Boquete, “Coding Prony’s method in MATLAB and applying it to biomedical signal filtering”, Fernández Rodríguez, BMC Bioinformatics (2018) 19:451 .