# Detection of Abnormal Conditions of Induction Motor by using ANN

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**Abstract**: ***Induction motors are the most common drive in today's industries due of its salient features. But its operating condition may sometime led the machine into the different fault situations. The external faults like Over Load, single phasing, unbalanced supply Voltage , locked rotor, phase reversal, ground fault, Under Voltage & Over Voltage happens more rapidly. These faults can result in drastic consequences for an industrial process. Early detection of abnormalities in the motors will help to avoid expensive failures & also can lead to greater plant availability, extended life, higher quality product, and smoother plant operation. Extensive research has been conducted in the last decade & several Artificial Intelligence (AI) techniques like Artificial Neural Networks (ANNs), have been developed and applied in the monitoring processes of faults. ANN can be applied in induction motor relays which provide inexpensive but effective fault detection mechanism. This paper addresses the detection of an external motor faults (e.g., unbalanced voltage, under voltage, overvoltage) with a digital protection set by using an artificial neural network (ANN) for a three-phase induction motor of rating 3HP, 414 V, 6.4A, 50Hz Sq Cage IM 1480 rpm. The proposed set-up has been simulated using "Matlab/Simulink" Software and tested for various conditions of unbalance voltages. This dissertation also talks about the causes of unbalance voltage fault & its effect on performance of motor. Same is verified by MATLAB simulation results. The data sheet is created by using MATLAB results at various unbalance voltage conditions and it is used to train & test the neural network. Well trained neural network with most sensitive parameters are used to detect abnormal conditions with more accuracy. Data sheet can be also obtained by performing actual experimental setup on motor at normal & abnormal conditions. A Stator current signals can be captured by DSO. Processed & Sampled data can be used to train neural network for detecting abnormal condition. The simulated results clearly show that well-trained neural networks can precisely of early fault detection, also validating the proposed setup as a simple, reliable and effective protection for the three-phase induction motor.***

**Keywords**: Artificial Neural Networks, Induction Motor, voltage unbalance. Fault detection, Matlab simulation

## 1. Introduction

Large three phase induction motors are very commonly employed in power system plays a very important role in electricity production because of their good self-starting capability, offers users simple, rugged construction, easy maintenance, low cost and reliability. Due to extensive use of induction motors in industry, motors can be exposed to different hostile environments, mis-operation, manufacturing defects etc. As a result motors are subjected with internal faults like inter-turn short circuits, ground faults, mechanical failure as well as external faults like mechanical overloads due to prolonged starting or locked rotor and stalling; abnormal supply conditions such as loss of supply voltage, unbalanced supply voltage, phase sequence reversal of supply voltage, over voltage, under voltage, and under frequency; faults in starting Circuit, due to interruptions in phases or Blowing of fuse / single phasing, and short circuit in supply cable. These faults are expected to happen sooner or later. Correct diagnosis and early detection of faults result in fast unscheduled maintenance and short down time for the machine under consideration. It also avoids harms and helps to reduce financial loss In industries like nuclear power and petrochemical, techniques able to detect the fault's early onset could avoid more serious problems. In this sense, there are many studies focused on early fault detection. In this manner, several artificial intelligence techniques like Artificial Neural Networks (ANNs) have been developed and applied in the monitoring processes of faults. They have numerous advantages over conventional diagnosis techniques. In general, when properly tuned, they could improve the diagnosis performance. They are easy to extend and modify, and they could be easily adapted by the incorporation of new data as they became available. Moreover, their design does not require a complete mathematical model of the induction motor. This paper discusses about the detection of external motor faults (e.g., unbalanced voltage, under voltage, overvoltage) of 3HP, 50Hz, 414 V, 6.4A, 1480 rpm Sq Cage IM. with a digital protection set by using an artificial neural network (ANN)

This methodology is applied to a three phase induction motor, using the well-known Matlab/Simulink software. In each simulation of the system, the induction motor faults conditions are varied. The simulated result data used to train ANN & well trained neural network used to detect voltage unbalance fault more efficiently and at a reduced cost.

## 2. Voltage Unbalanced Fault

Voltage Unbalanced is defined as a power quality problem where V in 1 or 3 phase gets increased or decreased in phase & magnitude above/below tolerance limit. A various Cases of possible Voltage Unbalance condition are Single phase under voltage unbalance-(1ø UV), Two phases under voltage unbalance (2ø UV), Three phase under voltage unbalance (3ø UV), Single phase over voltage unbalance (1ø OV), Two phases over voltage unbalance (2ø OV), Three phases over voltage unbalance (3ø OV), Unequal Single phase displacement (1ø A), Unequal Two phases displacement (2ø A)[3]

### 2.1 Causes of Voltage Unbalanced Fault

A voltage unbalanced fault may be created due to various reasons. Some causes of voltage unbalanced are harmonics due to electronics equipment, adjustable speed drive fed from inverter, unbalanced incoming utility supply, uneven distribution of 1 phase load , malfunctioning of p.f correction equipment, open delta connections, unbalance transformer tank, improper tap settings of transformer, sudden changes in load conditions, faults on transmission & distribution lines, heavy reactive 1 phase loads such as welders, current harmonics due to winding arrangement & iron core nonlinear behavior [4]

### 2.2 Effects of Voltage Unbalanced Fault on Motor Performance

Large induction motor is very sensitive to unbalance in supply voltage. The negative sequence component, which comes into picture because of the unbalance in the supply, is particularly troublesome. This is because the motor offers very small impedance to the negative sequence currents. In fact the negative sequence impedance is less than the positive sequence standstill-impedance as shown in figure 1. Further, the magnetic field due to negative sequence rotates at synchronous speed NS in the direction opposite to that of the rotor which is rotating at a speed equal to ( sNS ), which is slightly less than synchronous speed, where s is the slip of the motor this causes currents of [f(2-s)] frequency, i.e. almost double the supply frequency, to be induced in the rotor circuit.

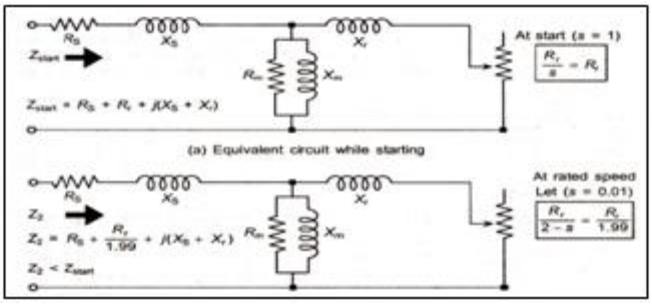



**Figure 1:** Equivalent circuit of induction motor

As the torque developed by an induction motor is proportional to the square of the applied voltage; therefore, any small reduction in voltage has a marked effect on the developed torque. The reduced torque may cause the motor to lose speed and draw more current.

So the Voltage Unbalanced Fault results in decrease in full load torque production, de-rating in motor characteristic, drawing unbalance current which causes overheating of rotor & stator, increase in losses so reduction in working efficiency, increase in resistance due to overheating results in thermal runaway & faster thermal ageing, additional charges to consumer due to extra load to utility, shorter life span of motor, mechanical damage of bearing due to induced torque component of double system frequency, slight reduction in full load speed , increase in Shaft vibration noise, change in working pf.[4] Therefore, for large motors any unbalance in the supply voltage needs to be quickly detected and corrective action taken.

## 3. Performance of Motor at Abnormal Voltage by Matlab

### Motor Specifications

3HP, 414 V, 6.4A, 50Hz Sq Cage IM 1480 rpm
R1=1.405ohm, L1 = 0.005839 H
R2'= 1.395ohm, L2' = 0.005839 H

The Matlab Simulink is developed for the above motor specification. This Simulink is simulated for all eight various cases of possible voltage unbalance conditions by varying voltages magnitude & phase. The various performance parameters of motors like all three currents, active & reactive power, negative phase sequence voltage component by phase sequence analyzer, torque, pf, efficiency, speed, mechanical output are studied for normal & all possible voltage unbalance conditions by observing display & scope.

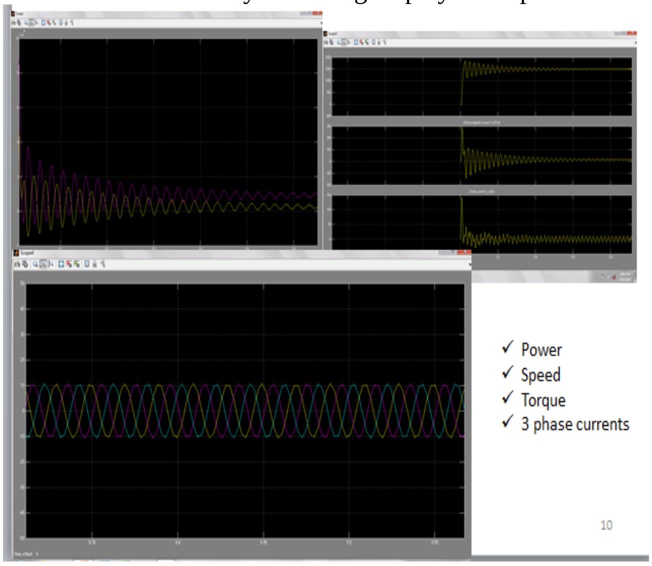



**Figure 2:** MATLAB results for Normal condition

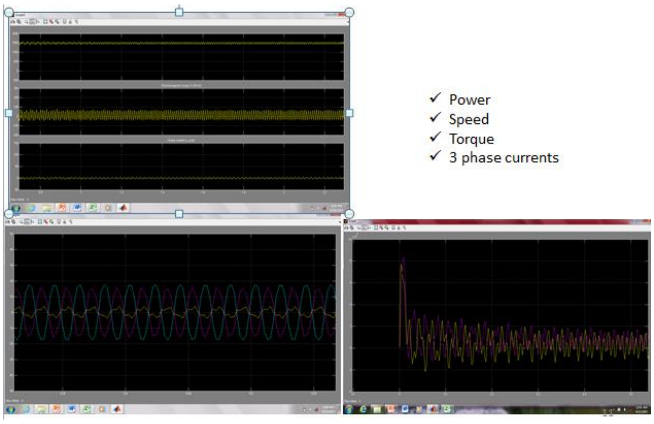



**Figure 3:** MATLAB results for Voltage unbalance = 7.010%

The Matlab results for normal condition & abnormal condition for Voltage unbalance=7.010% are as shown in figure 2 & figure 3 respectively. All motor performance parameters for various cases of unbalance voltage conditions are observed & recorded from display meters and Excel data sheet is prepared which is used for training neural network. A percentage voltage unbalance factor & percentage current unbalance is calculated by formula

1) $\%\ voltage\ unbalance\ factor\ (VUF)$

$$= \frac{\text{Negative sequence V component}}{\text{positive sequence V component}} \times 100$$

2) line voltage unbalance rate (LVUR) as defined by National Electrical Manufactures Association (NEMA)
% LVUR =

$$\frac{Max\ V\ deviation\ from\ avg\ line\ V\ magnitude}{average\ line\ voltage\ magnitude} X\ 100$$

$$= \frac{\max[|V_a - V_{avg}||V_b - V_{avg}||V_c - V_{avg}|\ ]}{V_{avg}} x100$$

Similarly percentage current unbalance rate is calculated. [3],[7]

For studying statistical data, correlation between percentage voltage unbalance & all motor performance parameters such as percentage current unbalance, negative sequence voltage, Positive sequence voltage, speed, torque & power is developed. From this correlation, Figure 4 , it is observed that negative sequence voltage, percentage current unbalance & torque is most sensitive parameters. So these most sensitive parameters can be used to train neural network for detecting voltage unbalanced condition fault accurately.

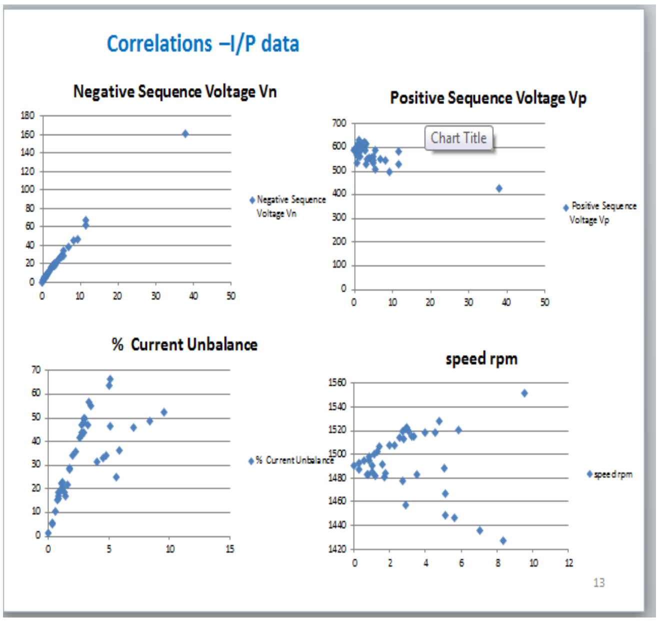



**Figure 4** Co-relation between VUF & motor performance parameters

## 4. Detection of Fault Condition by Artificial Neural Network (ANN)

### 4.1 Artificial Neural Network (ANN)

The ANN tries to simulate the biological brain neural network in a mathematical model. It is a set simple processing unit, connected to each other, with weights assigned to the connections. According to a learning rule it is possible to modify these weights, so, the ANN can be trained to recognize a pattern given the training data. There are several kinds of neural network structures. The most used structure is the feed-forward network. There can be several hidden layers in the network. In this network, the number of input nodes and the number of output nodes are determined by the number of patterns to be identified. The number of nodes in the hidden layer is selected for an application, generally using a trial and error method. The neural network has to be trained so that it can identify the output patterns corresponding to the input pattern. There are several kinds of training algorithms suggested in the literature. The back-propagation is one of the most popularly used algorithms. In the ANN-based systems, several quantities are utilized as input signals such as: stator currents and voltages, magnetic fields and frame vibrations, etc. In general, stator currents and voltages are preferred because they allow for the realization of noninvasive diagnostic systems and the sensors required are usually present in the drive considered.[6]

This paper presents a step toward the detection of voltage unbalanced condition by ANN. This technique utilizes results of Matlab simulation to train a neural network for monitor and detection of external motor faults .The parameters like percentage voltage unbalance, percentage current unbalance, negative sequence voltage, Positive sequence voltage, speed, torque & power are used to train neural network.

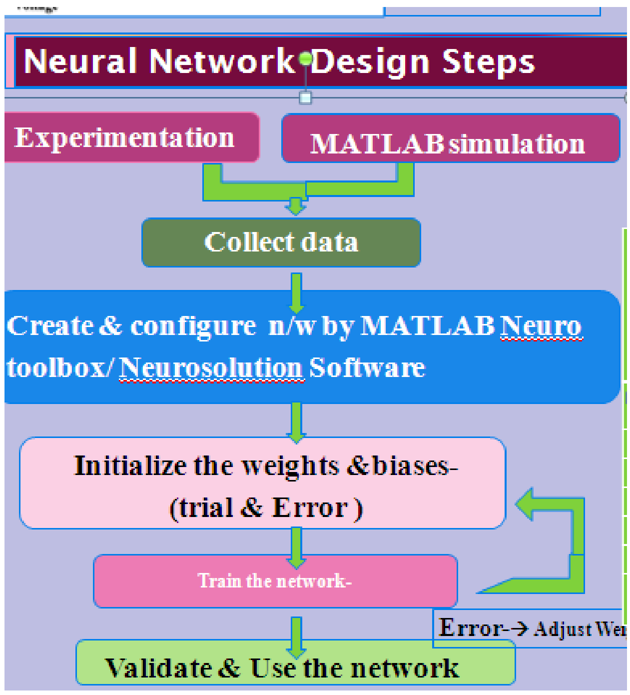



**Figure 5:** Steps for designing neural network

Figure 5 shows neural network design steps i.e a flowchart for use of neural network for fault detection. In this dissertation Neuro-solution for Excel module from Neuro-solution software is used to detect an abnormal condition of motor due to external fault –voltage unbalanced fault condition

### 4.2 Training & Testing of ANN

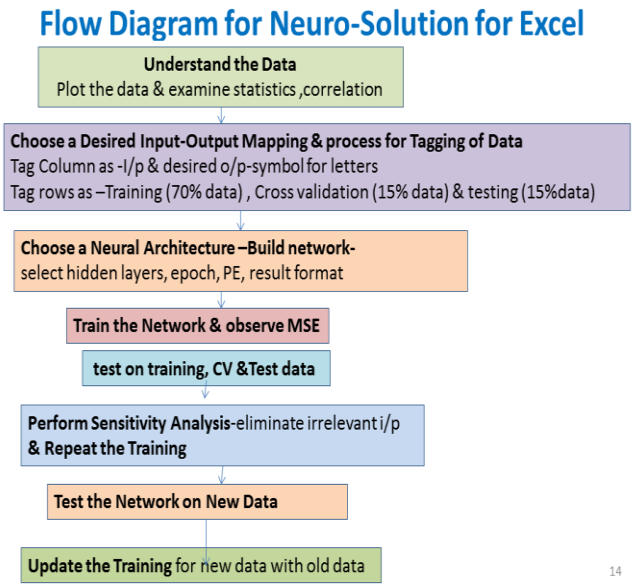
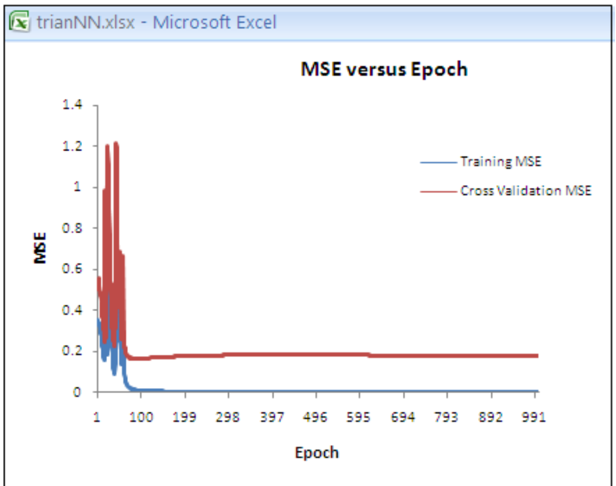



**Figure 6:** Flow diagram for Training & Testing ANN

Figure 6 presents a flow diagram describing the order in which the Neuro-Solutions for Excel modules can be used to solve the problem. It gives step by step procedure for training & testing neural network by using Neuro-solution for Excel module. In this module at a minimum, only three operations are required: Tag Data, Create/Open Network, and Train Network.

The rows of data in Excel data sheet are tagged before running a training process. Rows are tagged as "Training", "Cross Validation", "Testing", or "Production". Generally 70% of data is used for training, 15% for cross validation & remaining 15% for testing. Only the "Training" tag is required for running a training process. However, cross validation is a very useful tool for preventing over-training. So in most cases a portion of data is tagged as "Cross Validation". The rows of data to use for testing the trained network ("Testing") or producing the network output for new data ("Producation") can be tagged before or after the training process is run. These operations are usually followed up by testing the models performance (Test Network) and applying the model to new input data where the output is unknown (Apply Production Dataset).

After the completion of training process a sheet as shown in figure 7 is created which gives mean square error (MSE) of the process. The mean square error is a good overall measure of a successful training run process. When "Classification" is selected as the problem type, the Neural Expert stamps a pair of confusion matrix probes – one for the training set and one for the cross validation set as shown in figure 8.




| Best Networks | Training | Cross Validation |
|---|---|---|
| Epoch # | 1000 | 86 |
| Minimum MSE | 0.001701885 | 0.166031077 |
| Final MSE | 0.001701885 | 0.181440508 |

**Figure 7:** Result of Training ANN

Confusion Matrix

| Output / Desired | desired o//p(N) | desired o//p(ABN) |
|---|---|---|
| desired o//p(N) | 9 | 0 |
| desired o//p(ABN) | 0 | 20 |

| Performance | desired o//p(N) | desired o//p(ABN) |
|---|---|---|
| MSE | 0.007992041 | 0.008515798 |
| NMSE | 0.037340594 | 0.039787702 |
| MAE | 0.053708889 | 0.057196857 |
| Min Abs Error | 0.000831918 | 0.00055514 |
| Max Abs Error | 0.290870224 | 0.314828818 |
| r | 0.983974186 | 0.98408588 |
| Percent Correct | 100 | 100 |

Test Report on Training Data

Confusion Matrix

| Output / Desired | desired o//p(N) | desired o//p(ABN) |
|---|---|---|
| desired o//p(N) | 6 | 1 |
| desired o//p(ABN) | 0 | 1 |

| Performance | desired o//p(N) | desired o//p(ABN) |
|---|---|---|
| MSE | 0.09363625 | 0.092908488 |
| NMSE | 0.499393334 | 0.495511936 |
| MAE | 0.217374215 | 0.224817412 |
| Min Abs Error | 0.052270842 | 0.063767042 |
| Max Abs Error | 0.746065885 | 0.728752184 |
| r | 0.756620309 | 0.755373043 |
| Percent Correct | 100 | 50 |

Test report on cross validation data

**Figure 8:** Confusion Matrix

Confusion matrix tallies the results of all exemplars of the last epoch and computes the classification percentages for every output vs. desired combination. For example, refer to figure 8 in confusion matrix of report on training data, 9 normal condition exemplars were correctly classified while 0 normal condition of exemplars were classified incorrectly. Similarly, 20 abnormal conditions of exemplars were correctly classified & 0 abnormal conditions of exemplars were classified incorrectly. So percent correct for both conditions are 100. While in confusion matrix of report on Cross validation data, 6 normal condition exemplars were correctly classified while 0 normal conditions of exemplars were classified incorrectly & 1 abnormal condition of exemplars were correctly classified &1 abnormal condition of exemplars were classified incorrectly. So percent correct for both conditions are 100 for normal condition & 50 for abnormal condition.

A neural network can actually arrive at different solutions for the same data given different values of the initial network weights. The initial network weights define the starting point on the error surface. As the network transverses the error surface in the direction of the minimum error. So in order to develop a statistically sound neural network model, the network must be trained multiple times. Similarly we can train a neural network multiple times while varying any one of the network parameters to determine the optimum number of hidden layer processing elements.

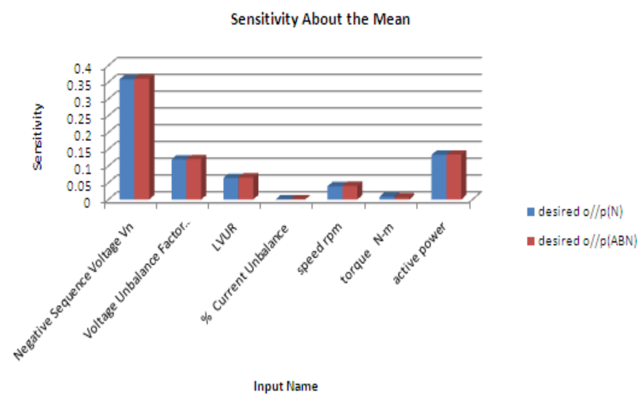
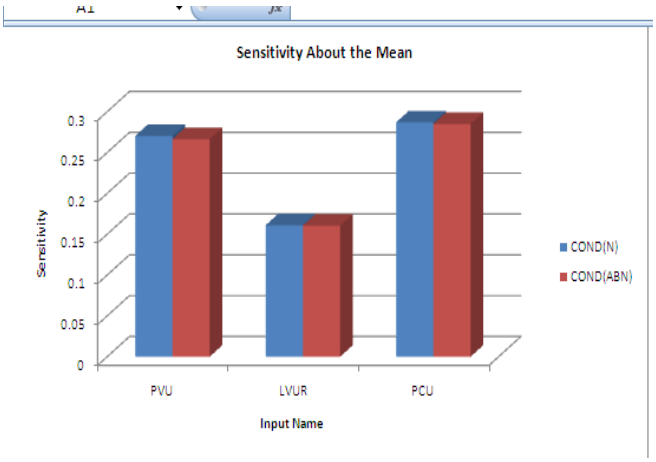
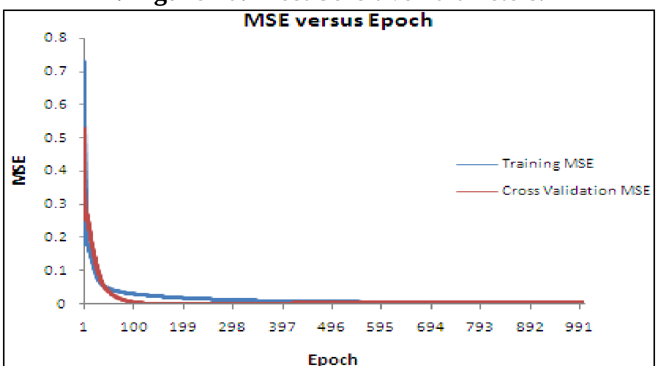



**Figure 9**: Sensitivity Analysis

By performing sensitivity analysis on a trained network we can often find and eliminate irrelevant inputs as shown in figure 9. The elimination of irrelevant inputs reduces data collection cost and can improve a network's performance. Furthermore, sensitivity analysis can give insights into the underlying relationships between the inputs and outputs




. **Figure 10:** Most Sensitive Parameters.




| Best Networks | Training | Cross Validation |
|---|---|---|
| Epoch # | 1000 | 174 |
| Minimum MSE | 0.004918673 | 0.00226782 |
| Final MSE | 0.004918673 | 0.004836656 |

**Figure 11:** MSE for most sensitive parameters

By using most sensitive parameters as shown in Figure 10 we can get more accuracy as shown in result of Figure 11.

## 5. Conclusions

- Proposed set of Induction motor has been simulated by MATLAB /Simulink model for healthy and voltage unbalanced conditions for various possible cases. Observed result data of simulation has been used to train back propagation FFNN by Neuro-Solution for Excel module from Neuro-Solution software. Then trained network can classify abnormal condition of motor Less no of Neuron will be required for more no of I/P. parameters. In order to obtain optimum design of neural network most sensitive inputs has been used.
- Motor can be tested experimentally at normal healthy & at for various voltage unbalanced conditions by using 1 phase variac, and corresponding stator currents can be captured by the modern signal processing tool –DSO. Data will be further processed by FFT to train ANN to visually detect the unbalance condition.
- well-trained NN can precisely of early fault detection, (4ms i.e. 1/4 cycle)
- 3-ph IM fault identification scheme using ANN is a simple, reliable and efficient protection setup & at reduced cost

## 6. Acknowledgement

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## Author Profile

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