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Experimental testing of the neural network based protection of synchronous generators

By

A. Helal, H. El Dessouki *   M. El-Saadawi, M. Tantawy, A. Hatata **

Abstract:

An internal fault detector and classifier for synchronous generator stator windings based on ANN have been implemented and its behavior is investigated on physical power system model. The hardware system is designed and built to acquire the three phase currents at both ends of synchronous generator terminals. A software program is developed to read currents, which used to train a proposed Neural Network structure using MATLAB. The trained network is placed in a LabVIEWTM based program formula node that monitors the currents online and display the fault types. Details of implementation and the experimental studies are given and analyzed in the paper. Lab work proves that the proposed approach is able to detect and classify the type of internal faults rapidly and correctly. It is suitable to realize a fast and accurate internal fault protection scheme of the synchronous generator.

Keywords:

Internal fault detector and classifier, Synchronous generator and Neural Network

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* Dept. of Elec. Engineering and Control, Arab Academy for Science and Technology, Alex. Egypt.
** Faculty of Engineering, Mansoura University, Mansoura, Egypt

1. Introduction:

Large synchronous generators are very important and vital component of electrical power systems. Due to its importance and cost, its protection needs to be detecting properly. The protection action should be fast and reliable. Proper continuous monitoring of synchronous generator can provide early warning of electric faults and consequently prevent catastrophic losses. It can minimize damages and enhances the reliability of power supply.

Differential relaying principles is the main protection approach used for large synchronous generators. It is a standard practice to use differential protection for generators of rating 1 MVA or higher [1]. This superior approach compares the currents at all terminals of the protected generator by computing and monitoring a differential current. The value of differential current greater than zero indicates an internal fault. The differential relays are affected by various factors such as grounding connection and impedance, over excitation and current transformer saturations.

The function of differential protection can be enhanced greatly by applying the artificial intelligence techniques. Artificial neural networks (ANN) are one of the most promising techniques in this way. The application of ANN in the protection of synchronous generator is getting momentum in the last few years. Different schemes based on ANNs have been reported [2-8]. The scheme presented in Ref. [2] was based on using two ANNs: the first one was employed to detect the fault occurrence, whereas the second one was used to classify the faulted phases. But the proposed scheme was applicable for detecting the ground faults only. In [3], the authors proposed a fault detector for generator protection. The detector consists of three ANNs, six input one output. Each ANN is fed with difference and average of the currents entering and leaving the generator windings. Fault diagnosis can was done by using the outputs of the three networks. Then the authors developed their scheme in [4], they replaced the three networks by seven ANNs-six input one output and one hidden. Ref. [5] analyzed generator turn-to-turn short circuit in rotor winding. Faulty samples were obtained through direct calculation; turn-to-turn short circuit fault of rotor winding was diagnosed by making use of ANN. Ref. [6] developed a Wavelet Transform (WT) analysis along with ANN for the diagnosis of electrical machines winding faults. Ref. [7, 8] proposed a fuzzy neural network (FNN) based inter-turn short circuit fault detection scheme for generator. The first reference used the second harmonic magnitude of field current and the negative sequence components of voltages and currents as inputs for the FNN fault detector [7]. Whereas, the second one proposed wavelet based adaptive neural fuzzy identifier system (ANFIS) for finding inter turn fault of generator. The scheme was based on measuring three phase currents of the synchronous generator [8].

The authors have developed an ANN based algorithm for detecting and classifying internal and external faults of synchronous generators. The proposed technique has been trained and tested through computer simulation studies for a typical machine power system model implemented in MATLAB [9, 11]. The proposed ANN base fault detector and classifier schemes for internal faults in stator windings of the synchronous generator is verified by implementing it on physical power system model. To accomplish this, a hardware system was designed and built to acquire three phase currents at both ends of the generator. A three phase synchronous generator 2kVA, 50Hz, is used for this propose. A LabVIEWTM program was written to read the currents and implement the ANN schemes in a friendly user interface. Details of proposed hardware and software lab work studies are given in this paper. Also the results of performance studies with the proposed ANNs are given and analyzed.

2. The Proposed NN Design:

In differential protection, it is common to use the three currents on both sides of synchronous generator as inputs to the ANN. The currents waveforms are sampled at a rate of 20 sample/cycle. In this study the information is used to cover 1/4 of the cycle of the current inputs. Thus, each phase current was represented by its 5 consecutive samples. This data window length meets both requirements of speed and reliable operation [9].

A. ANN based fault detection module

The function of NN-based fault detector module is to differentiate between the three generator states: the normal operation state, external fault state and internal fault state. A 30-input network with two neuron output layer was chosen as the fault direction identification network. The network needs two outputs to classify between three generator states. The values of the outputs during network performance will be analog between 0 and 1. If internal fault occurs, then the ANN unit should develop [0 1] output and if external fault occurs then [1 0] output pattern is generated. Likewise, in normal state then [0 0] output pattern will appear.

Many different neural network structures, with different number of neurons in their hidden layers were considered and trained. Training and test patterns were generated by simulating different types of faults on different locations of the stator windings of the simulated generator. These networks are trained with Marquardt-Levenberg (ML) algorithms. Several tests were performed to determine the optimum number of hidden neurons based on the mean square error (MSE) and number of training epochs. Moreover, different training functions were examined for convergence. It was found that the network which showed satisfactory results, while not having a big size had 30 inputs, 20 neurons in first hidden layer, 15 neurons in second hidden layer and two output neurons [9]. The ANN structure of the proposed fault detector is (30-20-15-2). The ANN structure of the fault detector is shown in Fig. 1.

The program used for implementing the algorithm is developed by applying the MATLAB neural network toolbox. The output layer is capable to minimize the MSE of the ANN to a final value less 6.06E-6 within 269 epochs.

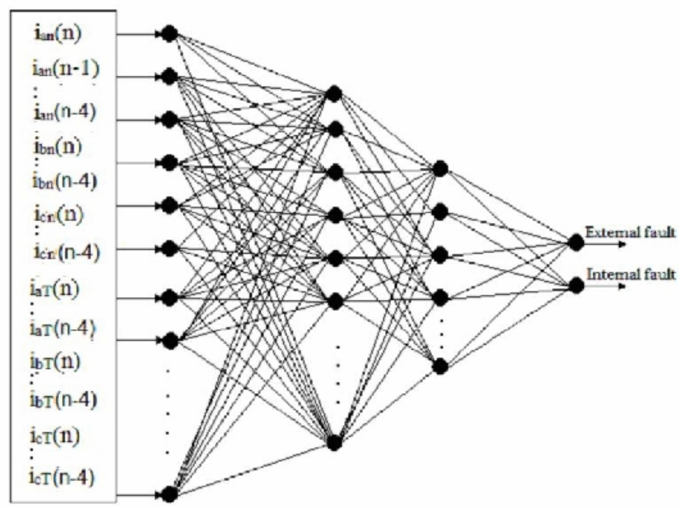

Figure (1) : *Structure of ANN fault detector*

B. ANN Based classifier module

The fault classifier (FC) is designed to detect the faulty phases and the fault type in the synchronous generator stator windings. The FC is activated after detecting a fault by the fault detector.

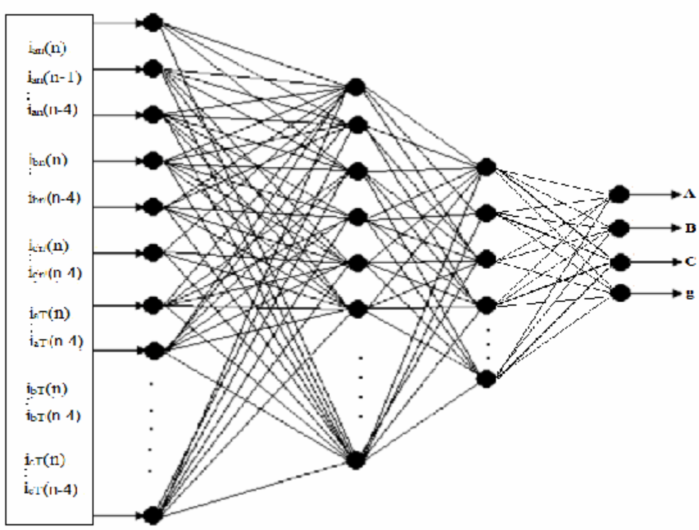

Figure (2) : *Structure of ANN fault classifier*

The FC has three layers with activation function tan-sigmoid for the hidden layers, and log-sigmoid for the output layer. The output layer has 4 neurons to represent the faulty phases and the ground. For example a single phase to ground (A-G) has an output equal to [1 0 0 1], and phase to phase fault (B-C-G) has an output equal to [0 1 1 1].

To get a good general performance, the fault classification module was tested with a set of independent test patterns to cover all types of faults. The training set consisted of about 2000 patterns representing different types of internal faults. These patterns were the internal fault patterns used previously for training the fault detector module. Various networks with different number of neurons in their hidden layer were proposed. The numbers of neurons for the two hidden layers of the network were finally chosen to be 15 and 10 neurons. The output layer is capable to minimize the MSE of the ANN to a final value less 4.69E-4 within 158 epochs.

3. Proposed Hardware Components:

Three phase synchronous machine was physically modeled in the Mansoura University Electric Machine Lab. An overall schematic diagram of the experimental system setup is shown in Fig. 3

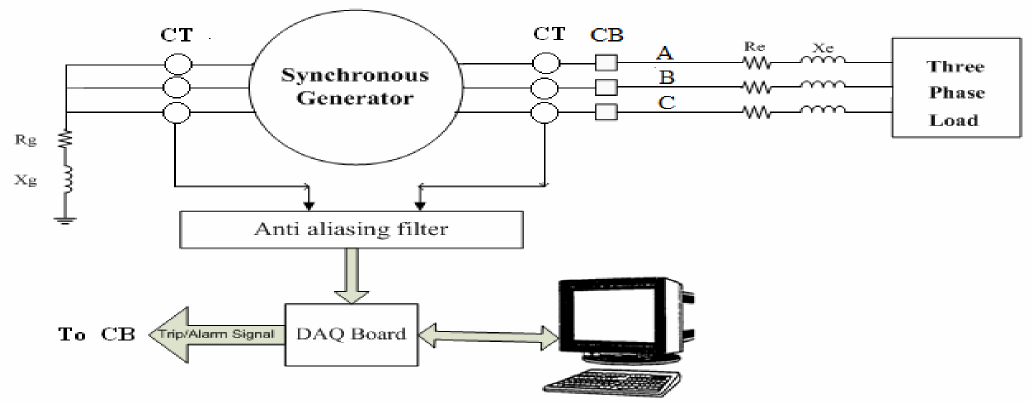

***Figure (3)** : Schematic diagram of lab work system*

The current signals from the power system are obtained through current transformers. The data acquisition board receives the analog signals through the analog input card. The anti aliasing filter is then transferred the filtered signal to personal computer through an internal Analog to Digital (A/D) converters. Details of those blocks are presented in the following sections.

A. Physical power system

The synchronous lab machine is a three-phase 2 kVA, 220 V universal laboratory machine driven by a separately excited dc machine and is connected to a three phase load bank.

B. Anti aliasing filter

The current signals must be converted into appropriate form so that the digital hardware can perform calculations and reach relaying decisions. A second order Butterworth band-pass filter has been used to attenuate the dc component and high frequency components. The Butterworth filter has a flat response in the pass band. The filter is centered at the nominal system frequency and its pass band is chosen to be 80 Hz. This value allows a considerable reduction of the high frequency and dc components with a small time delay.

C. Data acquision board

The objective of the DAQ is to convert the analog signals into a digital form ready for use by the computer. A 1 kHz sampling rate implies 1ms time interval between samples which is needed for an appropriate software and hardware setup to accomplish protecting relay task within this time interval. In this work a national instruments NI USB-6229 M series multifunction DAQ (16 bit, 250 kS/s, 32 analog inputs) [10] is used to acquire the current signals.

4. Proposed Software:

LabVIEWTM program is written to simultaneously acquire the signal conditioned instantaneous synchronous generator currents at both ends. The program acquires data at a sampling rate of 1 kHz. These signals are used to test the ANN based fault detector and classifier.

For the purpose of creating a Neural Network in LabVIEWTM, a model for the neuron is created. The LabVIEWTM software weights each of the inputs Xn by multiplying it by its respective weight value Wn. A sum of all these results is then calculated and a tan sigmoid transfer function is applied to that and consequently the neuron’s output is generated. The trainings of the fault detector and classifier networks were run using the MATLAB/Simulink environment. The optimum weights for all inputs of the neurons in the networks have been entered to LabVIEWTM program as matrices.

The program in Fig.4 consists of two networks: the first one is the fault detector. The second network is the fault classifier. The authors developed (designed) a Graphical User Interface (GUI) to illustrate the output of the neural network LabVIEWTM program so that the outputs of the program become simple and clear. The GUI shows the stator currents, the output of the ANN fault detector module and fault classifier module.

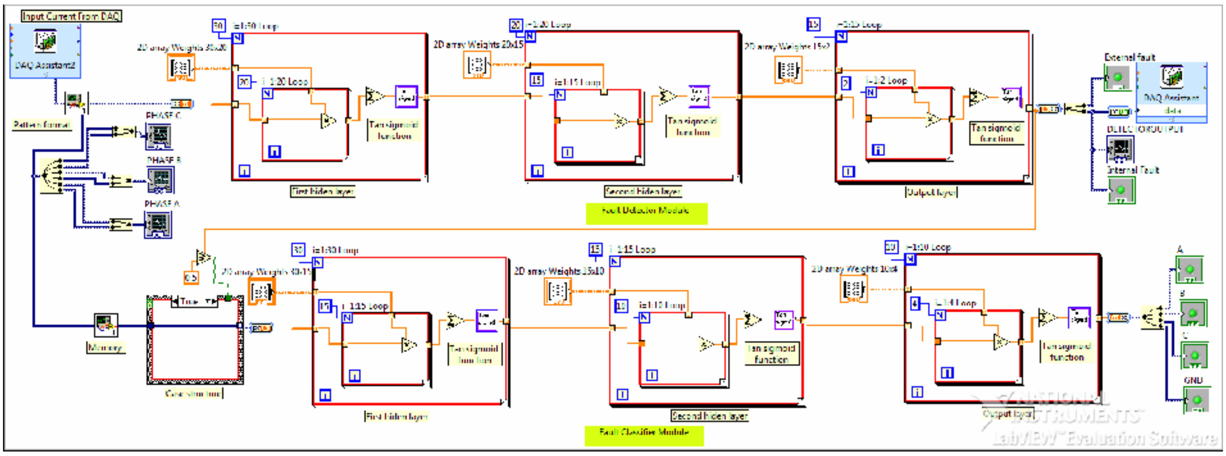

Figure (4) *: Block diagram of the proposed networks*

5. Experimental Results:

The laboratory power system shown in Fig. 3, was used to test the ANN based algorithm on-line. Various internal fault types at different locations (25%, 50%, 75% and 100% of stator windings), inception time and pre-fault loading were tested. The fault types include single phase to ground fault, phase to phase fault, double phase to ground fault, and three phase faults.

Figure 5 shows GUI for the stator currents waveforms before, during and after a single phase to ground fault applied at 25 % of windings of phase A from the neutral point. Fault inception time is 0.2 sec and can be seen from the increase of the current in the neutral side current of phase A. The figure also illustrates the type of fault as A-G fault. In the right side of the figure (below the current waveforms) the ANN fault detector modules output for A-G fault is illustrated.

It can be seen that the ANN is able to detect the fault in less than half cycle (about 8ms) and the current goes to zero. Figure 6 shows the GUI output for a double phase to ground A-C-G fault at 50% of stator windings from the neutral point. It is clear from those results that the ANN based scheme have successfully detected the internal faults for the synchronous generator and classified them. The response of the ANN is accurate and prompt in all cases. The on-line test results are very consistent within the off-line test results in [9]. It was not affected by the change of fault location, fault resistance, and inception time. The proposed ANN has the ability to be generalized and has high probability of producing the correct output for new input data, even for a distorted waveform.

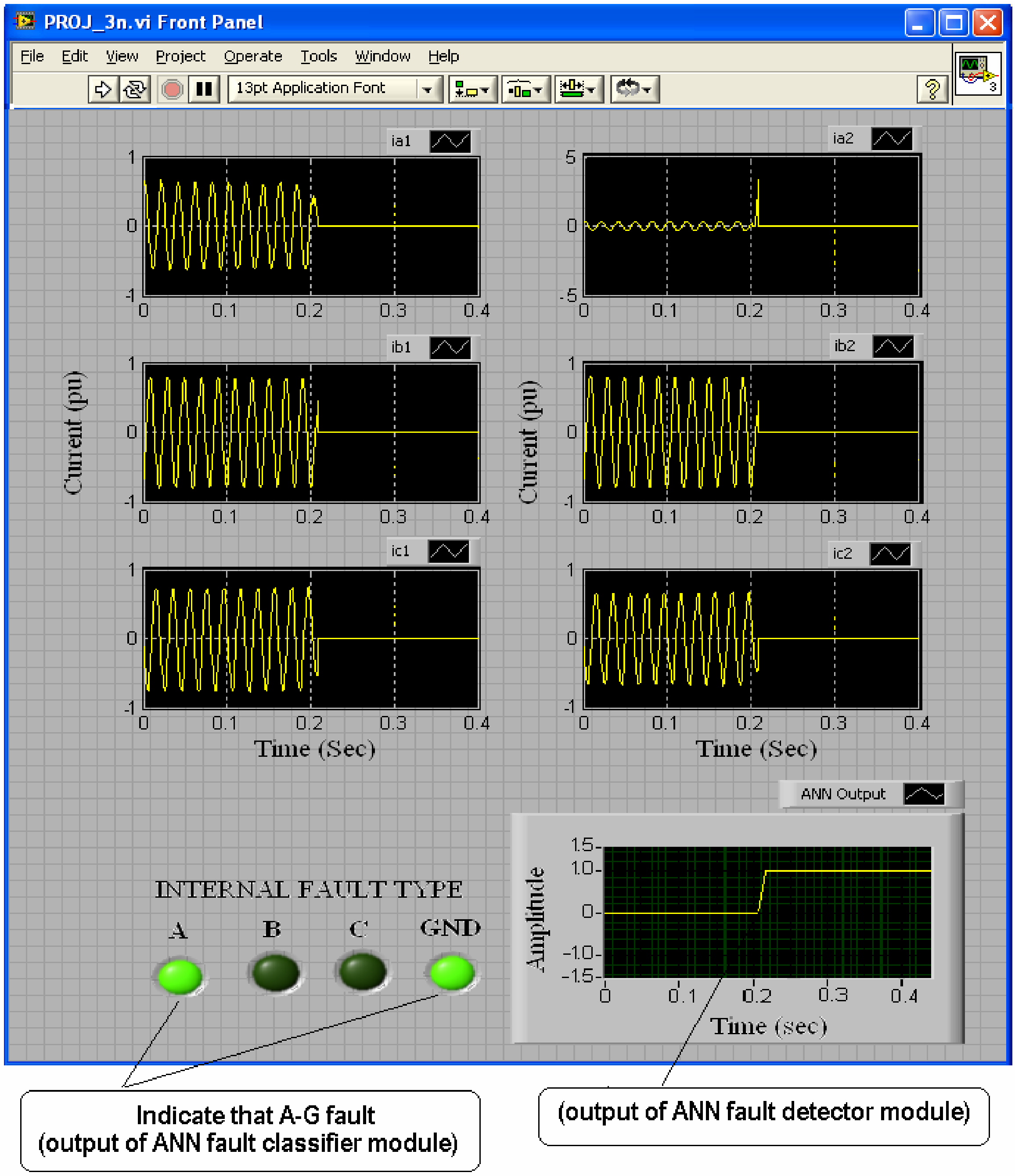

Figure (5) : *Current waveforms and ANN output for A-G fault on 25% of winding*

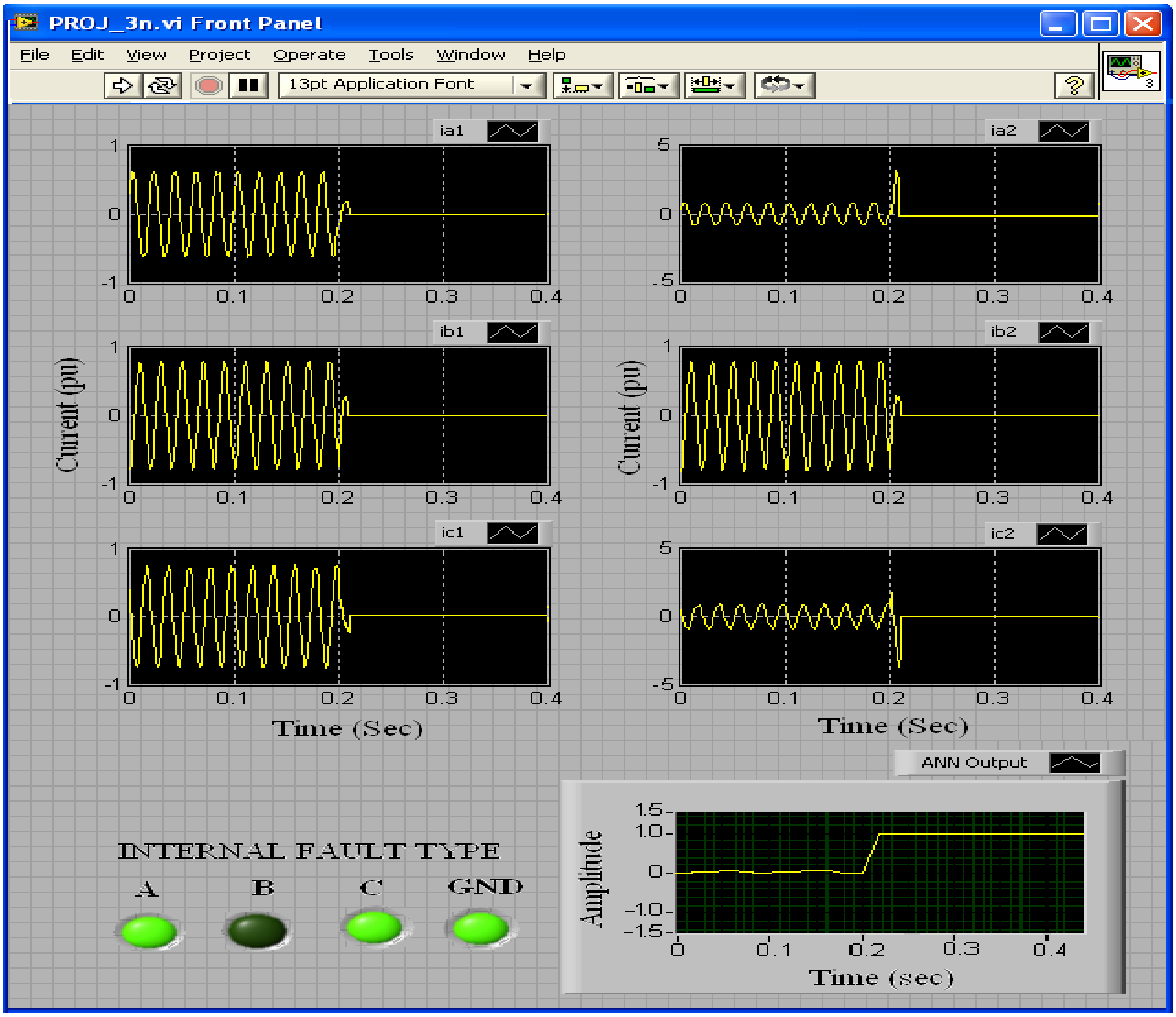

***Figure (6) :** Current waveforms and ANN output for A-C-G fault on 50% of windings*

6. Conclusions:

This paper described the implementation and testing of ANN based fault detection and classification of internal faults for a synchronous generator. To accomplish this, a hardware system was designed and built to acquire three phase currents at both ends of the generator. A LabVIEWTM program was written to read the currents and implement the ANN schemes. The ANN schemes were trained using the MATLAB tool box. The complete system was successfully tested in real time by creating different faults for the synchronous generator. This experimental study shows an example of how the theories behind neural networks work accurately in real world application. It was not affected by the change of fault location, fault resistance, inception time and the existence of the harmonics. In most of fault cases, the trip signal is delivered within a half cycle time period.

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