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Detecting the Single Line to Ground Short Circuit Fault in the Submarine's Power System Using the Artificial Neural Network

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Abstract: The electric marine instruments are newly inserted in the trade and industry, for which the existence of an equipped and reliable power system is necessitated. One of the features of such a power system is that it cannot have an earth system causing the protection relays not to be able to detect the single line to ground short circuit fault. While on the other hand, the occurrence of another similar fault at the same time can lead to the double line fault and thereby the tripping of relays and shortening of vital loads. This in turn endangers the personals' security and causes the loss of military plans. From the above considerations, it is inferred that detecting the single line to ground fault in the marine instruments is of a special importance. In this way, this paper intends to detect the single line to ground fault in the power systems of the marine instruments using the wavelet transform and Multi-Layer Perceptron (MLP) neural network. In the numerical analysis, several different types of short circuit faults are simulated on several marine power systems and the proposed approach is applied to detect the single line to ground fault. The results are of a high quality and preciseness and perfectly demonstrate the effectiveness of the proposed approach.

Keywords: Single phase to ground fault, Ungrounded system, Wavelet Transform, Neural Network, Shipboard.

1 Introduction

Along with the recent improvements in the marine industry and the tendency for using the full-electric instruments, the reliability of the shipboard power system as a marine instrument is newly regarded in some papers. This will be more important especially when the military ships are considered. Here, a few studies have been performed already on the new shipboard power system. However, still they are indeed insufficient and the new power system still requires more profound analyses and even some basic modifications.

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One important issue about the shipboard electric power system is that it does not have an electrical ground. This is mostly because of two main reasons. The first is that the ship is inherently a moving system and so its hulls cannot be a proper electrical ground for it. The second reason is that in a ship, there are some vital loads such as the ship steering system, its radar and helm. The reliability of the shipboard power system is indeed developed due to the necessity of supplying such loads. The not grounded system is more appropriate to provide such loads, since at least, in the occurrences of the single line to ground short circuit fault, the entire system will be remained as an integrated and stable system without shortening of its vital loads.

Here, the main incentive for the paper is posed: In the not grounded electric power systems, the protection relays are not able to detect the single line to ground short circuit fault, since its corresponding current level is much lower than the tripping current of relays. Meanwhile, the single line to ground fault can subsequently lead to the double line short circuit fault, which will result in a high-level fault current and the curtailment of the vital loads. That is why detecting the single line to ground fault in the shipboard power system is indeed of a special importance.

In the previous papers, there are some methods presented to detect the single line to ground fault in the shipboard power systems. They include the resistance (ohm-meter) method and the three-lamp method, which both have a low level of accuracy and are not suitable for being used in the high frequency faults. Moreover, several algorithms are also presented so far to detect the single line to ground fault. All of such algorithms are established on two steps: (1) Feature Extraction, and (2) Pattern Recognition.

The first step (Feature Extraction) is regarded in the previous papers via introducing several different algorithms like the Dominant Harmonic Vectors [2], Fractal Techniques [3], and Wavelet Transform in the pattern of high frequency noises [4]. On the other hand, some other techniques are proposed for the second step (Pattern Recognition), such as Expert Systems [5], Kalman filter [6], and Fuzzy Inference system.

Although all the above methods were somewhat prosperous, still there is not any comprehensive approach for detecting the intended fault. In most of the mentioned methods, the single line to ground fault is considered as a high impedance fault, which is not necessarily true, and so does not yield accurate results. Moreover, a proper approach should be utilized to distinguish between the inherent characteristics of the single line to ground fault and that of the other faults. This also has been disregarded in the previous papers.

In this paper, the fault features are extracted using the Discrete Wavelet Transform (DWT), and the pattern recognition process is carried out using the MLP neural network. The training samples are obtained from 30 cases of the shipboard power systems, which are described in the rest. Accordingly, the rest of this paper is organized as follows: In the second section, the Discrete Wavelet Transform (DWT) theorem is briefly discussed. Then in the third section, the proposed algorithm for detecting the single line to ground fault is introduced. The numerical analysis is presented in section four, and finally, section five concludes the paper.

2 Discrete Wavelet Transform (DWT)

Discrete Wavelet Transform is indeed one of the stronger tools for analyzing the time-transient aspects of different signals. Using this transform, the time-domain data of a signal is mapped into the time-frequency domain. The fundamental theorem of DWT and its comparison with the Fourier Transform (FT) is completely described in [9]. Moreover, the theorem and definition of DWT are briefly discussed in the rest of this section. In the Fourier Transform, the signal is extended into a trigonometric polynomial. Whereas, in DWT the signal is extended using the scaled wavelet coefficient resulted from compressing and expanding the original wavelet. This feature of the Wavelet Transform provides the ability of analyzing the transient signals locally and in an online form. The DWT can be formulated using (1).

$$DWT\ \ (m,n) = \frac{1}{\sqrt{a_0^m}} \sum_k x(k) g(a_0^{-m} n - b_0 k)\ . \tag{1}$$

According to (1), using the DWT, the main signal is decomposed into to two supplementary signals named Approximation and Detail. Approximation comprises the low frequency components of the signal and forms its fundamental. On the other hand, detail includes the transient and harmonic aspects of the signal that are of high frequencies. This process can be followed via segregating the resulted detail into the approximation and detail of the next level. It is known as the Multi Clarity Decomposition of the signal. Fig. 1 demonstrates how this decomposition can be realized.

The frequency range of each of the resulted details is dependent on the rate of sampling from the original signal. Due to the special logarithmic structure of DWT, each of its frequency ranges is called a level. The maximum number of the decomposition levels for Wavelet Transform (j) is defined as (2), where N is the number of samples.

$$j = \log_2^N\ . \tag{2}$$

By choosing $a_0 = 2$ and $b_0 = 1$ in (1), the DWT can be accomplished using a multi-level filter with the original wavelet as the low pass filter $l(n)$, and its dual form as the high pass filter $h(n)$.

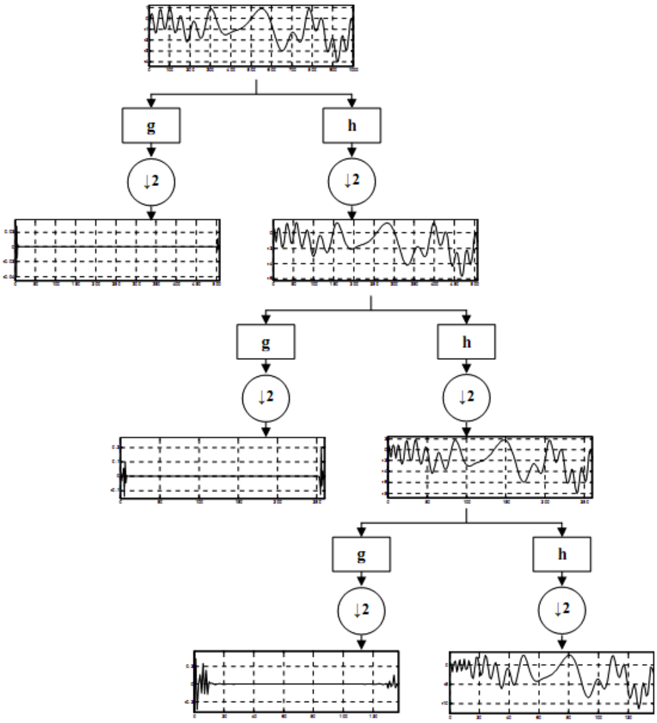

Fig. 1 – *Schematic manner of Multi Clarity Decomposition for a signal.*

3 The Proposed Algorithm for Detecting the Single Line to Hround Fault

In this section, the algorithm proposed to detect the single line to ground fault is described in its different steps. To this end, consider the sample power system of Fig. 2.

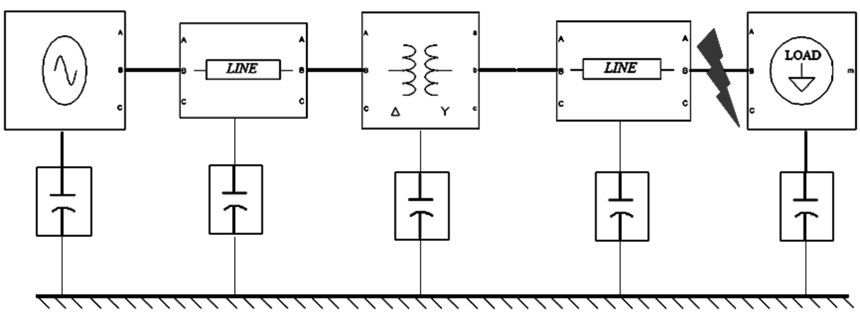

Fig. 2 – *Sample power system used for the analysis.*

The algorithm proposed to detect the single line to ground fault comprises three main steps as follows:

1. Simulating 30 sample cases of the shipboard power system in order to obtain their three-phase characteristics on the different conditions of single line to ground fault or any other occurrences.
2. Utilizing the DWT to obtain the features of the resulted three-phase voltage signal.
3. Extracting the appropriate features from the resulted signal characteristics to be used as the inputs for the MLP neural network.
4. Training the MPL neural network to accomplish the pattern recognition process and detect the single line to ground fault.

Here, all the above steps are carried out using MATLAB software for the mathematical computations.

4 Simulation and Numerical Analysis

In the rest, the simulation process is performed according to the four-step algorithm presented above. It should be noted that the single line to ground short circuit fault is applied on phase C and at the location illustrated in Fig. 2.

4.1 First step: Simulation of the sample power system

Due to the lack of the earth system in the ship, the conventional models of different electrical elements presented in MATLAB/Simulink are not appropriate for direct use, as in such a system the extended models should be used instead. To achieve the extended models, there are two ways:

1. Extracting the control block diagram of different elements according to the corresponding equations of their extended models. Although this work is accurate, it is very difficult and complex.
2. With a good approximation, the approximate extended models can be obtained via adding some other models to the present ones. This method is simpler and more appropriate as well.

The extended model is obtained here using the models of [11]. The ship hull (as the system earth) is connected to the elements via a capacitor in series. The model is prepared to be simulated through obtaining the values of the parameters existing in the extended model. The shipboard power systems have the same topologies (as depicted in Fig. 2) and their difference is just about their capacities. Hence, the training samples are prepared via analyzing 30 sample cases of the shipboard power system with different capacities.

The single line to ground fault is applied on phase C close to the load location, in the time interval between 0.025 s and 0.05 s, and the line voltages are measured both before the fault occurrence and during it. The voltage signal waveform for one sample is depicted in Figs. 3 and 4.

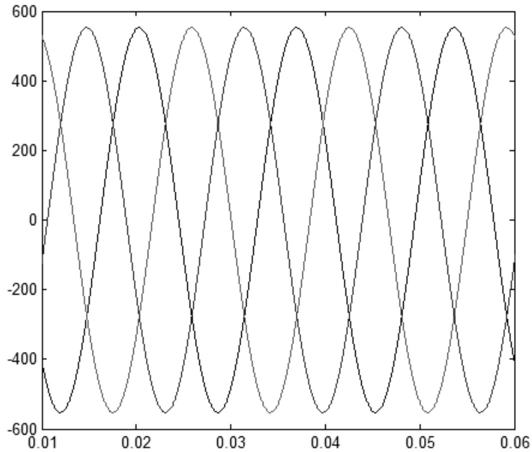

Fig. 3 – *Three-phase voltages before the fault occurrence.*

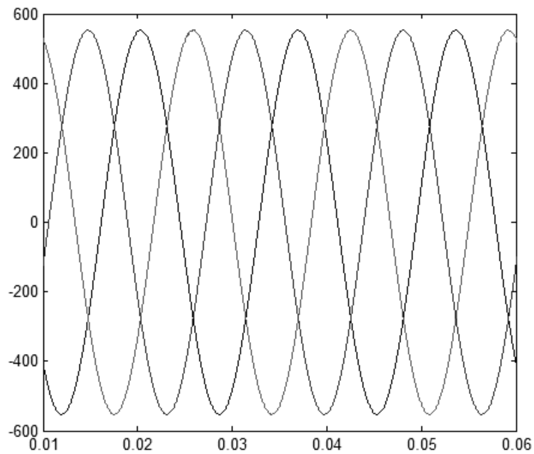

Fig. 4 – *Three-phase voltages during the fault occurrence.*

It can easily be seen that the line voltages are not considerably changed and so, the fault detection from such waveforms is almost not possible. In the rest, the fault features are extracted using the Wavelet Transform.

4.2 Second step: Discrete Wavelet Transform (DWT)

When using DWT, selecting the original Wavelet and the proper level is dependent on the sampling frequency, the transient phenomena under study, and the intended application. By analyzing the different simulation results, using the Wavelet db4 in the fifth level is known here as the best selection for the intended fault detection.

In different levels, the approximation and detail results are obtained via applying DWT on the line voltage signals during the single line to ground fault, and are depicted in Figs. 5-7.

Symbol a_5 represents the fifth level approximation of the line voltage signal and d_2 to d_5 are denoting the corresponding details of levels 2-5 of the Wavelet Transform.

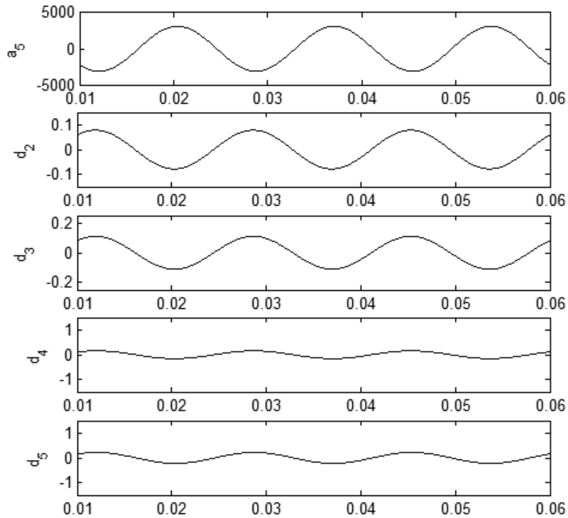

Fig. 5 – *The resulted approximations and details in different levels obtained for the voltage signal of line AB on the condition of the single line to ground short circuit fault.*

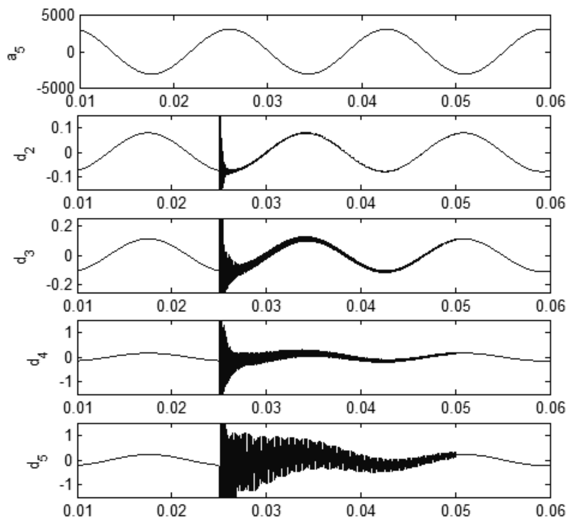

Fig. 6 – *The resulted approximations and details in different levels obtained for the voltage signal of line BC on the condition of the single line to ground short circuit fault.*

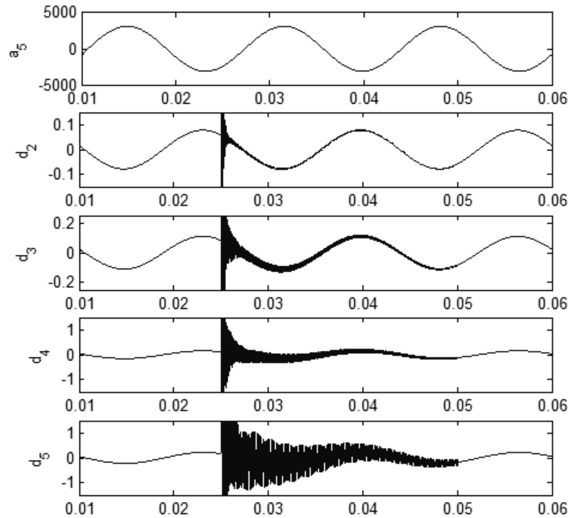

Fig. 7 – *The resulted approximations and details in different levels obtained for the voltage signal of line CA on the condition of the single line to ground short circuit fault.*

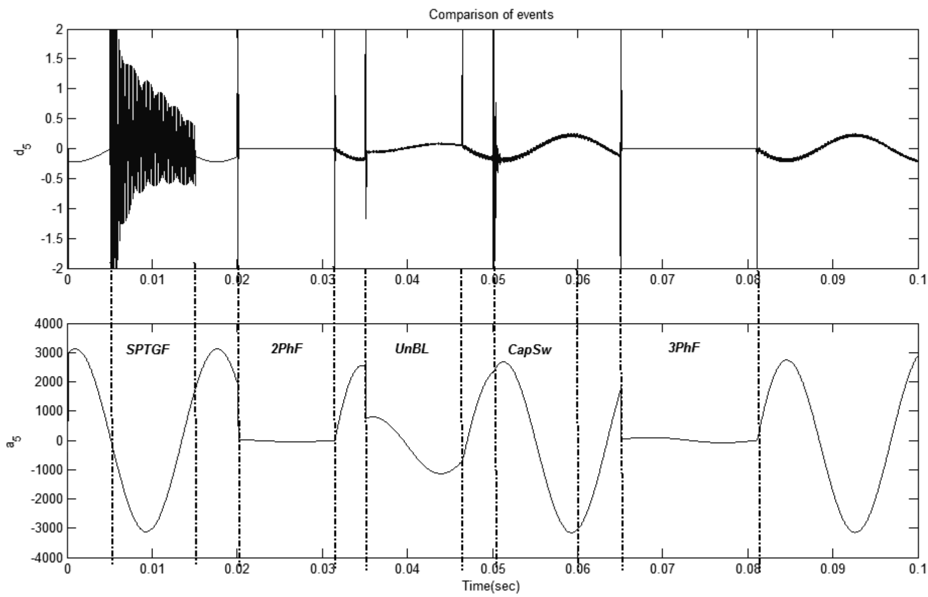

Fig. 8 – *Fifth level approximation and detail of the single line to ground fault and the other phenomena in a sample network* (*SPTG: Single line to ground fault, 2PhF: Double line fault, UnBL: Unsymmetrical load switching, CapSw: Capacitor bank switching, 3PhF: Symmetrical tree-phase fault*).

As is observable from the figures, the single line to ground fault causes a transient oscillatory signal with low-level amplitude and for a relatively long time interval in d_2 to d_5. However, the accurate values of the peak and lasting time for this signal are dependent on the circumstances of the fault occurrence and the network capacity. Anyway, the energy extents of these details within the time interval of the fault occurrence are completely different from that of the other occurrences of the system during its normal operation. This property can be utilized for detecting the single line to ground fault in the different types of shipboard power systems. Fig. 8 displays the comparison between the fifth level approximation and detail of either the single line to ground fault or those of the other phenomena in a sample network.

4.3 Third step: feature extraction

As mentioned in the previous section, in order to distinguish the single line to ground fault from the other phenomena, the durability properties of the signal can be used. For this purpose, the area under the curve and its sheath are introduced here as two appropriate criteria. In this paper, both of these two properties are utilized for the resulted detail of the fifth level of the Wavelet Transform so that to yield accurate and reliable results. The area under the curve can easily be obtained. Fig. 9 illustrates the value of this parameter for the (fifth level detail) voltage signal during the single-phase fault occurrence as well as the other phenomena in 30 different samples of the shipboard power system. It can easily be observed that in most of the samples, the value of the area under the curve during the single-phase fault is higher than that of the other phenomena. However, in some networks this value decreases and so, the intended fault may incorrectly be detected. As a result, this property is not singly sufficient to detect the single-phase fault from the other phenomena.

With the simultaneous use of the second feature, (i.e. the curve sheath) more accurate and reliable results can be obtained. Extracting the curve sheath for a signal is a difficult and complex work and can be accomplished via different approaches. The algorithm exploited here includes the following steps:

1. First, the absolute values of the curve points are calculated and the Extreme points of the resulted curve are identified.
2. Then, with the use of the Curve Fitting algorithm, an exponential function in the form of the following equation is fitted to the resulted points.

$$f(x) = a\mathrm{e}^{bx} + c\mathrm{e}^{dx} + e\,,$$

where, the coefficients *a*, *b*, *c*, *d*, and *e*, can be utilized to approximate the sheath of any curve. Fig. 10 illustrates a comparison between the curve sheath for the single phase to ground fault and the other phenomena in 30 different samples of shipboard power system.

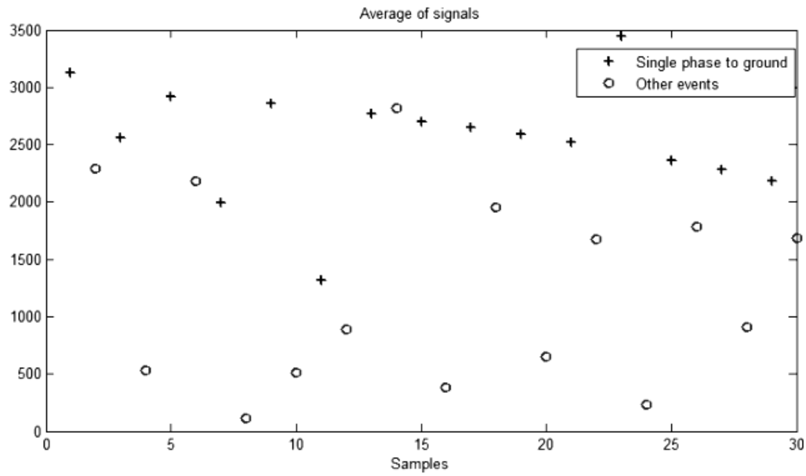

Fig. 9 – *A comparison between the values of the area under the curve of the (fifth level detail of) voltage signal during the single-phase fault occurrence as well as the other phenomena in* 30 *samples of shipboard power system.*

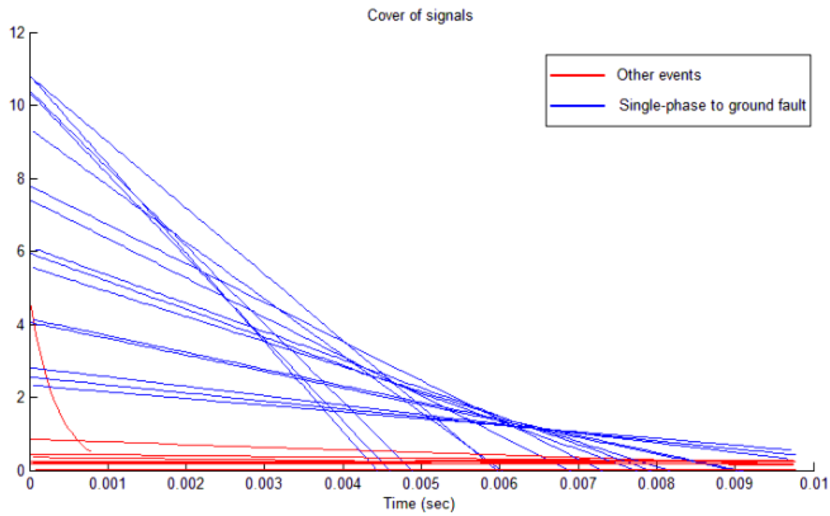

Fig. 10 – *A comparison between the curve sheath for the single phase to groun fault and the other phenomena in* 30 *different samples of shipboard power system.*

As is observable, the curve sheath for the single phase to ground fault is distinct from the other phenomena due to its more durability. Therefore, the vector of the final features extracted from the fifth level detail is formulated as follows. This matrix will be utilized as the input for the neural network.

$$Input = \begin{bmatrix} a \\ b \\ c \\ d \\ e \\ Integral \end{bmatrix}.$$

4.4 Fourth step: neural network

The neural network exploited in this paper, is a MLP (Multi-Layer Perceptron) with input and output layers as well as one hidden layer, as depicted in Fig. 11. Since the input is a vector with six elements, there are six neurons in the input layer. Using the experimental methods, the number of neurons in the hidden layer is selected equal to five. Finally, in the output layer, there are two neurons, one representing the single-phase fault class and the other for any other phenomena.

For each network, a six-dimensional array including the sheath coefficients and the area under the curve of the (fifth level detail of) voltage signal is obtained. All such arrays together form a 6×30 matrix as the training set used to train the neural network and obtain its weights. Then, the trained network is tested using the test samples. The main results obtained from both the train and test processes are illustrated in Fig. 12. As is observable from this figure, the results are perfectly desirable and detect the single-phase fault with an accuracy of about 100%. Hence, it can be inferred that the proposed method can efficiently detect the single-phase to ground fault in the shipboard power systems with a high reliability.

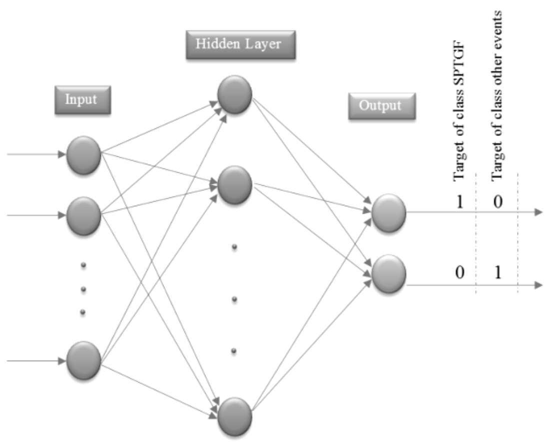

Fig. 11 – *Topology of the utilized MLP neural network.*

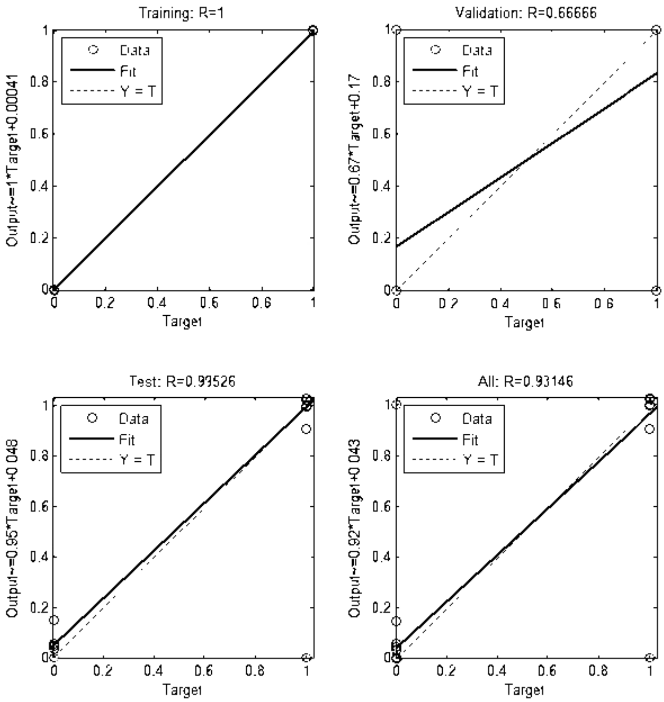

Fig. 12 – *The main results obtained for both the train and test processes of the MLP neural network*

5 Conclusion

In this paper, the Wavelet Transform and MLP neural network are exploited to detect the single-phase to ground short circuit fault in the shipboard power system.

The simulations performed in different occurrences validate the high accuracy of the proposed algorithm for detecting the intended fault. On the other hand, this algorithm correctly detects no faults on the condition of the normal occurrences (such as unsymmetrical load switching and capacitor bank switching) and the other types of faults (like double line fault) as well. This obviously validates the high reliability and accuracy of the proposed algorithm.

6 References

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