ANN Relays Used to Determine Fault Locations on Shipboard Electrical Distribution Systems

E.J. William *IEEE Student Member,* M. Manic *IEEE Senior Member,* B.K. Johnson *IEEE Senior Member*

***Abstract*--This paper observes an Artificial Neural Network Algorithm (ANN) distance relay solution. It traces the location of the fault on a shipboard power system. The United States Naval Surface Warfare Center has been exploring methods for increasing the reliability for shipboard electrical distribution systems. The electrical distribution system is protected when faults are located and isolated as quickly as possible. The goal is to increase the availability of shipboard electrical distribution systems by locating and isolating faults. Thus, introducing an ANN relay to locate the fault occurrence on the electrical distribution system. Maintaining the integrity of a shipboard power system in the event of multiple simultaneous electrical faults is necessary to achieve continuity of service to all loads under adverse battle conditions.**

***Index Terms*-- Algorithms, ART neural networks, Fault currents, Fault diagnosis, Fault location, Power transmission, Power transmission lines, Power system faults, Power system maintenance, Power system modeling, Power system, stability, Power transmission protection, Protection, Protective relaying**

I. Introduction

The United States Naval Surface Warfare Center has been exploring methods for increasing the reliability for shipboard electrical distribution systems. Faults cause disruption in service for the shipboard electrical distribution systems and must be prevented. The Electrical distribution system is protected when faults are located and isolated as quickly as possible. The goal is to increase the availability of shipboard electrical distribution systems using Power Systems CAD (PSCAD) and Artificial Neural Network (ANN) Analysis. ANN is composed of a network of neurons (Fig 1) working together to learn particular patterns of how a system responds. A protection scheme described in Somani's thesis [2] is a zero sequence voltage relay. A zero sequence voltage relay is used as a starting point for fault detection in all ungrounded and high resistance grounded systems. However, this method is not selective. Once the presence of a single line to ground fault is detected, the zero sequence voltage polarized ground voltage is recommended. This will detect the direction of a ground fault and ensure reliable fault direction detection. This relay developed in the power system industry is widely used for such applications. The other option such as wattmetric, varmetric, and conductance methods can also be used for specific system characteristics. [2] Artificial intelligence selection methods can be incorporated in the zero sequence voltage relay method for detection in all ungrounded and high resistance grounded systems. ANN relays can be used to find the direction and location of the fault on the line using a error back propagation (EBP) algorithm. PSCAD can be used to model a power system with zone protection. Ground faults are going to be generated while voltage and current waveform values are exported to a data file. This data file can be imported into Matrix Laboratory (MATLAB) where voltage and current characteristics values are plotted and the ANN EBP algorithm can be applied (Fig 2). Applying an ANN based relay may prove to be more efficient than using multiple solutions of zero sequence relays with: polarized ground voltage and conductance methods.

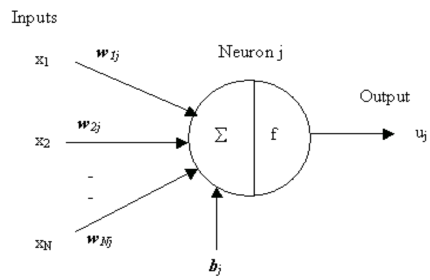

Fig 1: Neuron with inputs and weights. Several neurons make an ANN

II. Technical Work Preparation

This section serves as a brief overview of how three phase power systems operate. Voltage and current calculations are used to monitor power system stability which determines the following: how well the system is running, if a fault is present, and where the fault is occurring. ANN learn the patterns associated with impedance values that are in the fault regions of the distance relay (Figs 3,4). The ANN relay method can prove to be advantageous in detecting faults be finding impedance values in the trip region and reorganizing them in the non-trip region.

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A. Power Systems

Naval Power systems consist of 450 V_{ac} generators, bus-ties, switchboards with circuit breakers, and loads arranged in a radial, ungrounded configuration. Naval power systems are composed of multi-sourced to multi-load power systems. This configuration allows greater flexibility when managing generation versus load and it is also cost effective. Power systems are built to allow continuous generation, transmission and consumption of energy. Most of the power system operations are based on a three-phase system that operates in a balanced mode. (Often described with a set of symmetrical phasors of currents and voltages being equal in magnitude and that have the phase shift between the phases equal to 120 degrees). [1]

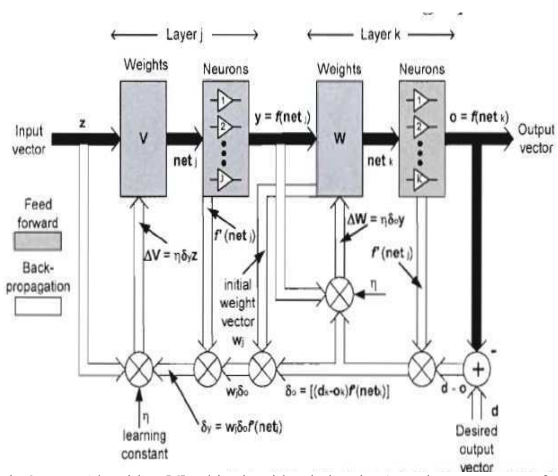

Fig 2: EBP Algorithm [6]. This algorithm helps the ANN learn patterns of impedance values plotted in (Figs 3,4).

Voltage phase equations are:

$$V_{an} = |V| e^{j0deg} \quad (1)$$

$$V_{bn} = |V| e^{j120deg} \quad (2)$$

$$V_{cn} = |V| e^{j240deg} \quad (3)$$

Current line equations are:

$$I_a = \frac{V_{an}}{(Z_Y e^{j\Theta})} \quad (4)$$

$$I_b = \frac{V_{bn}}{(Z_Y e^{j\Theta})} \quad (5)$$

$$I_c = \frac{V_{cn}}{(Z_Y e^{j\Theta})} \quad (6)$$

The most basic power system components are: Generators, transformers, transmission lines, buses and load components. They allow for power to be generated (generators), transformed (transformers) from one energy level to another, transmitted (transmission lines) from one location to another, distributed among a number of transmission lines and power transformers (buses), and finally used by the load components. In the course of doing this, the power system components are being switched or connected in a variety of configurations using circuit breakers. The circuit breakers are capable of interrupting the flow of power at a high energy level and hence may be used to disconnect the system components in case the components experience a fault. [1]

B. Artificial Neural Networks (ANN)

"A Novel Approach to Fault Classification and Fault Location for Medium Voltage Cables Based on Artificial Neural Network" [1] is an article that observes how to classify faults with an ANN algorithm. The study determines how to classify faults and locate where their primary point of malfunction. It also addresses the benefits to placing transmission lines below ground rather than the traditional above ground method. The advantages ot the underground approach are: The insulation of electromagnetic waves that prevent cancer. The disadvantages are: The costs and the problems that occur. Currently, the method for locating the fault is using an impulse generator while taking the transmission line out of service. An ANN relay allows for the transmission line to stay in service while using pattern recognition algorithms to monitor transient waveforms. An ANN based network relay has generalization capability, noise immunity, robustness and fault tolerance [1]. ANN based relays are not affected by variations of system parameters. The ANN based approach is used as an accurate fault classifier. A MATLAB EBP algorithm can reduce the affects of system variables such as fault resistance, fault type, fault inception angle, and decaying dc offset.

III. Fault Analysis

Currently there are two methods for locating ground faults. they are: isolation by network switching circuit tracing using signal injector and a hand held sensor detector. Fault location problems are [3]:

1. Intermittent fault conditions
2. Multiple faults on the same phase
3. Inverted ground faults

Intermittent ground faults are frequently found in industry when ground faults occur near cycled loads, and the fault is on the load side of the controlling contractor. Operators may fail to note the fault detection alarm. A ground fault can be detected and maintenance frequently become confused and unable to isolate the fault by switching [4]. The graphical representation of all the power system components is called a one-line diagram and is shown in the figure below.

IV. PSCAD Analysis

PSCAD is used to model a power system and implement fault analysis. The faults to be simulated are:

1. Single Line to Ground Faults (SLG)
2. Line to Line Faults (LL)
3. Three Phase Faults (ABC)

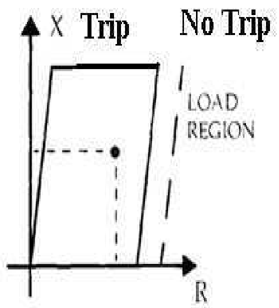

Fig 3: Distance relay low resistance load triggers trip [5]

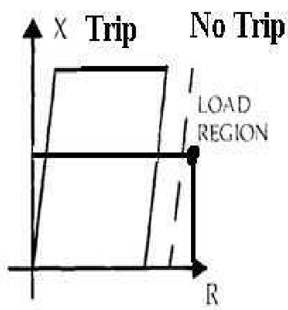

Fig 4: Distance relay high resistance doesn't trip [5]. This is the result of applying the EBP algorithm (Fig 2)

These voltage and current waveforms are exported to MATLAB where a EBP algorithm protects a system by locating these faults using a distance relay. The ANN based relay trips the breaker to protect the system based on ANN image recognition in the trip (Fig 3) and non-trip (Fig 4) regions of the distance relay. The model power system here is composed of 3-Phase signal voltage source, 2 Buses known as Bus1 and Bus2, finally 1MΩ load with a fault simulation behind Bus 2. We have a fault slider we can use to simulate SLG, L-L, ABC and no faults.

V. Training the Neuron

After the voltage waveforms are taken in from Power System CAD (PSCAD) we can export our data into MATLAB EBP algorithm.

PSCAD impedance values are implemented into lines and weights associated with an ANN. The final outcome of the ANN learning convergence will determine when the relay will trip and isolate the faulted system from the operational system. The convergence of how the neuron learns the pattern to implement the tripping from impedance values are displayed (Figs 3,4). The rate at which impedance values are plotted in the trip region (Figs 3,4) are identified and recalculated while training the neuron (Fig 1) to organize impedance values that fall in the non-trip region. Ideally, the system should never trip while maintaining a high resistance (Fig 4). The display shows the ANN relays with a EBP algorithm (Fig 2) in relation to a distance relay graph (Figs 3,4). The ANN can be used to recognize resistances vs. reactance plots on a trip zone and no trip zone. The plots can be reorganized using a EBP algorithm (Fig 2). Lines in the form of neurons can be designed on the distance relay plot to separate data from trip and non-trip locations. It can take up to 8 neurons and 8 more hidden neurons that may total up to 16 neurons. Once the 16 neurons are set the weights can be determined and updated while learning how to adjust and correct the pre-loaded fault conditions to locate the fault on the transmission line in the least amount of time.

The current and voltage phasor waveforms will be obtained from PSCAD data files and imported into MATLAB. The ANN EBP (Fig 2) algorithm will determine where the data lies on the trip and non-trip regions (Figs 3,4). These preloaded fault conditions can then help render the fault location in MATLAB.

VI. Error Back Propagation (EBP) Algorithm

The EBP algorithm starts by calculating the net (7) from the weights and the x variables from the arbitrary line equation applied to (Figs 3,4). The net calculations are then used to find the actual output values (8).

Forward Computation [6]

$$net = \sum w_i x_i \quad (7)$$
$$out = \tan(k * net) \quad (8)$$

Next we use an arbitrary actual output value of +1 or -1 (9) to help calculate the error (10).

Error Computation [6,7]:

$$d = [+1 - 1]^T \quad (9)$$

$$error = desired\ output - actual\ output \quad (10)$$

Once the error is determined in the forward computation its time to go to EBP calculations appending the error calculations to the EBP algorithm. The primed function is the uses the gain value and the actual output calculated from (8) and the error in the forward propagation calculations (11,12,13).

$$f' = gain(1 - out^2) \quad (11)$$
$$\Delta_g = f' * error \quad (12)$$

EBP first layer [6,7]:

$$f' = gain(1 - out^2) \quad (13)$$
$$\Delta_g = f' * \sum w * \Delta_g \quad (14)$$

Calculate layer a weight update for each neuron [2]:

$$\Delta w = alpha * \Delta * x \quad (15)$$

Perform layer a update for each neuron [6,7]:

$$w = w + \Delta w \quad (16)$$

Finally, Equation 12 helps us derive equation (14,15) and the alpha is given from arbitrary values to test the equation. The delta w in (15) is a newly calculated weight that is applied to the initial w that was used in forward propagation. Equation 16 renders a new weight w that is used to conclude one iteration of the EBP algorithm (Fig 2). Another iteration using the same steps starting at (7) must be used again using the new weight w (16). Once the second iteration is achieved we must compare the error from the first and second iterations. If the errors (10) are different and not the same more iterations must be performed in (Fig 2) that obtains a converging error (10). The converged error will plot an impedance value on the distance relay plot per iteration (Fig 2). The final outcome relative to distance relays will be an array of impedance values that are plotted in the non-tripping region. In retrospect, the higher the error (10) the more fault prone and unprotected the power system is by the ANN relay. The lower and more converged the error (10) becomes means the neurons (Fig 1) have learned the patterns to correct the faulted impedances by placing them in non-tripping regions (Figs 3,4).

VII. Conclusion

The ANN is an advantageous method to locate faults versus the single and double ended negative sequence algorithms. Let's review Somani's algorithms [2] before we compare to data from ANN algorithm of Fault location analysis. Upon the detection of the faulted feeder using directional relays, the exact location of single line to ground fault on a faulted feeder can be evaluated using negative sequence fault currents.

Somani mentions two algorithms that can be used to locate the fault on a line using directional relay on a single line to ground (SLG) fault for a faulted feeder. Double and single ended negative sequence fault algorithms help us to determine the locations of the SLG fault on the line. The single ended algorithm is a more robust solution as it is easier to implement and cheaper. The only problem with this is that the fault path accuracy is unpredictable and requires sensitive current measurement devices.

1. Double ended negative sequence fault algorithm is used to detect faults on all types of grounded systems. [2]
2. Single ended negative sequence fault algorithm developed at the University of Idaho, provides promising fault location results for single line to ground faults in ungrounded and high resistance grounded systems. This algorithm is simple, cost effective, and easy to understand. The drawback with this algorithm is that with large fault resistances in the fault path the accuracy of the fault path is affected. This algorithm also requires sensitive current measuring devices which not only are accurate for low magnitudes of ground fault currents. [2]

Somani mentions for future works that automatic reconfiguration is needed for successful detection and location of the first SLG fault on an ungrounded and high resistance grounded system, Artificial Neural Networks can be used as a automatic configuration relay.

Using an ANN relay solution to locate the fault is the first step in assuring system service and stability. This is needed to isolate the faulted system from a operable system and prevent double line to ground faults which can occur from any of the un-faulted phases. The MATLAB based EBP algorithm during analysis is an optimal way to locate faults in the distance relay trip region and non-trip regions. The slew of data from PSCAD is exported to MATLAB where the data is set up in vector form. We learned to search through the M by N matrix to generate a Distance relay plot that shows the resistance versus reactance plot. We apply the EBP algorithm to obtain the location of data from our image recognition analysis. Using ANN is beneficial in learning the random impedance values that fall in the trip region (Fig 3) and re-allocates the plots to the non-trip region (Fig 4). For future works I will apply genetic programming and algorithms to compare fault correction times with the EBP algorithm.

VIII. Acknowledgment

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X. Biographies

Edward James William II, IEEE Student Member was born in San Diego, California, USA. He received his B.S in Electrical Engineering from Arizona State University. He is currently a graduate student attending the University of Idaho. His employment experience included the Boeing Company, Honeywell Inc. His special fields of interest included Power System Protection. He received 1st place prize for the 2005 Minority Engineering Program Technical Paper competition for his research in Ion Channel Bio-sensors.

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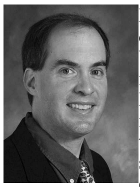

Dr. Brian K Johnson, (M92--SM07) received the Ph.D. degree in electrical engineering from the University of Wisconsin, Madison, in 1992. He is currently a Professor in the Department of Electrical and Computer Engineering, University of Idaho, Moscow. His interests include HVDC transmission, FACTS, custom power technologies, energy storage, and utility applications of superconductivity, power system protection, and electromagnetic transients in power systems. Dr. Johnson is a member of CIGRE and is a Professional Engineer in the States of Wisconsin and Idaho.