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Application of Artificial Intelligence for Power Quality in Distribution System

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Abstract: Power distribution systems play vital role in providing electricity to the needs of industries and households. With diversity in power generation systems, power distribution became increasingly complex and prone to various issues such as quality, harmonics, line to line fault, line to ground fault and switching. In this paper, a hybrid power distribution system is simulated. It is made up of the power sources from wind power plant and photovoltaic system. Both are integrated to a power grid with the help of point of common coupling devices. The system is built using MATLAB Simulink and simulated it for generating data. Afterwards, Wavelet Transform (WT) is used to obtain different features from the negative sequence component at point of common coupling. They include loading of the hybrid system, standard deviation (SD) and energy content of WT coefficients of negative sequence voltage signal at different levels such as level 3 and level 4. Then, Artificial Intelligence (AI) based technique known as Artificial Neural Network (ANN) is trained with the collected features. Based on the knowledge gained from the features, the ANN is able to predict various faults associated with the hybrid power distribution system. The empirical study revealed that the system is capable of identifying different problems so as to improve the quality of power distribution system using AI based algorithm.

Keywords: Hybrid power distribution system, artificial intelligence, artificial neural network, power quality improvement

1. INTRODUCTION

It is essential to monitor power distribution systems in order to identify bottlenecks and address them from time to time. When faults are identified, they can be overcome to enhance quality in power distribution systems. However, power quality enhancement is non-trivial and needs specific procedures to solve the problems [1]. Due to number of heterogeneous devices and different power generation sources, distributed power generation systems are complex in nature. They suffer from different faults such as islanding, line to line and line to ground, switching and so on. As the complexity of the systems increase, it is a necessity to use a data science based approach to solve the problem. The problems are addressed using data-driven approach as explored in [10], [12], [13], [14], [15] and [16]. Application of AI methods are found to be useful as they can process huge amount of data arrive at business intelligence (BI).
The concept of structure learning is used in [4] for short term voltage assessment. Extreme machine learning is used in [8] for locating faults in power grids. Loss of main detection [10], power loss reduction [17], optimal power flow [12], [18] are other studies focused on enhancing power distribution systems. From the literature, it is understood that different machine learning methods or AI methods are used in power quality enhancement. However, there is need for a holistic approach for identification different faults with AI based system. It is overcome in this paper as the proposed methodology considers different kinds of faults.
In the proposed system, in this paper, the voltage signals of negative sequence component at the point of common coupling are decomposed by DWT to have different frequency bands. Once the required features are obtained, an ANN classifier is trained to predict aforementioned faults in the system. Thus the faults identified in the power distribution system lead to enhancement of quality in power distribution. MATLAB is used to define ANN code while the power distribution system is designed using Simulink. The experimental results revealed that the proposed methodology based on AI is capable of detecting faults with higher level of accuracy at 96.66667%.

1. We proposed a hybrid power generation and distribution system that is made up of power generation sources such as PV system and wind energy system.
2. We proposed an AI based system based on Wavelet Transform and ANN for effective detection of faults in order to enhance quality in the hybrid power distribution system.

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3. We evaluated the system using simulations with MATLAB/Simulink and the results revealed that the system is capable of identifying different faults such as islanding, line to line fault, line to ground fault and switching.

2. THE PROPOSED ARTIFICIAL INTELLIGENCE BASED SYSTEM

This section provides the details of the proposed system used to find problems in hybrid power distribution system. It throws light into problem definition associated with the hybrid power generation system, the hybrid power distribution system simulation diagram designed using MATLAB Simulink, the methodology, proposed algorithm and evaluation procedure.

2.1 Problem Definition

A hybrid power distribution system is prone to different kinds of problems such as islanding problems, line to line and line to ground faults and switching problems. A hybrid power distribution system shown in Figure 1 may cause these problems. For instance, islanding problem can lead to damage to equipment, hazard to workers and even damage to distributed generators. These problems can deteriorate quality of power distribution systems. Therefore, addressing these problems is considered in this paper.

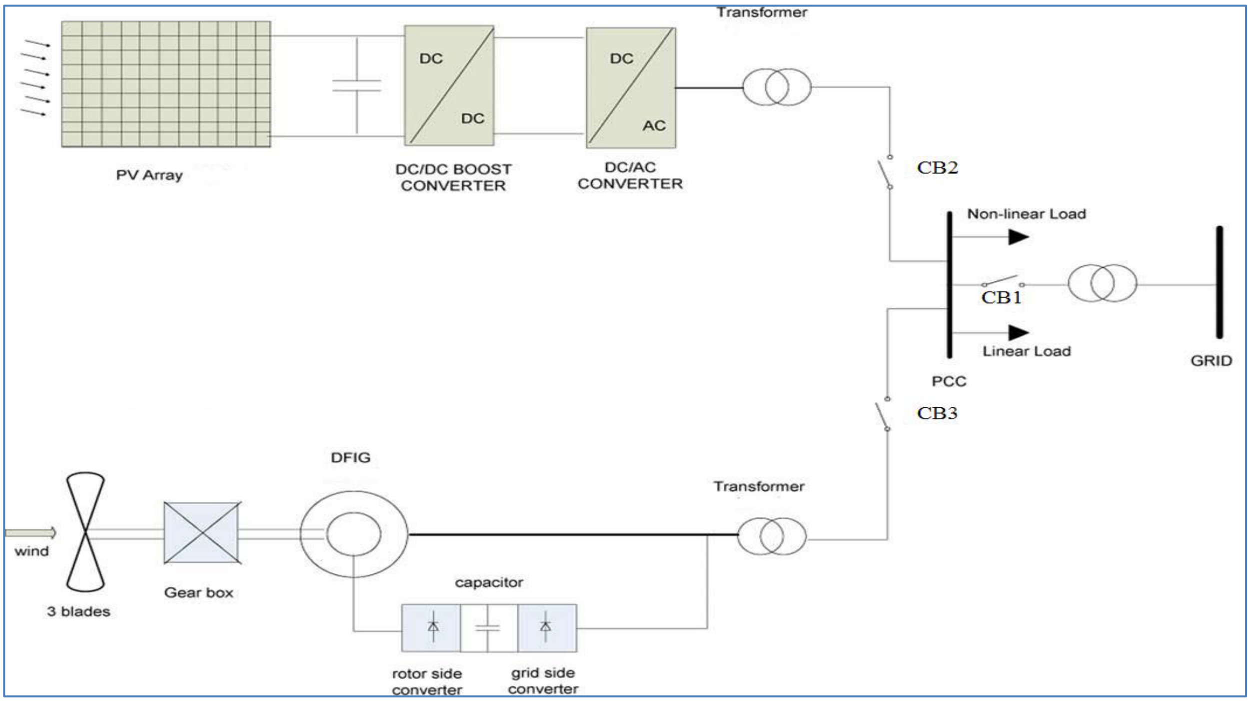

Figure 1: Hybrid power distribution system

2.2 Proposed Hybrid Power Distribution System

We proposed a hybrid power distribution system that has power generation from wind and photovoltaic power systems. The system is designed using Simulink while the implementation of algorithm is made using Matlab for detection of islanding and other faults in the system for quality enhancement. The proposed method is based on efficient capturing of negative sequence voltage signals at point of common coupling using Wavelet Transform (WT) and training an Artificial Neural Network (ANN) to estimate various kinds of faults in the system. Since real time classification of power transients is challenging problem, artificial intelligence (AI) based approach is followed in prediction of faults. WT is used to obtain frequency components of signal besides preserving properties pertaining to time domain. In this paper Discrete Wavelet Transform (DWT) is used to detect islanding problem in the distributed power generation system. As presented in Figure 2, the PV system is of 250 kW whose irradiance is at 1000 W/m^2. Whereas the wind plant is of 1.5 MW with 12 m/s constant wind speed. The array used in PV system has 86 strings arrange in parallel. Each string has 7 connected power modules in series. The modules are known as Sun Power SPR-415E. A PWM controlled 3-level IGBT bridge is modelled as converter. There is provision for harmonics filter that could handle harmonics caused by IGBT bridge. The inverter is connected to distribution system using a three phase transformer of 250-kVA 250V/25kV. The grid is modelled after a typical distribution grid. It contains two 25 kV feeders, ground

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transformer, loads and a transmission system of 120-kV.

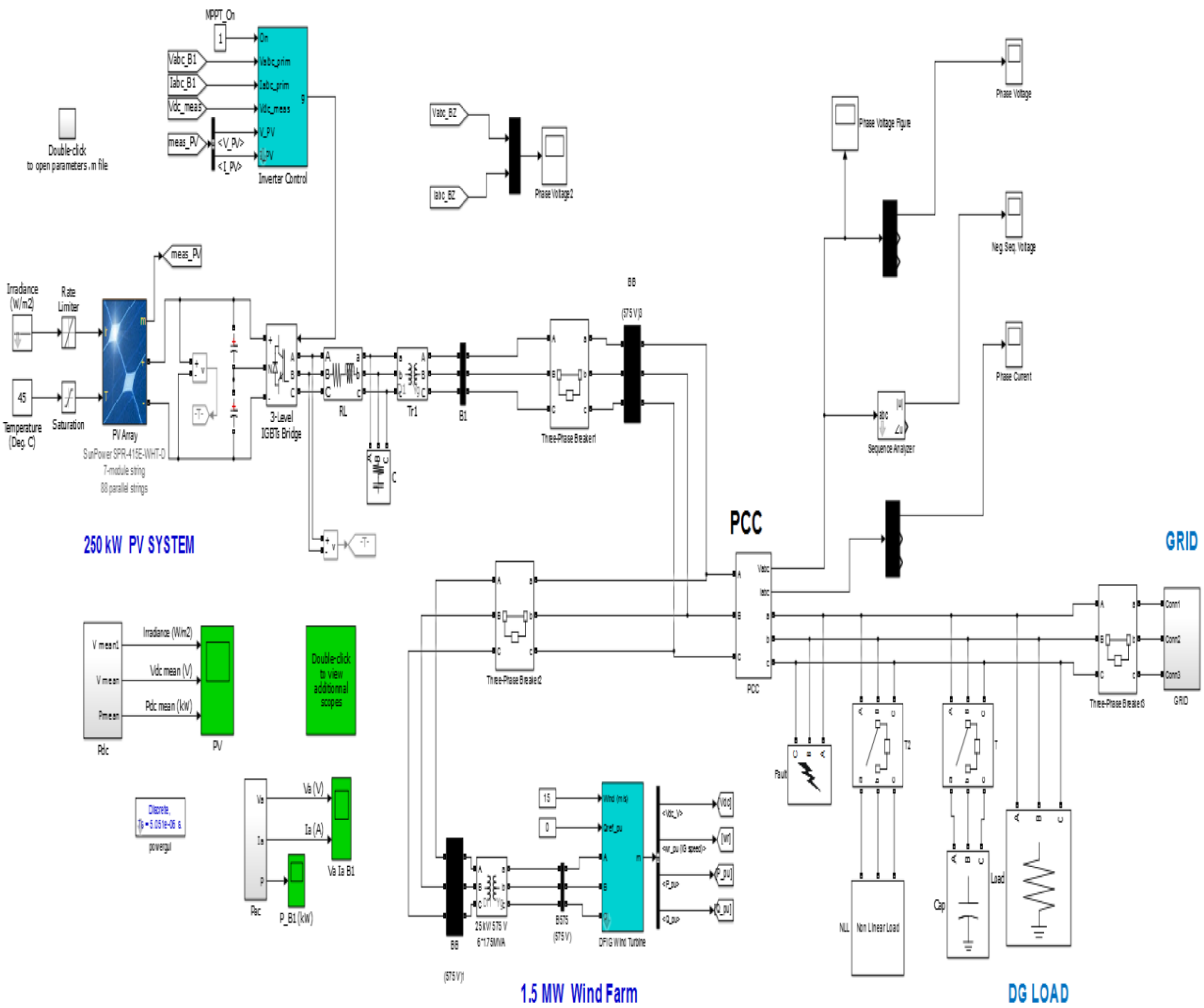

Figure 2: Simulation diagram of the proposed hybrid power distribution system

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The PV system converts solar energy into electricity in solar cell (semiconductor) which is a unit to deliver certain amount of power. Many such solar cells are connected in a panel or array to obtain desired level of voltage and current. The cell generates power when exposed to sun light. Photoelectric effect is the basic phenomenon in the solar cell. The characteristic of a solar or PV cell is described in the Eq. 1.

$$I=I_{pv,cell} - I_{0,cell}\left[\exp\left(\frac{qv}{akT}\right)-1\right] \quad (1)$$

Where current generated light is denoted as $I_{pv,cell}$ which is proportional to Sun's irradiation while the Shockley diode equation is denoted as I_d and leakage current of diode is denoted as $I_{o,cell}$. The electron charge is denoted as q, Boltzmann constant is denoted as k and temperature is denoted as T. Many connected PV cells form an array as expressed in Eq. 2.

$$I=I_{pv} - I_0\left[\exp\left(\frac{V+R_sI}{V_ta}\right)-1\right]-\frac{V+R_sI}{R_p} \quad (2)$$

Where photovoltaic current is denoted as I_{pv}, the saturation current of the array is denoted as I_o. Equivalent series and parallel resistances are denoted as R_s and R_p respectively. Voltage of the array is represented as $V_t=N_skT/q$ where number of cells (N_s) are connected in series. There is relation between temperature and solar irradiation that influences light-generated current as expressed in Eq. 3.

$$I_{pv} = (I_{pv,n} + K_I\Delta_T)\frac{G}{G_n} \quad (3)$$

Where light generated current at nominal conditions is denoted as $I_{pv,n}$. T and T_n denote actual and nominal temperature in Kelvins respectively. Similarly, G and Gn denote actual and nominal irradiation measures in watts per square meters

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respectively. The diode saturation current denoted as I_o is expressed as in Eq. 4.

$$I_0 = \frac{I_{sc,n} + K_I \Delta_T}{\exp\left(\frac{V_{oc,n} + K_V \Delta_T}{aV_t}\right) - 1} \quad (4)$$

Where current and voltage coefficients are denoted as K_I and K_V respectively. Another power generation system used in this paper is wind energy. Wind is actually occurred when a fraction of Sun's energy is converted. There is atmosphere formed with cool, heat and pressure zones. When air flow is sent through wind turbines, it results in electricity generation due to some mechanical process. Wind power is renewable energy source and it does not harm environment as it won't omit greenhouse gases. Wind form contains many wind turbines and they are connected to power distribution system. Wind turbines may be either horizontal or vertical in nature based on the orientation of blades. A wind turbine is capable of converting air's kinetic energy into mechanical power. The power generated using wind system is expressed as in Eq. 5.

$$P_w = \frac{1}{2} C_p(\lambda, \beta)\rho A V^3 \quad (5)$$

Where pitch angle is denoted by β, power convertion coefficient is denoted as C_p, wind speed is denoted a V, area swept by blades of turbine is denoted as A, and ρ denotes density of air which is generally 1.225 kg/m^3. The harmonic current in a current or voltage signal is computed as in Eq. 6.

$$THD = \frac{\sqrt{\sum_{h=2}^{H} V_h^2}}{V_1} x100 \quad (6)$$

Where THD stands for Total Harmonic Distortion.

The fundamental frequency component is denoted as V_1 while V_h denotes all harmonic components. Harmonics in power distributions systems come from two sources such as power electronic converters and devices that show non-linear relationship between current and voltage at the point of common coupling in hybrid distribution systems. When THD is monitored at the point of common coupling, it is possible to detect islanding and other defects in the distribution system. Based on this hypothesis, this paper uses DWT and ANN for identification of detects leading to enhancement of quality in power distribution systems.

2.3 Methodology

This subsection describes the proposed methodology using DWT and ANN for detection of faults in the hybrid power distribution system. The discriminative features are extracted from the negative sequence voltage signal at the point of common coupling. The signals captured are subjected to WT in order to have them decomposed to form various frequency bands. Such features are obtained from the proposed hybrid power distribution system shown in Figure 2. The simulations made using the system in Simulink are used to generate the required discriminative features. These features are used as training set for the ANN technique. An excerpt from the discriminative features are shown in Table 1. Once the ANN is trained with the discriminative features, it is capable of detecting islands, line to line faults, line to ground faults, non-linear load switching and normal distribution without problems. At the point of common coupling, three different sequence components such as negative sequence component, positive sequence component and zero sequence component are expressed as in Eq. 7, Eq. 8 and Eq. 9.

$$v_n = \frac{1}{3}(v_a + \lambda^2 v_b + \lambda v_c) \quad (7)$$

$$v_p = \frac{1}{3}(v_a + \lambda v_b + \lambda^2 v_c) \quad (8)$$

$$v_z = \frac{1}{3}(v_a + v_b + v_c) \quad (10)$$

Where the three phase voltages obtained from point of common coupling are denoted as V_a, V_b and V_c. The positive, negative and zero sequence voltages are denoted as V_p, V_n and V_z. The complex operator is denoted by λ. In Simulink of MATLAB, negative sequence component is extracted by using a three phase sequence analyser block. The results are used to create a training set for ANN and that has led to the prediction of different faults in the hybrid power distribution system.

2.4 Artificial Intelligence (AI) Based System

Artificial intelligence based system is built in order to identify faults in the proposed hybrid power distribution system. It is made up of DWT and ANN. The former is used to capture the signals pertaining negative sequence component at point of common coupling. It results in obtaining features that are useful to train ANN classifier. Then ANN classifier is used to predict the possible faults in the distribution system. ANN is made of many neurons or processing units. These neurons operate in parallel to perform intended functions. A neuron used in ANN appears as in Figure 3.

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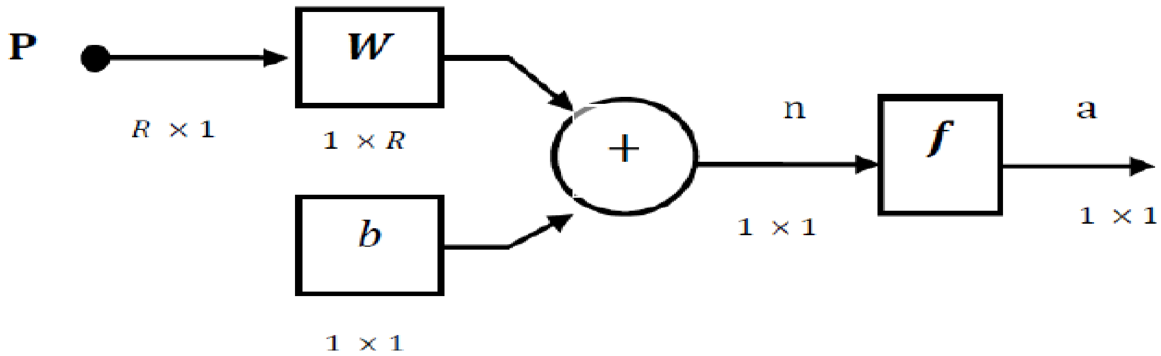

Figure 3: A typical neuron structure in ANN

As presented in Figure 3, an input vector denoted as P with dimension denoted as R x 1 is used as input. A weight denoted as W with 1 x R dimension is multiplied with P. Then for the generated product, denoted as PW, a bias is denoted as b is added. The activation function or transfer function denoted as f is used to produce desired output denoted as a. The function f takes argument n to produce output. The parameters such as bias and weight are adjustable. The functionality of neuron can be expressed as a=f(WP+b).

3. EXPERIMENTAL RESULTS

Experiments are made with MATLAB R2020b. The training data has mix of different classes. As presented in Table 1, the training data is an excerpt from the whole dataset. It has five different class labels determined based on the features such as loading, standard deviation at level 4, standard deviation at level 3, energy content at level 4, energy content at level 3. Based on the data of these features, the class label is determined. The five class labels are normal (1), islanding problem (2), line to ground fault (3), line to line fault (4) and non-linear load switch problem (5).

Loading	Standard Deviation at Level 4	Standard Deviation at Level 3	Energy Content at Level 4	Energy Content at Level 3	Class Label
0.910091	0.00016	0.0001231	0.001322	0.001399	1
1.155116	0.000165	0.0001051	0.001365	0.0012	1
1.050105	0.046225	0.0352732	0.38173	0.403887	2
1.120112	0.046214	0.0411371	0.381461	0.471944	2
0.980098	0.011983	0.0049479	0.098813	0.056435	3
1.085109	0.012011	0.0049539	0.099043	0.056504	3
1.365137	0.0291	0.0091221	0.239996	0.104064	4
1.715172	0.028972	0.0091341	0.238943	0.104204	4
1.225123	0.025086	0.0128058	0.206867	0.146744	5
1.435144	0.025061	0.0128018	0.206658	0.146713	5

Table 1: An excerpt from training data

Based on the runtime dynamics of the hybrid distribution system, these are different kinds of faults that may occur. The training and testing samples are taken at 80:20. It does mean 80% of data as training samples and 20% of data as testing samples. Simulation made with MATLAB/Simulink has resulted in observations with respect to different faults. The following sections provide observations pertaining to each fault and normal case in terms of three phase voltage at point of common coupling, negative voltage at point of common coupling and WT details.

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4. EXPERIMENTAL RESULTS

4.1 Normal Case

It is the case where the hybrid power distribution system is functioning normally without disturbances. Negative sequence voltage from point of common coupling is the basis for feature extraction and training ANN for prediction of faults.

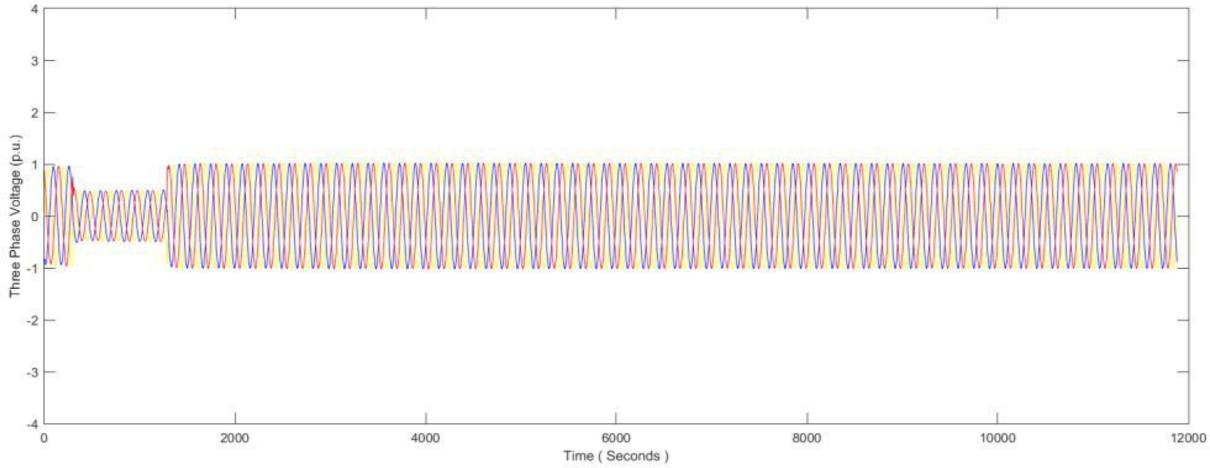

Figure 4: Shows three phase voltage at point of common coupling at normal conditions

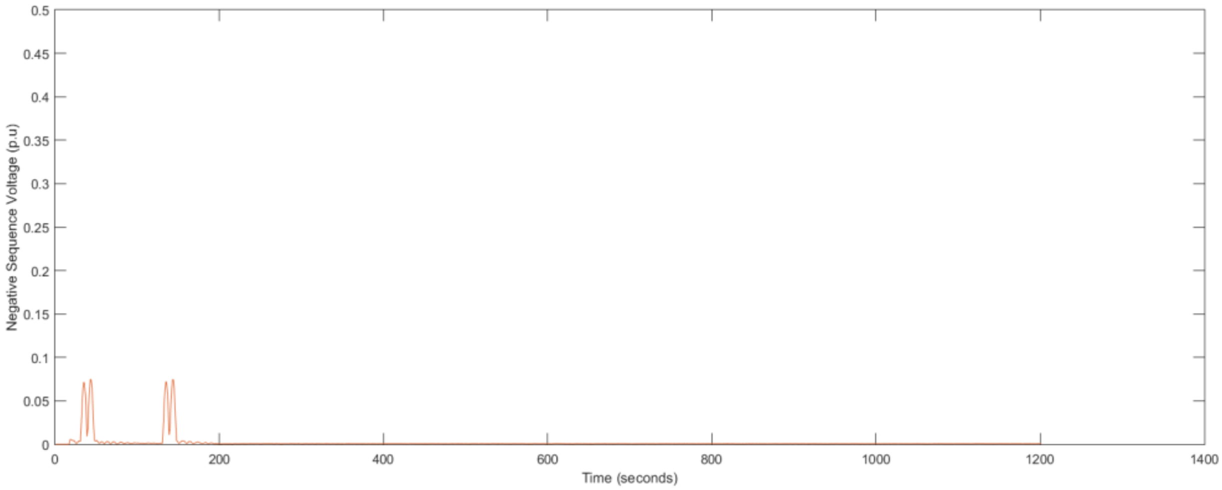

Figure 5: Shows negative voltage at point of common coupling at normal conditions

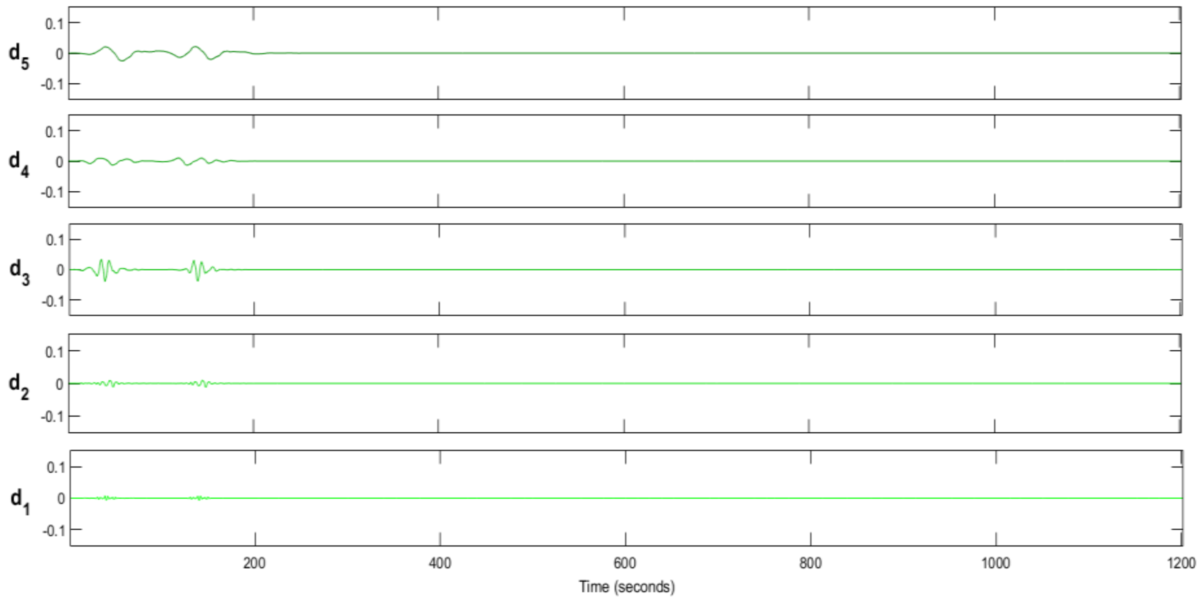

Figure 6: Shows WT details at point of common coupling at normal conditions

As presented in Figure 4, Figure 5 and Figure 6, the observations are shown at point of common coupling in terms of three phase voltage, negative voltage and details of WT.

4.2 Line to Line Fault

The line to line fault occurs in a power distribution system when two conductors are short circuited. It is also known as unsymmetrical fault. The observations pertaining to line to line fault are as follows.

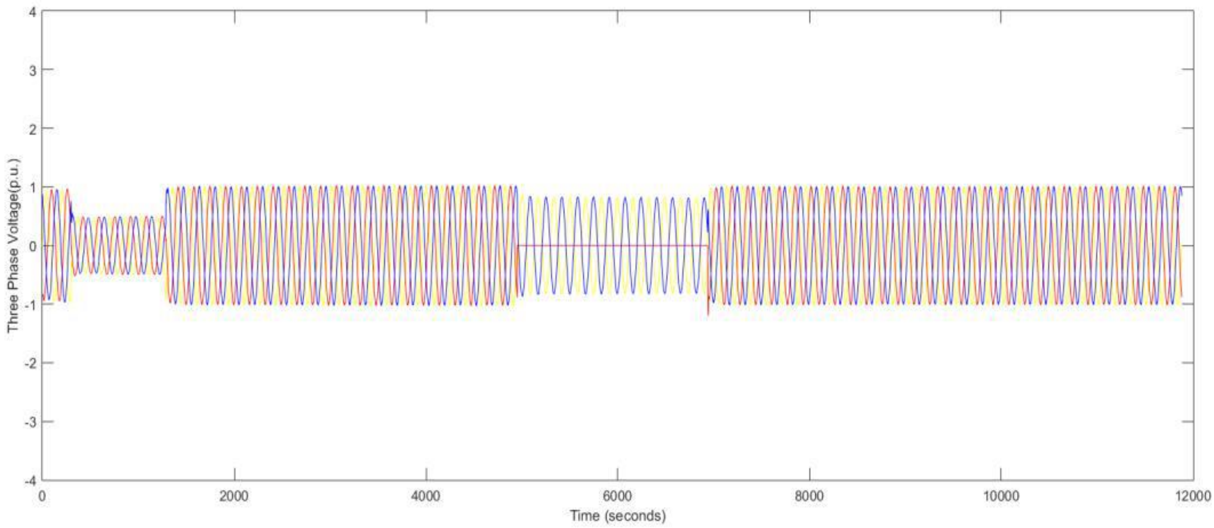

Figure 7: Shows three phase voltage at point of common coupling during line to line fault

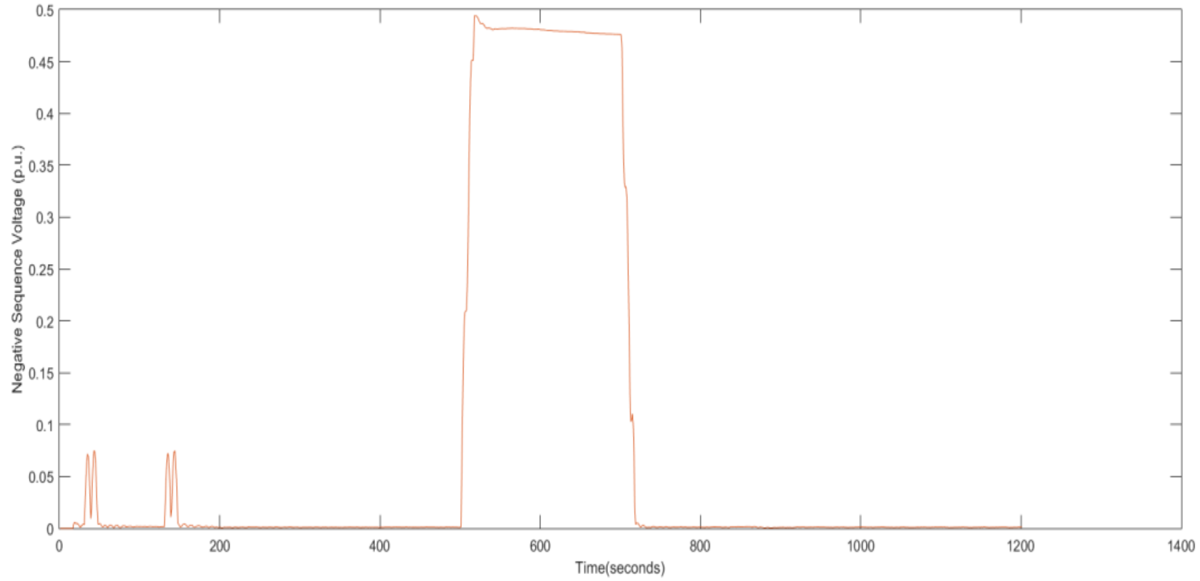

Figure 8: Shows negative voltage at point of common coupling during line to line fault

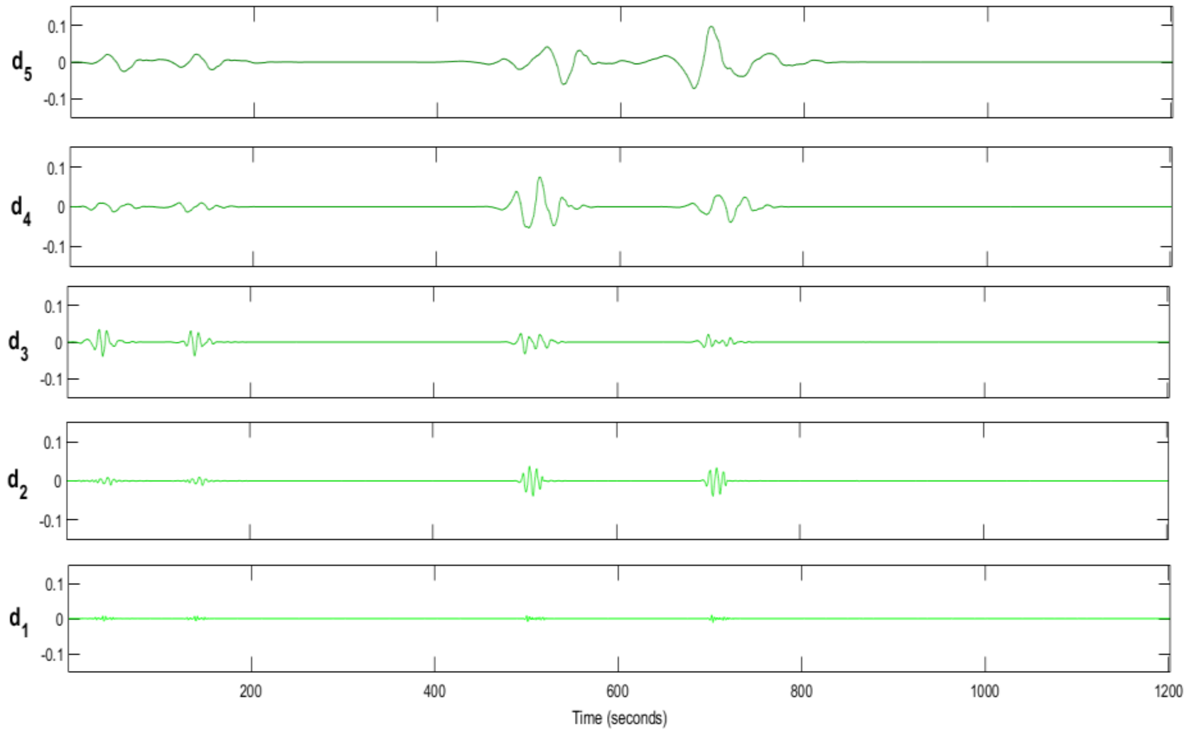

Figure 9: Shows details of WT at point of common coupling during line to line fault

As presented in Figure 7, Figure 8 and Figure 9, the observations are shown at point of common coupling in terms of three phase voltage, negative voltage and details of WT during line to line fault.

From the results, it is understood that the proposed system is able to identify different kinds of faults in a power distribution system. This has potential use case in enhancing quality of power supply by rectifying known issues in the hybrid power distribution system.

Finally, the performance of ANN to identify faults is evaluated. The number of samples used for testing is 60. The number of false positives found is 1 and the number of false negatives found is 1. Therefore, the accuracy of the ANN in detecting faults is 96.66667%.

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5. CONCLUSION AND FUTURE WORK

In this paper a hybrid power distribution system is built using MATLB/Simulink. It is made up of both wind and PV system. Point of Common Coupling devices are used in order to realize the integration of hybrid power generation and distribution systems. The proposed hybrid distribution system is simulated using Simulink. In the process, the data is collected from the negative sequence component at point of common coupling. This data has got features that are used to have discriminative knowledge to determine various faults in the proposed distribution system. An artificial intelligence based approach is used to find various faults such as islands, line to line faults, line to ground faults, and non-linear load switching problems. The voltage signals of negative sequence component at the point of common coupling are decomposed by DWT to have different frequency bands. Once the required features are obtained, an ANN classifier is trained to predict aforementioned faults in the system. Thus the faults identified in the power distribution system lead to enhancement of quality in power distribution. MATLAB is used to define ANN code while the power distribution system is designed using Simulink. The experimental results revealed that the proposed methodology based on AI is capable of detecting faults with higher level of accuracy at 96.66667%.

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