Power Quality Disturbance Classification using Artificial Neural Network

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***Abstract*— With growing use of sensitive equipment, studies on power quality had developed to conduct data analysis on power quality. Wavelet transformation method has been very useful in investigating diverse types of events in power quality. This paper compares the use of various wavelets at different scales and level of decomposition in analyzing actual Power Quality (PQ) events from a cable model or signal is generated using MATLAB background. In this system voltage sag, swell, harmonics, momentary interruption, fault conditions and transient events are performed.**

The system proposed includes elements smaller than the traditional procurement process. In this method wavelet transform identified different power quality events and then classified them via Artificial Neural Network (ANN). Power quality disturbances are defined by the load received after neural network training. Separate MATLAB simulation model is designed to produce various power quality events such as voltage sag, swell, momentary interruption, harmonics, transient and fault signals. ANN learning also wiped out MATLAB simulation using NN toolbox for power quality disturbance detection through the aliasing of voltage signals energy. Satisfactory results obtained in MATLAB simulink using such techniques.

***Keywords*— Wavelet transform, Power quality, Neural Network**

I. Introduction

In the power system there are different types of faults but overhead transmission lines has highest rate of occurrence of fault because their exposure to different environmental conditions is more. Line failures caused by fire, rain, falling trees, fog and mist of salt on dusty insulating material are beyond the control of man. Single line-to-ground, line-to-line and double line-to-ground faults in nature are unsymmetrical in nature, three phase shunt and three phases to ground circuits these types of faults are symmetrical.

Any irregular flow of electric current in power system is known as electric fault. Example, when flow of current eliminates the normal load which called as short circuit fault. When the circuit is break by some failure that fault is called as open circuit. The protective equipment can detect fault conditions in power systems and operate circuit breakers and other devices to minimize service loss due to a failure. If a fault in a poly phase system can affect all phases equally then it is called as "symmetrical fault." The resulting fault is called "asymmetric fault," which becomes more difficult to evaluate because of the simplification of presumption of equivalent current magnitude in all phases, when only certain phases are affected. Because the study of asymmetric fault form is complex "symmetrical components" are used for analysis. A symmetrical or balanced fault has an equal effect on all of the three phases. Faults in power systems are essentially unbalanced in practical terms. Whereas fault does not have equal effect on all of the three phases.

Throughout this study, various approaches for transmission l ine protection focused on wavelet transformation are discuss ed focusing primarily on the specific methods for the detecti on, diagnosis and isolation of transmission line failures.

Some of these method involved wavelet transform. High speed fault clearance is very important in a modern power system and different techniques have been developed to achieve this goal.

The framework proposed [1] for identification of power quality for power system disturbances using adaptive wavelet networks (AWNs). An AWN is a network that compose of two-sub network architecture which consisting of the wavelet transform and the probabilistic adaptive network. Symlet wavelet is used to derive characteristics from different disturbances, and an adaptive probabilistic network analyzes the relevant characteristics and performs tasks for discrimination. AWN models are applied for flexible execution, with autonomous goal modification and parameter adjusting for add-in and delete functions.

The Continuous Wavelet Transform (CWT) [2] on the sampled signals can be used for identification of the power quality events and there time periods. Disturbance amplitude is calculated by decomposing, through the Discrete Time Wavelet Transform (DTWT), the signal in frequency sub-bands in an optimized manner. The proposed strategy in this paper identified by high noise elimination, produced by both the measuring sequence and the system being evaluated and is designed for an agile identification of power quality events. In addition, it is also planned for potential use in both real-time measuring equipment and an off-line analytics tool.

II. PROPOSED METHODOLOGY

A. Wavelet Transform

In power system wavelet transformation technique has been another appropriate and effective signal representation processes. Wavelet analysis has become a fairly new procedure for power system and is successfully added by many researchers in power systems due to its time and frequency domain analysis capabilities [3],[4]. These are two areas that have many applications fare power quality research and power system security. Using the following equation, the definition of a continuous wavelet transform (CWT) for a given signal x(t) is specified in relation to a mother wavelet ψ(t)

$$CWT\,(a,b) = \frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} x(t \qquad (1)$$

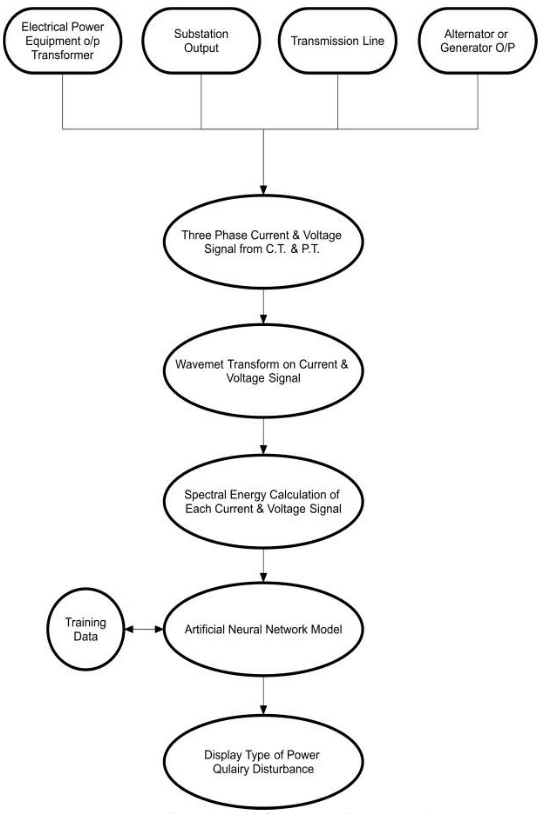


Fig.1. Flowchart of proposed approach

Where the scaling factor is a, and where the translation factor is b. All the factors t, a and b are continuous for CWT. Distinct configuration of t, b and a seen in equation (1) used in wavelet transform procedure involving Discrete wavelet transform.

$$DWT\,(m,n) = \frac{1}{\sqrt[m]{a_0}}\sum_k x(k)\,\varphi\left(\frac{k - nb_0a_0}{a_0^m}\right)$$

The DWT description written in above equation where the initial and variables in (1) are changed to be integers n, m's functions. And k is an integer variable corresponds to the number of samples in an input signal.

Fig.2. Shows the useful implementation of DWT which is known as Multi-Resolution Analysis. Both high pass h(n) and low pass l(n) filter are used in this approach. To get the coefficients for detail (D1) and for approximation e(A1) the results of both filters then are exterminate by two at the end of stage one. During second stage approximation coefficients are forwarded and same procedure is repeated. We get the signal at the end of the process, which decomposes to the required level as shown in Fig.2. where the original measurement is frequency F, the signal data collected by D1 is between frequency bands f/4 and f/2. Extracts data from f/8, and f/4, D3. Extracts information between f / 16 and f / 8 and A3 keeps the rest of the original information 0 and F / 16.

Thus, we can efficiently gain meaningful data from the source signal into different frequency bands, yet at the same time matching the information to the time span associated. .The increasing the wavelet's capacity, the more information can be retained following its decomposition.

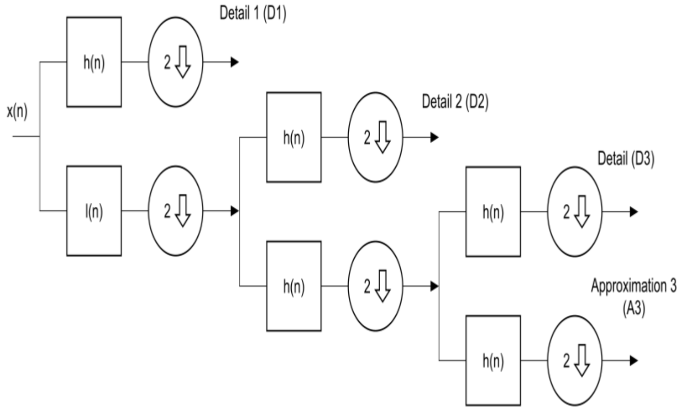


Fig.2.Wavelet multi-resolution analysis

Using the following Eqs. (3) & (4) the total energy and mean power can be expressed in terms of x[n] signal.

(3)

$$P = \lim_{x\to\infty}\frac{1}{2N} \qquad (4)$$

After an useful technique of decomposition we obtained the energy coefficients of each signals which are transferred to the neural network for internal and external classification of faults. Here data window length of the wavelet transform can change by variance in scale factor. After a good step of decomposition, we got the energy coefficient of individual signals passed to the neural network to identify faults internally and externally. We are select amount of decomposition stage of Multi-resolution study and form of Mother Wavelet based on the best result occurs in proposed research. This choice is completely focused on MATLAB Simulation Analysis.

B. Artificial Neural Network

Artificial neuron array is likewise state as a neural network. A mathematical model of the biological neuron is an artificial neuron in its simplest form. Biological neurons are seen as elementary units in any nervous system for information processing.

Mathematical model of an artificial neuron is based on the following, without defining its neurobiological validity.

1. Neurons are the essential component of a nervous system which processed the information.

2. Incoming information takes the form of signal that are shared via connection links

3. By connection link has a proper weight that multiplies the signal transmitted.

4. Base on the bias and firing threshold each neuron has an internal action, resulting in activation function being added to the weighted sum of the input signal to generate the output signal. And when input signals x1, x2, . . . ,xn are reach the neuron through connection links with corresponding weights w1,w2, . . .,wn respectively, the resulting input to the neuron, called the net input, is the weighted sum . If the threshold for firing is b and the activation function is f, then the neuron's output is

$$y = f\left(\sum_{i=1}^{n} w_i\, x_i\right)$$

In the first theoretical model suggested by McCulloch and Pitts for artificial neurons, outputs are binary, and the function f is the step function.

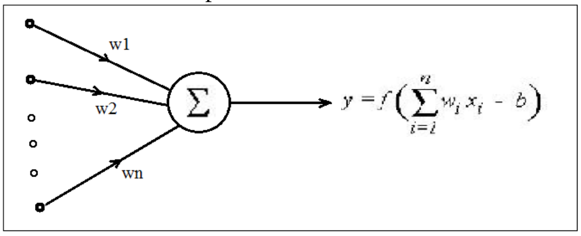


Fig.3. Mathematical model for artificial neuron

Defined by

$f(x) = 1 if x \geq 0$

$f(x) = 0 if x < 0$

so that the activation of that neuron is

$$f\left(\sum_{i=1}^{n}(w_i\, x_i - b)\right) = 1 if \sum_{i=1}^{n} w_i\,; x_i \geq b$$

$$f\left(\sum_{i=1}^{n}(w_i\, x_i - b)\right) = 0 if \sum_{i=1}^{n} w_i\,; x_i < b$$

This is depicted in Figure 3. An artificial neuron is defined by the parameters y = (w1,w2, . . . ,wn, b, f).

C. Potential Transformer (P.T)

Potential transformer used for operating of wattmeter potential coil and high voltage line relay coil during abnormal conditions. Potential transformer design is quite similar to a power transformer design but potentially transformer loading is always low, sometimes just a few volt-ampere. In this system rating of potential transformer is such that instrument load receives a voltage between 100 to 120 volt. The voltage of the secondary winding of potential transformer which is connected across tripping circuit is 110 volt in system.

D. Working of Proposed Approach

A current transformer (CT) and potential transformer (PT) are used to calculate the three phase output current and voltage signal of any transmission line, transformer, generator or alternator, substation or other electrical equipment. This current signal for signal extraction is sent to wavelet transform block. Spectral energy of all individual phase current signal is measured using wavelet transform techniques in this section. This current coordinates spectral energy submit to neural network data. Neural Network already prepare for different condition of PQ disturbance. Based on training data set Neural network offers its preference for PQ type disturbances.

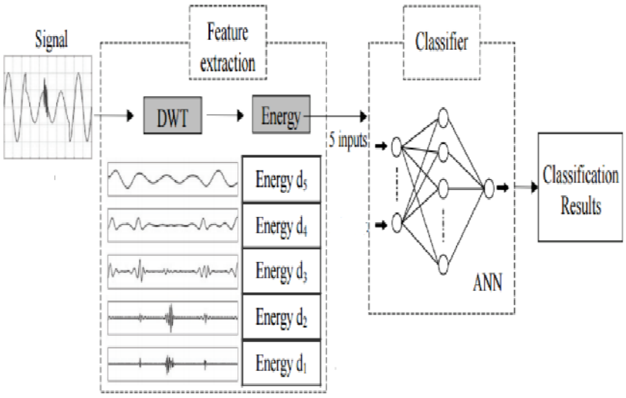


Fig. 4. Working of proposed approach

III. Simulation Model and Results

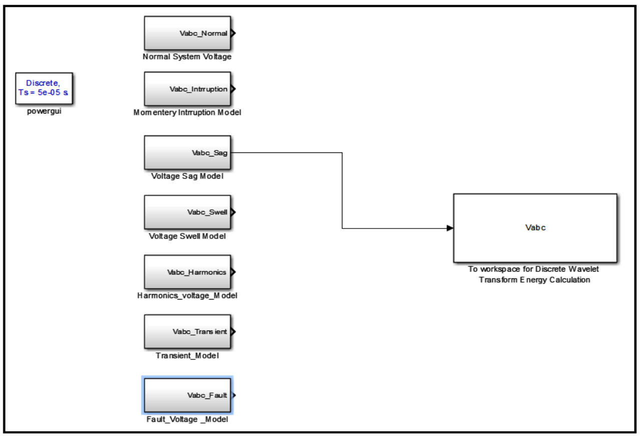


Fig.5. Complete MATLAB simulation for power quality analysis

Figure 5 shows the complete MATLAB simulation model for all power quality disturbance analysis. This model consists of seven subsystem model. Each subsystem model generate different power quality disturbance voltage signal like voltage sag, voltage swell, momentary interruption, transient, harmonics and fault voltages signals. This generated voltage signal get transfer to MATLAB workspace for performing wavelet transform or spectral energy calibration using wavelet toolbox.

TABLE .I. NORMAL VOLTAGE SUBSYSTEM MATLAB SIMULATION MODEL PARAMETER SPECIFICATION

Sr. No.	*Name of simulation block*	*Parameter specification*
1.	Three phase pvoltage source (gen1)	Phase to phase rms voltage = 153 KV Phase angle of phase A = 0 degree; Frequency = 50Hz; Three phase short circuit level at base voltage = 100 MVA; Base voltage = 34.5 KV; X/R ratio = 7.
2.	Three phase transformer (xmer1)	Nominal power = 50 MVA; Frequency = 50 Hz; Winding1 (primary side) : Ph-

		ph rms voltage = 34.5 KV; R1 = 0.002 pu; L1 = 0.008 pu; Winding 2 (secondary side): ph-ph voltage = 10 KV; R2 = 0.002 pu ; L2= 0.008 pu ; Magnetizing resistance Rm =500 pu; Magnetizing inductance Lm = 500 pu; Bothe primary and secondary are solidly grounded.
3.	Transmission line1 5Km	Number of phases = 3; Frequency for RLC specification = 50Hz; Positive sequence resistance r1= 0.01273 Ohm/Km; Zero sequence resistance r0 = 0.3864 Ohm/Km ;Positive sequence inductance L1= 0.9337 mH/Km; Zero sequence inductance L0= 4.1264 mH/Km ; Positive sequence capacitor C1= 12.74nF/Km; Zero sequence capacitor C0= 7.751nF/Km; Line length = 5 Km.
4.	Three phase fault block	Fault resistance Rf = 0.3 Ohm; Transition time = 0.1 to 0.3 second; Snubber resitance Rp = 1 MOhm.
5.	Transmission line2 5Km	Number of phases = 3; Frequency for RLC specification = 50Hz; Positive sequence resistance r1= 0.01273 Ohm/Km; Zero sequence resistance r0 = 0.3864 Ohm/Km ;Positive sequence inductance L1= 0.9337 mH/Km; Zero sequence inductance L0= 4.1264 mH/Km ; Positive sequence capacitor C1= 12.74nF/Km; Zero sequence capacitor C0= 7.751nF/Km; Line length = 5 Km.
6.	Three phase series RLC load	Nominal phase to phase voltage = 440 V; Frequency = 50 Hz; Active power = 10 W; Inductive reactive power Q_L = 0 VAR; Capacitive reactive power Q_C = 20 VAR.

E. Power Quality Disturbance analysis using Wavelet Transform

In MATLAB simulink model is use for producing signals of power quality disturbances. A 34.5 KV Distribution network consists of three phase loads and one nonlinear load, simulating various disruptions of power quality events. Simulation specifications: Total simulation time=1sec, Time for detecting PQ disturbance from 0.2 to 0.4 second.

F. Normal Voltage

Analysis of the wavelet transform was performed on normal voltage waveform by considering db-1 mother wavelet decomposition up to five stages. Upto five levels of any condition in the model are decomposed, five detail coefficient are obtained. For different types conditions in power system, the standard deviation of detail coefficients obtain are different is shown in fig.8.

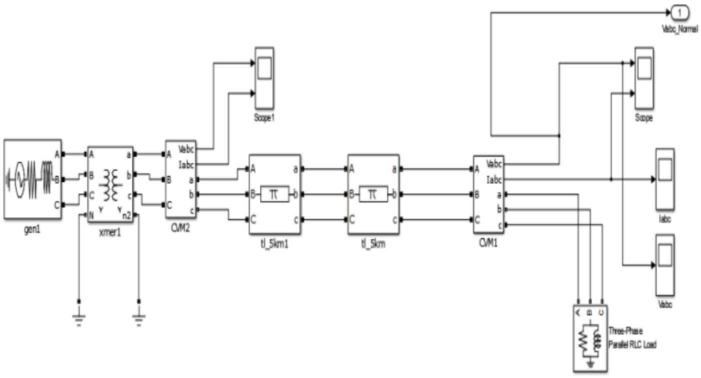


Fig.6.Simulation model for generation of power quality disturbance voltage signals

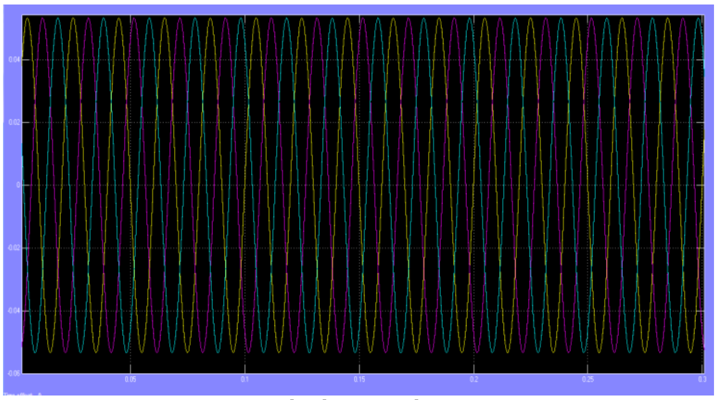
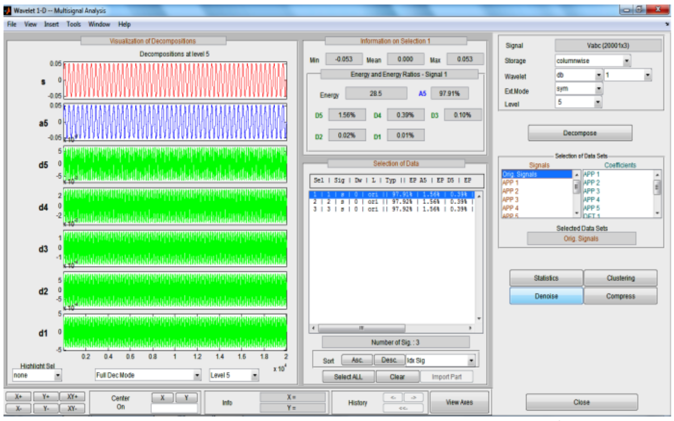


Fig.7. Normal voltage signal output



Fig,8.Wavelet multi-resolution analysis using Wavelet toolbox for normal voltage signal and energy calculation

G. Voltage Sag

We consider 34.5 KV transmission model with 440 Volt, 50Hz reactive load of 30 KVAR and active load of 10W to produce sag voltage in matlab simulation model. Sag produced in 0.1 to 0.4 seconds. The total simulation time is 1 second for the matlab model.

Analysis of the wavelet transform was performed on voltage sag waveform by considering db-1 mother wavelet decomposition up to five stages. Upto five levels of any condition in the model are decomposed, five detail coefficient are obtained. For different types conditions in power system, the standard deviation of detail coefficients obtain are different is shown in fig.10

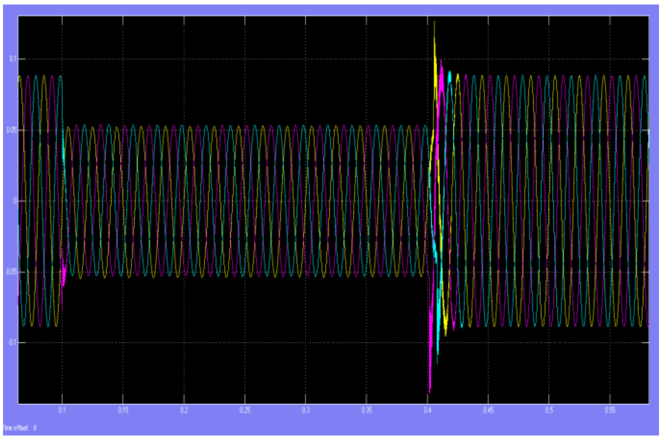


Fig.9. Voltage sag signal output

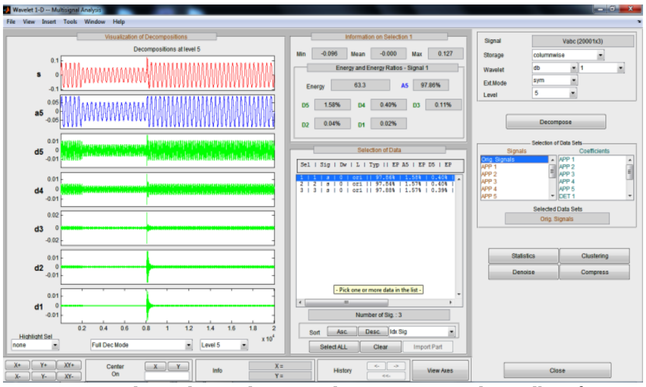


Fig.10. Wavelet multi-resolution analysis using Wavelet toolbox for sag voltage signal and energy calculation

H. *Voltage Swell*

We consider 34.5 KV transmission model with 440 Volt, 50Hz capacitive load of 30 KVAR and active load of 10W for generating swell voltage in matlab simulation model. Swell produced in 0.1 to 0.4 seconds. Here the simulation is performed for 1 second in Matlab.

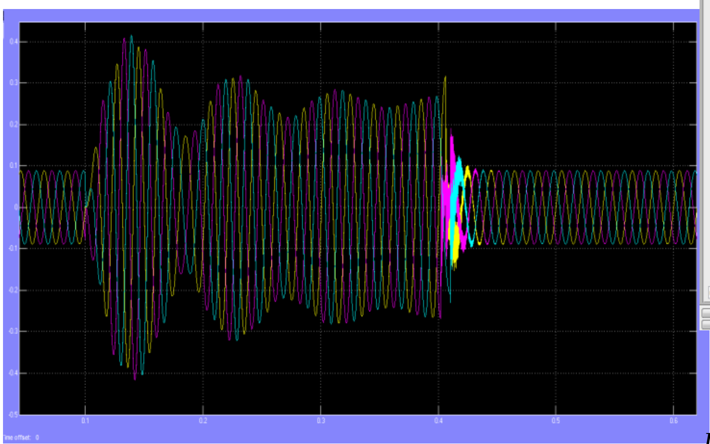
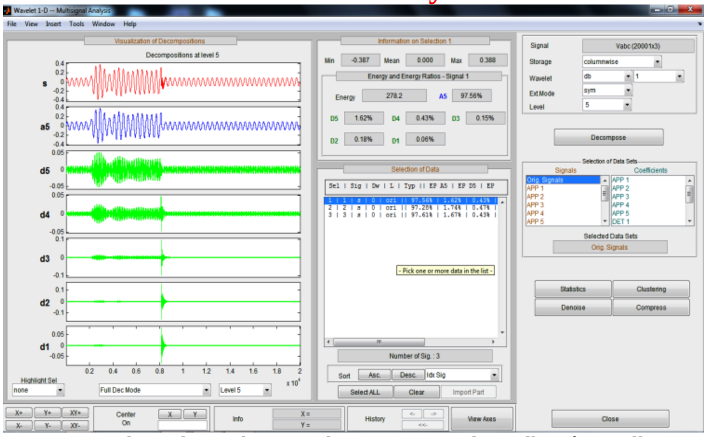


Fig.11. Voltage swell signal output



Fig,12. Wavelet multi-resolution analysis using Wavelet toolbox for swell voltage signal and energy calculation

I. *Momentary Interruption Voltage*

We consider 34.5 KV transmission model with 440 Volt, 50Hz inductive load of 30 KVAR and active load of 30W for generating momentary interruption voltage in matlab simulation model. In between 0.1 to 0.4 seconds created momentary interruption. Here the simulation is performed for 1 second in Matlab.

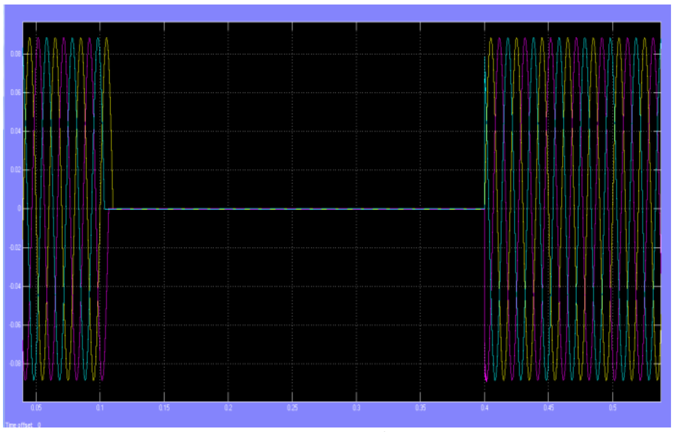


Fig.13. Momentary interruption of voltage signal output

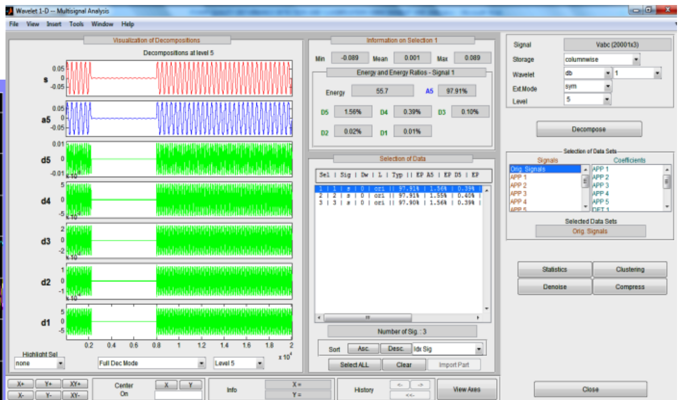


Fig.14. Wavelet multi-resolution analysis using Wavelet toolbox for momentary interruption of voltage signal and energy calculation

J. *Voltage with Harmonics*

We consider 34.5 KV transmission model with series RL load branch of inductance 22mH and resistance 5 KΩ for the generation of voltage harmonics in matlab simulation model, Universal Bridge consists of diode resistance100

MΩ snubber resistance 1Ω and forward voltage 50V. Total simulation time is 1 second.

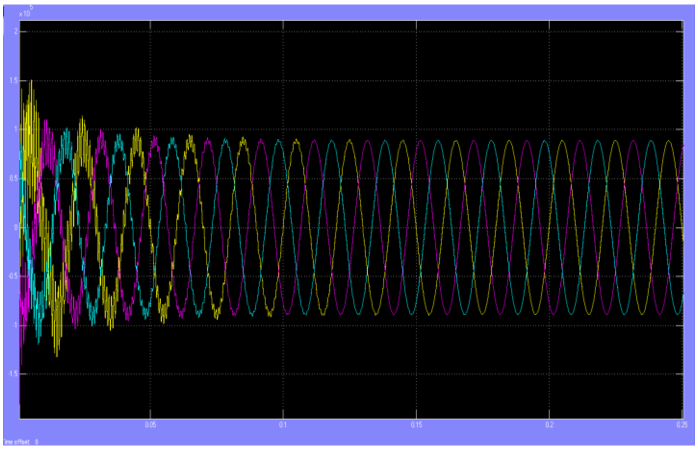


Fig.15. Harmonics using Matlab simulation model output

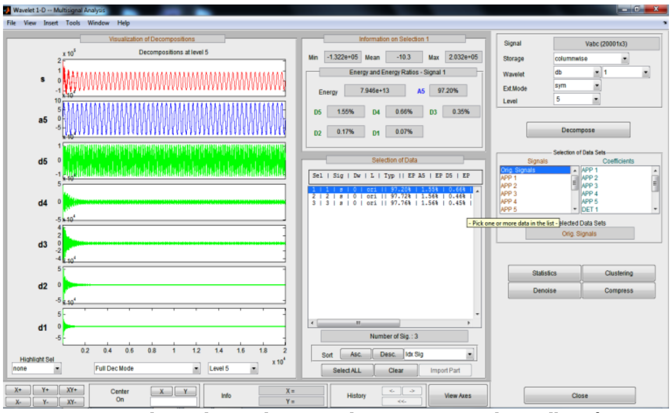


Fig 16.Wavelet multi-resolution analysis using Wavelet toolbox for Harmonics of voltage signal and energy calculation

K. Transient Voltage

We consider 34.5 KV transmission model for transient voltage generation in matlab simulation model with transformer start rating 50MVA. High transients are prodalthough during startup of transformer. Starting is done at 0.4 second. Total simulation time is 1 second.

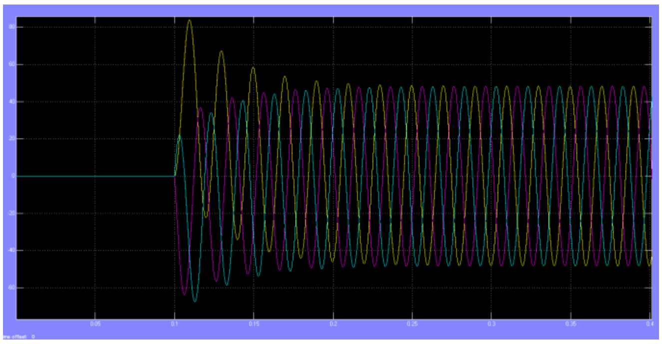


Fig 17.Generated voltage transients using Matlab simulation model

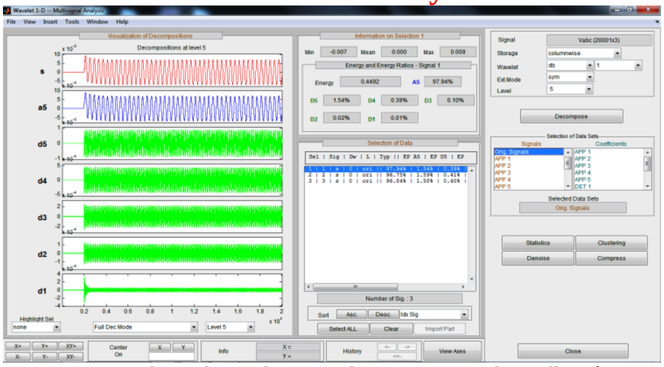


Fig.18.Wavelet multi-resolution analysis using Wavelet toolbox for Transient of voltage signal and energy calculation

L. Fault Voltage

For generation of fault voltage signal in matlab simulation model, we consider 34.5 KV transmission model with different types of three phase fault on transmission line. In this case we simulate fault between Phase A to Ground for LG fault. Fault occurs between o.1 to 0.4 second. Total simulation time is 1 second. The length of transmission line is 10 km fault occurs at 5 km in between line.

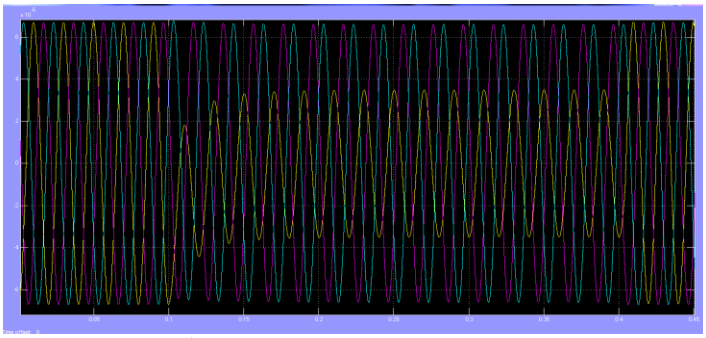


Fig.19.Generated fault voltage signals using Matlab simulation mode

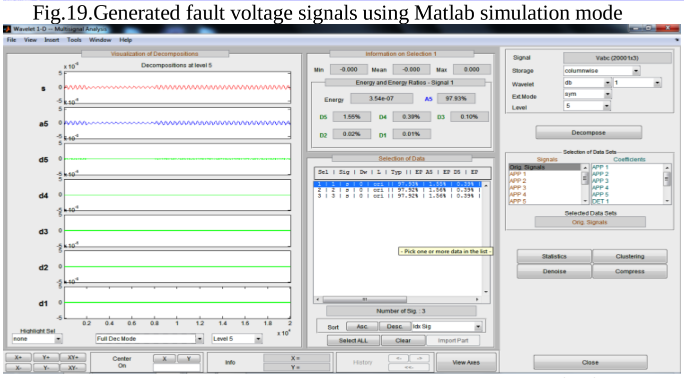


Fig.20.Wavelet multi-resolution analysis using Wavelet toolbox for faulted voltage signal and energy calculation

M. Power Quality Disturbance Classification Using Neural Network

We can train the neural network by using spectral energy coordinates that are optimized by multi resolution analysis of wavelet. We apply energy coefficient upto level 5 of multi resolution analysis (MRA) for training neural network. Apply input as energy of A5, D5, D4, D3, D2 and D1 to the neural network.

Data set input and target data set generated using disturbance cases above of power quality. Table II displays the training data collection for various power quality disturbance signals for train neural network.

TABLE 2: INPUT TRAINING DATA FOR NEURAL NETWORK

PQ Disturbance	*A5E*	*D5E*	*D4E*	*D3E*	*D2E*	*D1E*
Normal Voltage	97.91	1.56	0.39	0.10	0.02	0.01
Momentary interruption	97.91	1.56	0.39	0.10	0.02	0.01
Voltage sag	97.86	1.58	0.40	0.11	0.04	0.02
Voltage swell	97.56	1.62	0.43	0.15	0.18	0.06
Harmonics	97.21	1.56	0.65	0.36	0.18	0.07
Transient	97.95	1.55	0.38	0.11	0.02	0.01
LG Fault (AG)	97.93	1.55	0.39	0.10	0.02	0.01
LLG Fault (ABG)	98.04	1.47	0.37	0.09	0.02	0.01
LLLG Fault (ABCG)	98.12	1.41	0.35	0.09	0.02	0.01
LL Fault (AC)	98.03	1.48	0.37	0.09	0.02	0.01

TABLE.III. TARGET TRAINING DATA FOR NEURAL NETWORK
TABLE TYPE STYLES

PQ Disturbance	*ANN Target*
Normal Voltage	1
Momentary interruption	2
Voltage sag	3
Voltage swell	4
Harmonics	5
Transient	6
Fault voltage	7

Where, A5E = Approximate coordinate of spectral energy at level 5
D5E = Detail coordinate of spectral energy at level 5
D4E = Detail coordinate of spectral energy at level 4
D3E = Detail coordinate of spectral energy at level 3
D2E = Detail coordinate of spectral energy at level 2
D1E = Detail coordinate of spectral energy at level 1

N. Training performance of Neural Network

We generate set of numbers for each form of power quality disturbances to train neural network for a 105 power quality disturbance event. For each power quality disturbance 15 condition has been generated and during that power quality disturbance the neural networks gets trained for that condition using voltage signal energy.
Neural network hidden neurons were 10 during training on neural network. For this neural training requires 27 epoch with0.05992 Mean square error (MSE) from target to actual output.
Neural network testing results on 5 % cent evaluation data, 5 % validation data and 95 % training data seen in figure 20.

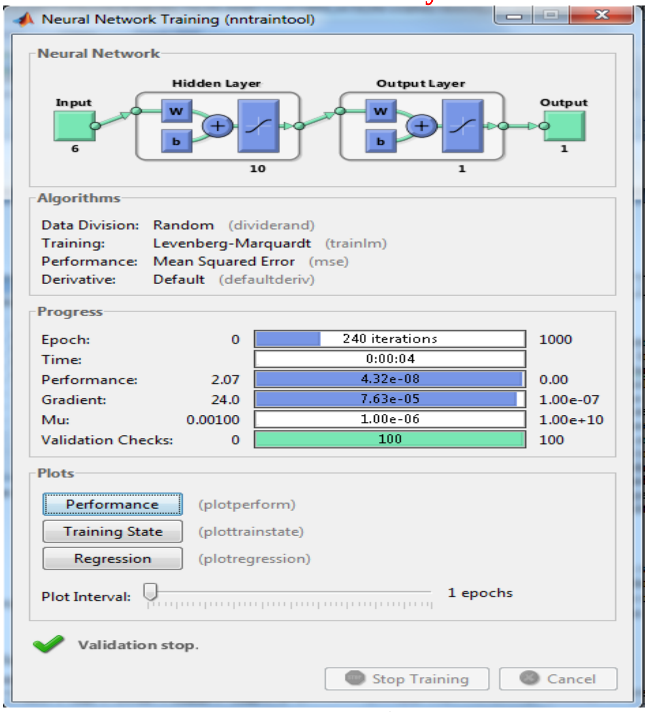


Fig.21.Training window during training of selected neural network in MATLAB simulation

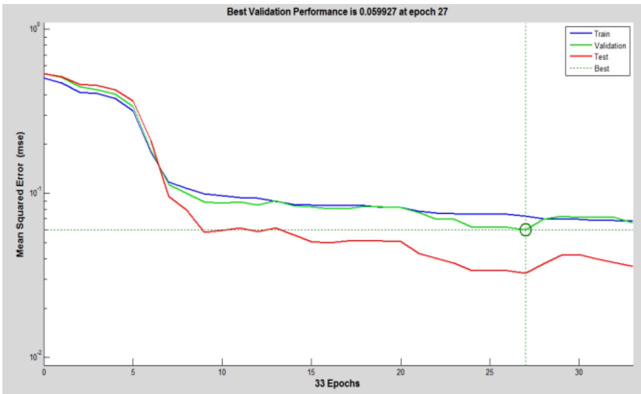


Fig 22.Training performance of neural network during training using MATALB

O. Results from Neural Network

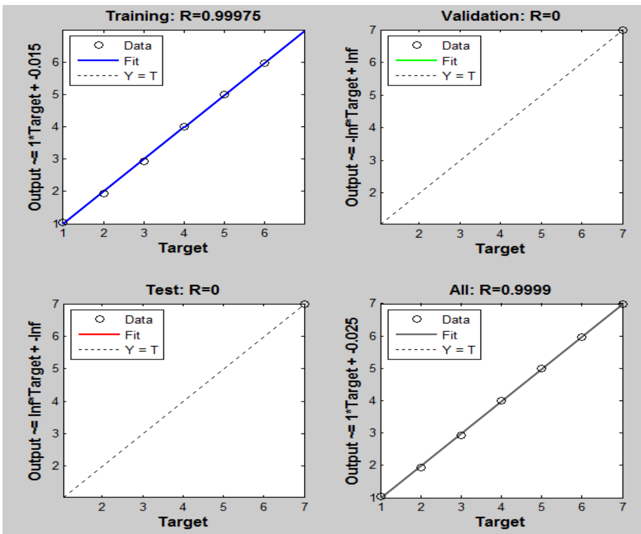


Fig.23. Actual output from neural network after training (Regression matrix)

Out of 90 power quality disturbance event 71 PQ disturbance event classification with 99 % accuracy after training neural network.

For the remaining 19 PQ disturbance event neural network in confusing state do not successfully identify the PQ disturbance. For improve the ANN accuracy or efficiency new neural network model with different number of transfer function and different number of hidden neurons design essential. This work extended for future work.

Figure 24 shows that all types of fault class classification done by neural network. This ROC figure shows the how many categories effectively classify using ANN.

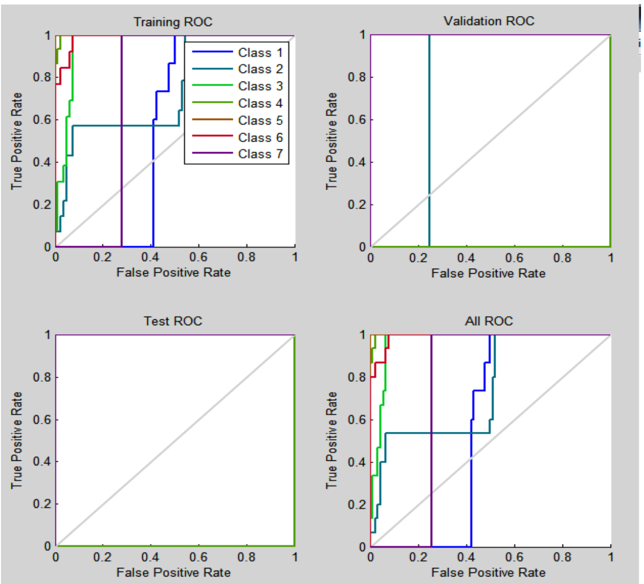


Fig.24.Reason of conversion (ROC) FOR ANN

III. Conclusion

Using Artificial Neural Network (ANN) and Wavelet Transform, this method was used to detect and classify disturbance of power quality in the power system. The proposed method includes features that are less numerous than traditional recognition approaches. The feature extracted through the wavelet is being trained for event classification by Artificial Neural Network. The obtained weight is used after training the neural network to identify the Power Quality (PQ) problems. The overall efficiency of neural network for Power Quality disturbance analysis is 99 %.

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