

Application of Artificial Neural Network for Power System Frequency Prediction in FNET

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Abstract

This work presents the application of Artificial Neural Network (ANN) on time series data of voltage magnitude, voltage angle and system frequency measurements obtained from Local Frequency Monitoring Network (LFNET), set up using Frequency Disturbance Recorder (FDR) and a Personal computer (PC) for power system frequency prediction. The predicted results obtained from the ANN model was validated with the mean square error (MSE) conventional statistical method. The MSE of the model was found to be 1.38×10^{-5} and that of statistical approach were 1.02×10^{-2} , to this extent the superiority of ANN over conventional method has been ascertained. Hence the developed model can be used for power system frequency prediction.

Keywords: *Frequency monitoring network, Artificial neural network, Power frequency.*

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Background to the Study

Frequency is a universal parameter all over an interconnected power system (Lai, 2012). It is desired to be maintained constant. But it is well known that frequency of operation is never constant however, it is allowed to vary over a small range (Chudamani, 2009). To keep the frequency constant there must be a constant speed of generator sets which is driven by prime movers, a constant line parameters and a constant/steady load (Kothari, 2006). But, these parameters are never constant in real sense. Both active and reactive power demand are never steady, they continually change with rising or falling trend. The input to the generators must therefore be continuously regulated to match the active power demands, failing which the machine speed will vary with consequent change in frequency which may be highly undesirable. A basic difficulty with electric energy production and consumption is that, large electric energy cannot be stored; it must therefore produce at the same time as it is consumed (Amir Rastegarnia, 2015). In order to create balance between production and consumption the active power generated must be equal to the sum of active demand and losses, at this balance the frequency is exactly at nominal value i.e.50Hz in the case of Nigerian system. Any mismatch results to frequency variation; though, it is allowed to vary within a narrow band of 49.75Hz -50.25Hz (NERC, 2014). Frequency monitoring, control and prediction in power system are essential in order to save the system from stress of instability, system collapse, and prevent electrical/electronic equipment from damage and in an event of measurement failure, predictions function as an emergency backup (Illian, 2011).

Frequency Monitoring Network (FNET) system is an internet based, wide- area sensor network consisting of high-precision Frequency Disturbance Recorders (FDRs), a central processing server, and an Information Management System (IMS). Basically, the FDRs perform local Global Positioning System (GPS) synchronized measurements of voltage phase angle, phase voltage magnitude and phase frequency. Thus these measurements are time stamped and report 10 samples each second and then transmitted to the central server for further usage. The IMS handles the data collection, storage, communication, data base operations, and web services (Dong jin, 2013).

Prediction technique has been broadly classified into two main categories namely: the Traditional methods and Artificial Intelligent (AI) methods (Simarjit Kaur, 2013). The traditional methods were Time-Series based technique and Regression based technique. These techniques are mostly found to have limitation in terms of accuracy, longer computational time, and difficulty in imitating the nonlinearity nature existing between the frequency and various factors that influence the changes (Simarjit Kaur, 2013). The AI based techniques such as Expert system (ES), Fuzzy logic (FL), ANN etc. are found more accurate and faster than the traditional methods (Simarjit Kaur, 2013).

Various literatures have proved that ANNs are capable of learning from historical data and can easily model the nonlinearity between variables, such as frequency and other dependent variables like real power generated, load demand, voltage magnitude, voltage angle, etc. (Simarjit Kaur, 2013). ANN is a technique that is mathematically model the way in which the human brain performs a particular task, it learns from experience rather than programming and it is implemented using electronic components or simulated in software on a digital computer (Koivo, 2008).

Frequency Prediction Problem Formulation

Any periodic signal can be expressed as a Fourier series (i.e., as a linear combination of harmonically related sinusoids) (Theraja, 2002). Hence, periodic voltage waveform can be expressed as (Theraja, 2002):

$$V(t) = a_0 + \sum (a_n \cos n\omega t + b_n \sin n\omega t) \quad (1)$$

Where:

$$\sqrt{a_n^2 + b_n^2}$$

Is the magnitude of the n th harmonic component and $\omega = 2\pi f$ is the fundamental frequency in radian per second. Since $V(t)$ does not usually contain D.C. component, power system waveforms are usually half symmetric and if the major component is the fundamental frequency, Equation 1 can be reduce to; (Chudamani, 2009).

$$V(t) = a_1 \cos \omega t + b_1 \sin \omega t = A_1 \sin (\omega t + \Phi) \quad (2)$$

Where:

$$A_1 = V_{\max} = \sqrt{2} V_{r.m.s}$$

Φ , is the voltage phase angle, which is measurable in power systems.

$V_{r.m.s}$ Is the root mean square value of the voltage, and is also measurable.

$V(t)$ And ω are unknown, since the system frequency and the instantaneous voltage equation are related and therefore; the frequency can be estimated as:

$$f = \frac{[\sin^{-1} (v(t) / v_{\max}) - \Phi]}{2\pi t} \quad (3)$$

With equation 3, the frequency can be determined at any instance, chosen arbitrary initial value of the instantaneous voltage and iteratively computing the frequency until converges. But in order to have a reliable prediction, Artificial Neural Network (ANN) among other techniques is capable of learning from the available data to estimates and provide a good prediction of the system frequency at any given interval of time without following the process of equation 3.

Methodology

Data Capturing

In order to have adequate data to be used for the training of the network a Local Frequency Monitoring Network (LFNET) was set up as shown in the figure 1.

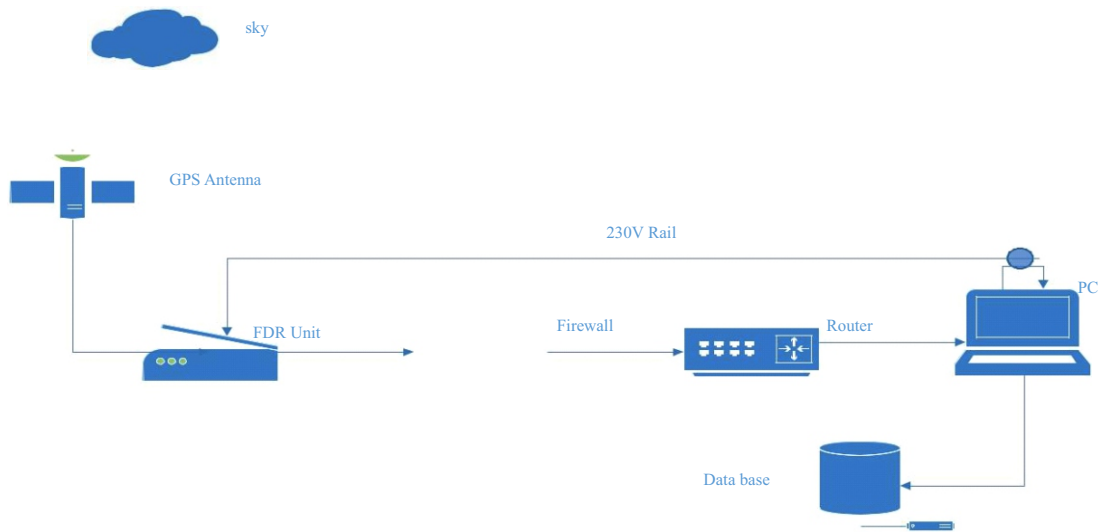


Figure 1: Local Frequency Monitoring Network (LFNET) Set up

The network was installed such that the GPS antenna is directly facing the sky in order to facilitate good reception. The FDR is directly connected to 230V socket as shown in figure 1.

An external storage (Database) is incorporated to serve as support to the PC. The PC and the database in this case serve as the IMS.



Figure 2: The Physical LFNET Setup

Model Design and Development

Following a successful implementation of LFNET, Data sampling was done in order to extract information from the huge amount of data available with the network; it was sampled at the sampling interval of one second for a complete one hour (i.e. a total of 3,600 samples) were used for the ANN Training, validation and testing.

The model was designed to have two frequency dependent variables as inputs x_1 and x_2 (i.e. the voltage phase magnitude, and voltage phase angle) and a frequency data as targets (output) figure 3 shows the SIMULINK block diagram of the ANN model

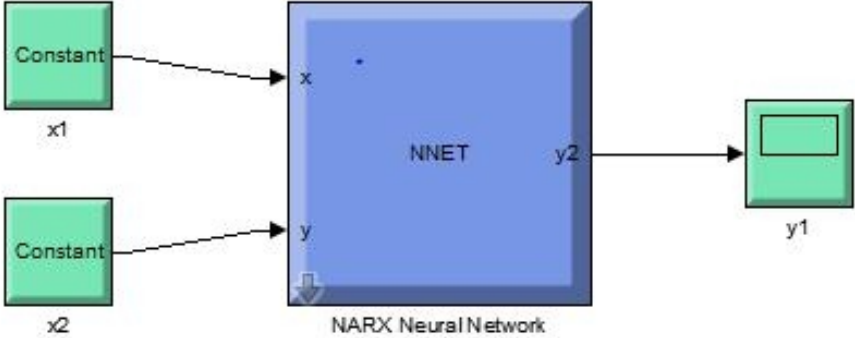


Figure 3: SIMULINK Block Diagram.

A complete procedure taken for the model design and development is summarized in flow chart figure 4. As soon as the data has been sampled, it was arranged in 60×120 matrixes as input data. And 60×60 matrixes as targets data accomplished using Microsoft excel. The data was imported to ANN MATLAB tool box and partitioned (divided) into three; 70% for training, 15% for validation and 15% for testing. Data partitioning is shown in the dialogue box figure 5. The network was trained and retrained by adjusting the delays and number of hidden neurons, in order to achieve a good prediction based on trial and error approach. But only result of the best performance among the trials is presented.

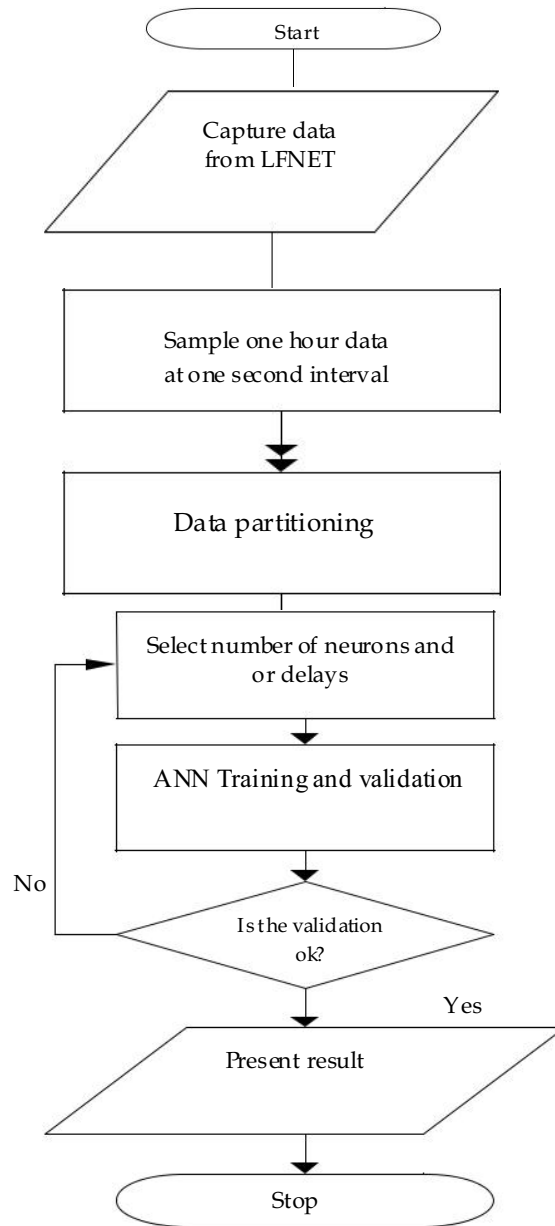


Figure 4: Flow Chart for the ANN Model Development.

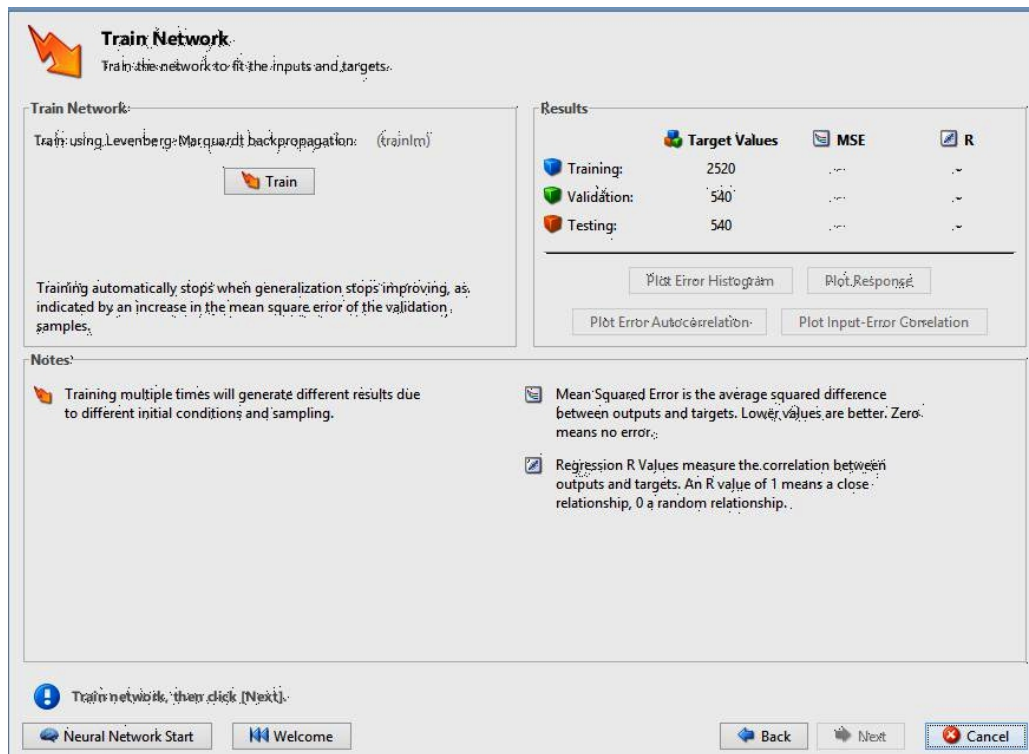


Figure 5: Data Partitioning Dialogue Box

Training is the process of repeatedly (iteratively) exposing a Neural Network to samples of historical data, known as the 'Training Set'. Often, training is expected to stop when the training algorithm converges. The number of hidden neurons and the delays were searched from 1 to 25 for both hidden neurons and delays, at different combination but the best result happens to be at 2 neuron and 1 number of delay, It was observed that the lower the number of hidden neurons the better the MSE performance result. The network was trained using levenberg- Marquardt back propagation algorithm. The best result was obtained at 5 iterations within just three second.

Validation

Validation of the model was carried out using two different ways; first, the output result of the model is plotted in the same axis with the actual measurements as shown in the figure

Secondly the MSE of the model is compared with the MSE of the statistical approach Obtained from equation 4.

$$MSE = \frac{1}{N} \sum (f_f - f_a)^2 \quad (4)$$

Where:

N = Total number of samples

f = Predicted frequency and

f_a = Actual measured frequency

MSE is the sum of average square difference between the predicted value and the actual value.

Results and Discussions

Regression and Error Measures

The network was trained with the data of Wednesday 24th February, 2016 at 6 am to 7am local time. The result of the Regression as well as the MSE is shown in the Table 1.

Table 1: Regression Performance Measure

| Parameter | Regression | MSE |
|------------|------------|-------------|
| Training | 0.99944 | 1.38 E-05 |
| Validation | 0.99941 | 2.3317 E-05 |
| Testing | 0.99908 | 3.218 E-05 |
| Overall | 0.99938 | --- |

Regression is the relationship between the networks output and the target data, all the regression values gives an inspiration on the accuracy of the trained model; the value of the regression (R) on each parameter illustrates how accurate it is. It is perfect when R=1. The closer the value of R is to one, the better the result. While MSE preferred value is zero, when it is zero it means no error and the closer it is to zero the better. The result in table 1 shows a good regressions and errors values, signifying an excellent performance.

Performance Function

Performance function plot presented in figure 6, describes the plot of the mean squared error against the number of training epochs. It shows the learning development and computational error improvement as the number of iterations increases. It can be accomplished that, the network was trained close to zero error because; an error of 2.3317 e-5 is negligible. Therefore, it can be said to have effectively learned the complex and nonlinearity relationship that was presented by the input data.

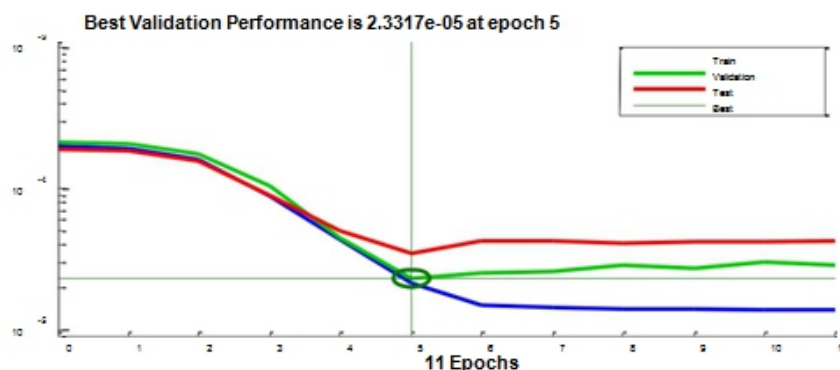


Figure 6: Performance Function Plot

Model Output

The graph of figure 7 is the expected frequency value of the Nigerian interconnected power system between 7am to 8 am, of Wednesday 24th February, 2016 an hour ahead based on the previous hour measurements.

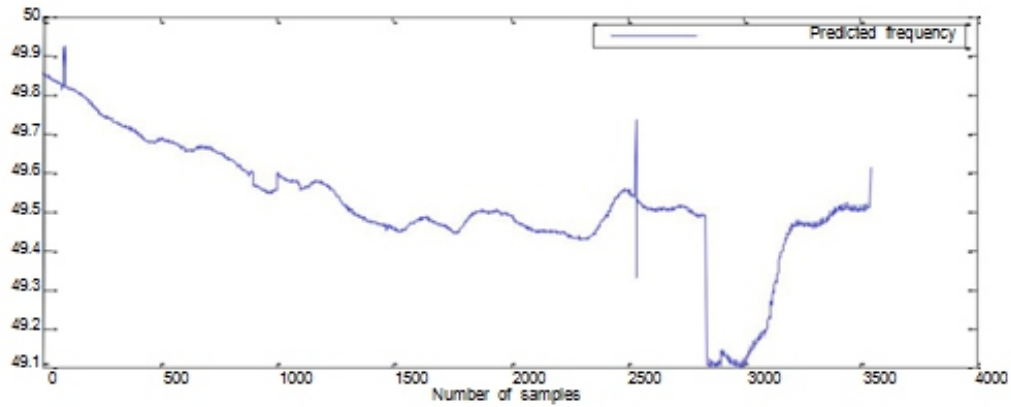


Figure 7: Output Result of the Model

MSE Comparison

The arithmetic in equation 4, was done in MATLAB and was found to be 1.02×10^{-2} while the MSE obtained during model training was 1.38×10^{-5} . Comparatively, it can be seen that the simulation value is closer to zero than the statistical approach. And therefore this validates the result of the work and authenticates the robustness of ANN over the conventional statistical approach.

Comparison between Measured and Predicted Results

Figure 7 indicates the relationship between the actual measurement result and the predicted result, the results shows a good agreement with little disparity which are caused by unpredictable disturbance.

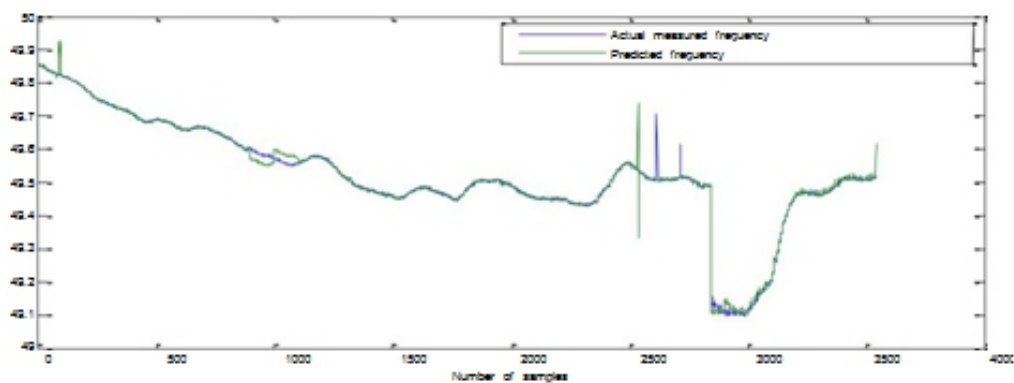


Figure 7: Comparison between Actual and Predicted Frequencies

Conclusion

The development of ANN based frequency prediction model has been presented, with a very good performance measure that will cater for the stochasticity nature of the Nigerian network. The model has been validated using MSE statistical method which substantiate the superiority of ANNs over the conventional method. For further research work, it will be a great achievement if the system interference (noise) is model as the research assumes Gaussian noise.

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