International Journal of Smart Sensor and Adhoc Network

Volume 3 | Issue 2 Article 9

January 2022

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Abstract- Renewable energy sources are becoming more popular, providing a much-needed alternative to traditional, limited, and climate-unfriendly energy sources. Wireless sensors, cloud computing, cyber security, and wide-area monitoring are basic communication and control technologies for smart grid applications. Design of communication and control architectures for the adoption of smart energy grids for rural loads and distributed energy, including energy storage solutions. In this work, a Machine Learning module called scikit-learn is used for pre-processing of labeled input data by using StandardScaler, KFold for cross-validation, and Confusion matrix for measuring performance. Also,the ML technique uses the binary classification method to divide the 'stabf' data into two parts as stable and unstable. Here deep learning-based Artificial Neural Network (ANN) has been used to evaluate the result and to predict new grid data to enhance stability. ANN takes 12 input nodes in the input layer and three hidden layers out of which two hidden layer takes 24 nodes and another one takes 12 nodes and an output layer consisting of a single node. Adam optimizer has been used for model compilation and loss function calculation 'binary_crossentropy' is used. Finally, after successful completion of the evaluation process, this model gives a test accuracy result of 98.33%.

Keywords: Grid Stability, Machine Learning, Deep Learning, Artificial Neural Network.

1 INTRODUCTION

A smart grid is a powerful service that connects digital communications technology to allow for the two-way flow of electricity and data, as well as the detection, response, and avoidance of variations in usage and also other problems. Because system safety is dependent on multidimensional system states, ML approaches to resolve the state explosion problem in safety classification [1]. Smart Grid integrates renewable energy sources, smart transmission, and distribution to provide an efficient and dependable end-to-end intelligent two-way delivery system from source to sink. An electric grid transports the electricity from the source to destination such as households, industries, consumers, or various organizations via power plants and substations where it is generated India has set a target of adding 175 Gigawatt by 2022, including solar, wind, and bioenergy (100 GW Solar, 60 GW wind and 15 GW BioEnergy). These goals apply to power distribution electricity plants along with rural off-grid standalone facilities. Three machine learning models, such as random forest, support vector machine, and artificial neural network, would accurately predict power-grid node synchronization recovery [2]. In India, renewable energy sources like solar and wind power comprise less than 2% of total electricity generation. Renewable energy sources are becoming more popular, providing a much-needed alternative to traditional, limited, and climate-unfriendly energy sources. Smart grid composed of various resources for measuring performances such as:

- Smart meters: It is an electrical device that records data such as electric energy consumption, voltage levels, current, and power factor. Smart meters transmit data to consumers to gain a better knowledge of usage patterns, and also to power suppliers for monitoring the system and customer invoicing. Smart meters often monitor energy at adjacent times and send out reports at regular intervals during the day.
- Smart distribution boards: Smart home automation system configured with a power distribution system that a technique for dividing an electrical power source into subsidiary circuits. This board has a protective fuse or circuit breaker for each circuit in a single container to avoid any overload or short circuit.
- Demand and Response: A modification in an electric utility customer's power consumption to better match the demand for electricity with the supply is known as demand response.
- Renewable energy: It is useful energy obtained from renewable resources that are naturally regenerated on a human timescale, such as carbon-neutral sources (for example sunlight, wind, rain, tides, waves, and geothermal heat).
- Reliable distribution fiber broadband is required to connect, monitor, and backup wireless.

The grid is comprised of several diverse networks, however, there are three major areas: power generation, transmission, and distribution. The below figure 1 describes the process of supplying energy to a consumer over unidirectional flows. End users or consumers get advantages of smart grids technology and also make the ability to produce with supply makes bidirectional. As displayed in above figure 1, Energy has been generated from different sources like Power stations, Solar, and Wind that can pass through a different transmission medium (like as transformers, substations, and towers) to the consumers (like as Home, Industries, Organizations and many more). With consumers worldwide and thousands of generators connected to a power grid, complete human-built models are no longer capable of capturing the entire dynamics of this complex system. For system modeling and prediction, modern machine learning techniques offer a potent alternative [3].To prevent power loss, it is vital to properly distribute electricity to families and companies. Smart Grids can eliminate such power losses in the delivery of electricity. Machine learning and deep learning approaches have been effectively used to improve client demand prediction accuracy [4]. Power quality parameter monitoring, prediction, and optimization are required to keep their variations within the prescribed range, allowing fault-tolerant functioning of various electrical equipment. Complete PQ data for all potential combinations of dozens of grid-connected appliances is not possible to measure. In the genuine off-grid operation mode of systems using ANN, an artificial intelligence (AI) model is essential since induced power is influenced notably by changing weather conditions.

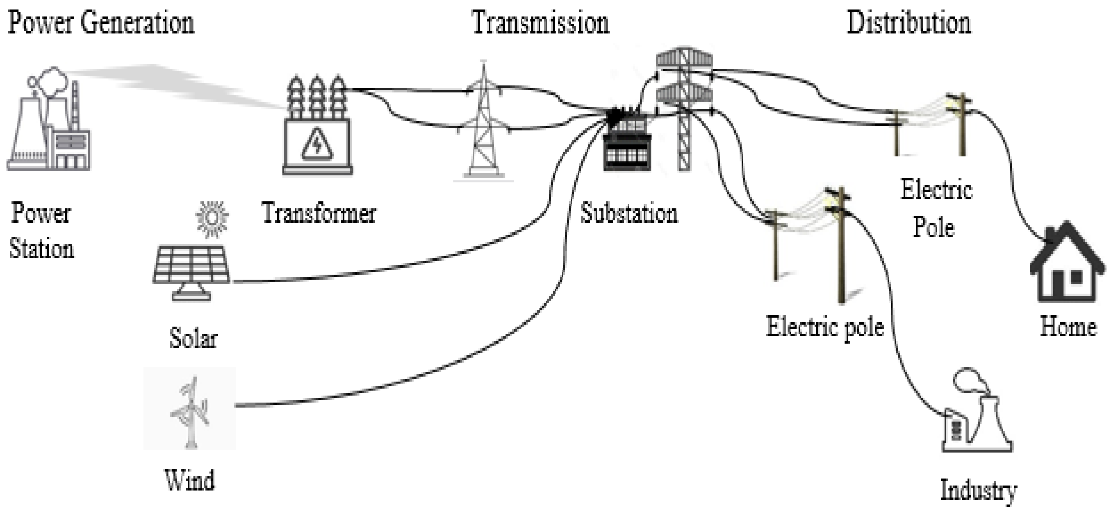

Fig. 1. Smart Grid Design

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2. RELATED WORKS

Quantum TSA (qTSA) is a low-depth, high impressibility quantum neural network that enables scalable and efficient data-driven transient stability prediction for bulk power systems [5]. To transmit warning signals on time, frequency security early warning is required. With the warning signals, proper precautions can be done ahead of time to reduce potential losses. The uncertainty of renewable generation can be handled with a machine learning-based frequency security early warning system [6]. Machine learning methods could be useful in identifying the relationship between unit commitment performance and power system characteristics, revealing the logic behind the relationship, and finally resolving these issues more efficiently and accurately [7]. Companies that generate power using renewable energy sources (RES) will be penalized financially. Unbalanced electricity is toanticipate electricity, the instabilities of RES generation must be taken into account. So, the ANN technique is used to compensate for erroneous forecasts [8].

3. DATASET

This grid dataset has been collected from the UCI Machine Learning Repository that contains 60,000 observations [9]. Although it contains 12 primary features and two dependent variables.

3.1 Primary features:

- 'tau1' to 'tau4': the response time of every network participant, expressed as a value between 0.5 and 10 ('tau1' refers to the supplier node, 'tau2' to 'tau4' to the consumer nodes).
- 'p1' to 'p4': each network participant's nominal power produced (positive) or consumed (negative), with a value ranging from -2.0 to -0.5 for consumers ('p2' to 'p4').

- 'g1' to 'g4': the changes in price coefficient is assigned to each network member and has a real value between 0.05 and 1.00 ('g1' corresponds to the supplier node, 'g2' through 'g4' to the consumer nodes; where 'g' stands for 'gamma').

3.2 Dependent variables:

Here stab and stabf are used as two dependent variables. If the system is linearly unstable then stab gives a positive result otherwise gives a negative result. But stabf is the categorical value i.e. either stable or unstable. It specifies that if stab <= 0, then stabf will be stable otherwise unstable as specified in this dataset. This dataset has been implemented in Jupyter by using python programming where 'stable' is replaced with '1' and 'unstable' is replaced with '0'.

4. BACKGROUND STUDY

A successful Smart grid implementation requires proper utilization of renewable resources, electric grids by applying recent technologies such as Machine Learning and Deep Learning. Machine learning (ML)-based virtual inertia (VI) syncretization in synchronverter topology for high-frequency stability integration of the solar PV system and the power grid. To decouple active and reactive power regulation, the ML-based VI is synthesized by combining the action and critic networks [10]. However, in these days deep learning-based Artificial Neural Network (ANN) is used for feature extraction [11].

4.1 Machine Learning (ML)

The constant growth of computational technologies in ML, particularly in data management and analysis enables the implementation of numerous machine learning techniques in smart grid applications. The process in ML technique includes collecting the input data, cleaning this data, training the model, measuring the performance, and finally deploying that model in real-time applications. Machine Learning-based scikit-learn is used for data prediction that has built-in libraries such as NumPy, SciPy, and matplotlib. Although this can be used for classification, regression, and clustering problems. Machine learning helps in reducing the number of variables, feature extraction, improved accuracy, and many more. Ml algorithms make it easier to analyze data and make informed decisions about how to run the grid. It fits the smart grid system, which is based on data collecting, analysis, and decision-making. Machine learning would detect attacks, initiate appropriate measures to resolve known vulnerabilities, and alert systems engineers. ML can able to, (a) prepare for and avoid power grid outages, (b) avoid Brownouts by using real-time analysis and AI prediction, (c) detect a fault in the electricity grid, (d)make the grid symmetric, (e) identify outages between the power system and security and also (f) detect the theft of electricity.

4.2 Deep Learning

The word "deep" in deep learning refers to the usage of multiple network layers. Deep learning is mostly used for the feature extraction of non-linear images or videos [12]. Topological Convolutional Networks (TCNN) is a modern deep learning framework designed primarily to model the underlying architecture of power grids and efficiently extract information [13]. The multiple hidden layers used in deep learning methodology provide a more accurate and effective result as compared to the ML algorithm. The power system's simulation model, which is based on a deep learning algorithm, can detect faults and perform detailed fault analysis, allowing the power grid to reduce losses more quickly [14]. For the Smart grid stability measure, in this article, Deep Learning based Artificial Neural Network is used for extracting features to get better accuracy results.

5. METHODOLOGY

Due to the application of AI techniques for load prediction, power grid stability assessment, fault detection, and security challenges in the smart grid and power system, Artificial Intelligence (AI) approach in the smart grid is becoming increasingly important [15]. Three machine learning libraries such as StandardScaler, confusion matrix for measuring performance, and KFold for cross-validation are used for manipulating operation and graphics development [16]. Also, two Keras objects such as sequential and dense layers are used. Analysis of electric data, new methods such as ML, fuzzy logic, data mining, ANN, Support Vector Machine (SVM), and genetic algorithm are used. Among all in this article, the combination of both ML and ANN methodologies achieve better results while estimating the exact electricity demand and predicting both energy production and consumption.

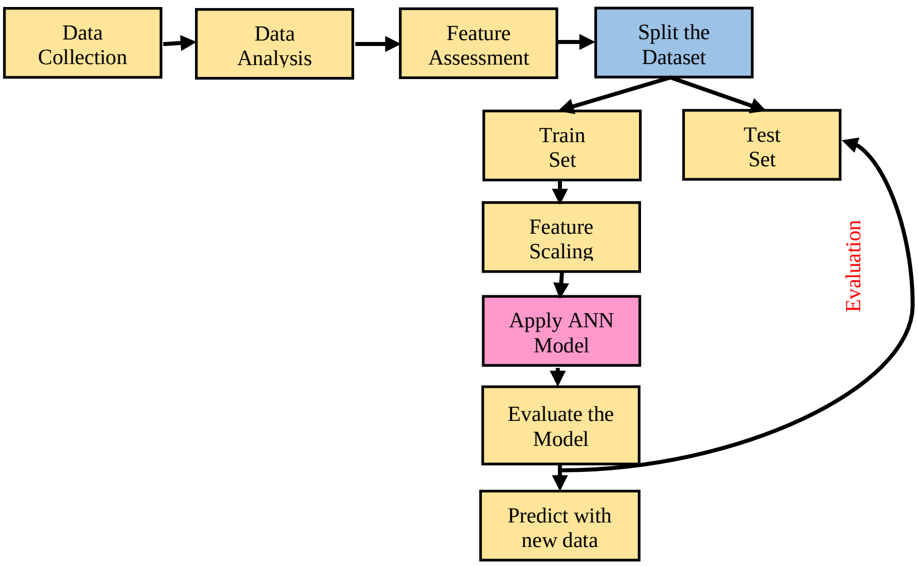

Fig. 2. Process and Evaluation of Electric Grid data

The above figure 2 represents the process of electric grid data using ML techniques and also evaluating the test result by applying the ANN model. The collection of labeled input data goes for the data analysis by applying scikit-learn libraries. In this period the independent variables are mapped to an augmented dataset having 60,000 observations i.e. ‘stable’ is replaced with ‘1’ and ‘unstable’ is replaced with ‘0’. After that in feature assessment, for every of the 12 dataset features, the distribution patterns and connection with the 'stab' dependent variable are plotted. Here also the correlation between the dependent variable ('stabf') and the 12 numerical features are plotted. This dataset has split by using ML algorithm into a training set and test set; where the first 54,000 observations will go for training and the remaining 6,000 will go for testing.

5.1 ANN*:* ANN is the collection of neurons connected with neural networks like the human brain. It has trained to change the input values through a non-linear function known as activation function based on environmental conditions. Kalogirou proposed an Artificial Neural Network (ANN) model that predicts the energy consumptions occurred in buildings as well as able tomanage the renewable sources [17]. An artificial neuron receives a signal, analyses it, which is a real number, and each neuron's output is generated by some non-linear function of the sum of its inputs [18]. The connections are known as edges. The weight of neurons and edges typically changes as learning progresses. The Nigerian 330kv transmission network's consistency instability is handled by introducing greater voltage stability utilizing an ANN controller [19].

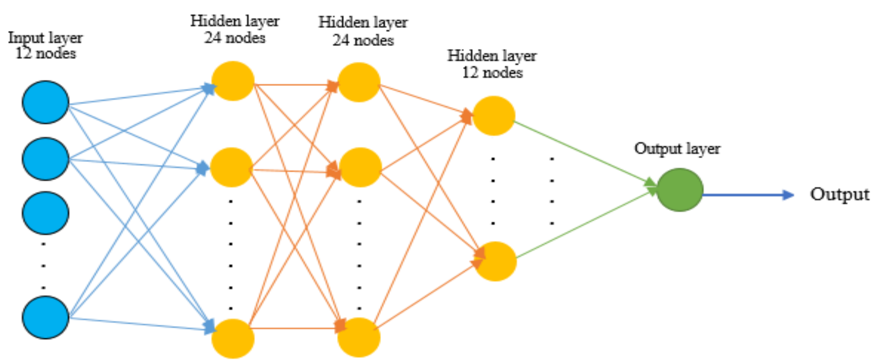

Fig. 3. ANN Model’s Architecture

Above figure 3 shows the architectural view of the ANN model where every circular node represents an artificial neuron, and each arrow represents a connection between the outputs of one artificial neuron and the inputs of another. Also, there has been one input layer consisting of 12 nodes, three hidden layers (i.e. 24, 24, and 12 nodes respectively), and one out a layer having one single node. The rectified linear activation function or ‘ReLU’ is used will output the input directly if it is positive, otherwise, it will output zero. ReLU has been used in each hidden layer as a classifier to get better performance results. Here binary classification is done i.e. '0' for 'unstable', '1' for 'stable'. Finally input to output layer from the connected hidden layer, the sigmoid activation function is used for handling non-linear separable data. Although ANN algorithm use ‘ADAM’ optimizer method especially for computer vision that has individual learning rates for different parameters using gradient descent method. An Artificial Neural Network (ANN) is used to create an effective and reliable controller for solar Photovoltaic (PV) based decentralized energy units for regulating the grid-connected Micro-Grid (MG) during load fluctuations and irradiance variations [20].

5.2 Model Fitting and evaluation: This training and test split data have fitted within the ANN model for finding results. This result has fed into the test set for measuring the accuracy. Although this result will go for the prediction of new data. The KFold classifier has trained with 5400 training sets of data and evaluates 10 rounds within a few minutes as shown in figure 4. ANN has proved a good model for predicting power grid stability. A cross-validation technique of ML algorithm called KFold engine has been selected with 50 epochs. This model shuffles with training and test dataset with 10 different validation sets.

```
Model evaluation

169/169 [==============================] - 0s 950us/step - loss: 0.0746 - accuracy: 0.9706
Round 1 - Loss: 0.0746 | Accuracy: 97.06 %
169/169 [==============================] - 0s 878us/step - loss: 0.0544 - accuracy: 0.9774
Round 2 - Loss: 0.0544 | Accuracy: 97.74 %
169/169 [==============================] - 0s 1ms/step - loss: 0.0576 - accuracy: 0.9774
Round 3 - Loss: 0.0576 | Accuracy: 97.74 %
169/169 [==============================] - 0s 1ms/step - loss: 0.0431 - accuracy: 0.9830
Round 4 - Loss: 0.0431 | Accuracy: 98.30 %
169/169 [==============================] - 0s 971us/step - loss: 0.0360 - accuracy: 0.9844
Round 5 - Loss: 0.0360 | Accuracy: 98.44 %
169/169 [==============================] - 0s 925us/step - loss: 0.0444 - accuracy: 0.9824
Round 6 - Loss: 0.0444 | Accuracy: 98.24 %
169/169 [==============================] - 0s 785us/step - loss: 0.0363 - accuracy: 0.9844
Round 7 - Loss: 0.0363 | Accuracy: 98.44 %
169/169 [==============================] - 0s 718us/step - loss: 0.0503 - accuracy: 0.9815
Round 8 - Loss: 0.0503 | Accuracy: 98.15 %
169/169 [==============================] - 0s 785us/step - loss: 0.0277 - accuracy: 0.9896
Round 9 - Loss: 0.0277 | Accuracy: 98.96 %
169/169 [==============================] - 0s 773us/step - loss: 0.0296 - accuracy: 0.9889
Round 10 - Loss: 0.0296 | Accuracy: 98.89 %
```

Fig. 4. Model's Accuracy result

6. PERFORMANCE MEASURE

The best way to measure the performance of the model is by applying a confusionmatrix. Building a confusion matrix can help us understand what our classification model gets right and what types of errors it makes. Every row in this matrix is represented as an actual class whereas each column represents a predicted class. Some of the measure performances used in the confusion matrix are Precision, Recall, and F1Score as defined in equation 1,2 and 3 respectively..

- Precision: When the cost of false positives is high, precision has used.

$$Precision = (TP) / (TP+FP) \tag{1}$$

- Recall: It defines the true positive rate

$$Recall = (TP) / (TP+FN) \tag{2}$$

- F1-Score: It is defined as the arithmetic mean of precision and recall.

$$F1\text{-}Score = 2*(Recall*Precision) / (Recall + Precision) \tag{3}$$

- Accuracy: It is the ratio of correct predictions to total predictions made.

$$Accuracy= (TN+TP) / (TN+FP+FN+TP) \tag{4}$$

Here, TP represents the number of true positives, FP is the number of false positives, FN is the number of false negatives, and TN is the number of true negatives.

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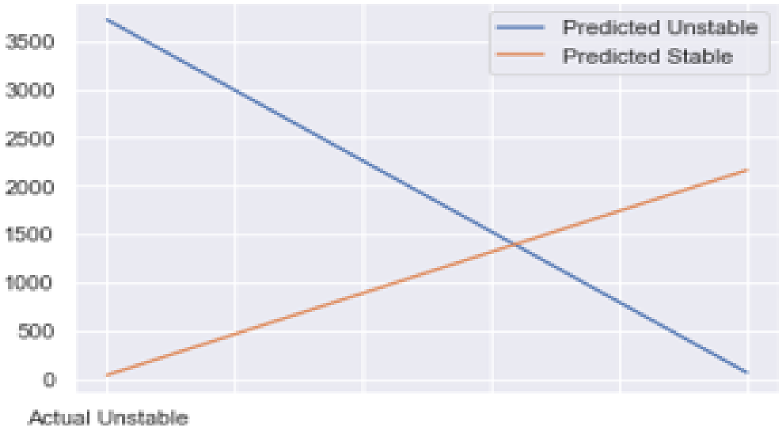

Fig. 5. Representation of Stable and Unstable data

The above figure 5 displays the segregation of confusion-matrix where predictable unstable is represented with a blue color straight line and predictable stable represents with an orange straight line. Although, the confusion_matrix gives the accuracy of 98.10 percent after using ANN techniques while predicting grid stability that has displayed in the below figure 6.

```
In [16]: print(f'Accuracy per the confusion matrix:

         Accuracy per the confusion matrix: 98.10%
```

Fig. 6. Accuracy results in the Confusion matrix

7. RESULTS AND DISCUSSION

It has proven that this deep learning-based ANN model would be able to predict the smart grid stability in real-time scenarios. The high accuracy obtained from the test set (i.e. 98.10 percent) confirms that this model can fulfill our requirements. However, more numbers epochs would be applied for fitting this model that can better predict accuracy. ML algorithms use an augmented dataset with 6000 observations; out of which 5400 are used for the training set and the remaining are for the testing set. After fitting the model to the training set, make predictions for the testing set that considers the 'threshold' of 0.5 (i.e. 'unstable' cases <= threshold whereas 'stable' cases > threshold).

8. CONCLUSION AND FUTURE SCOPE

Smart grids include increased quality and effectiveness of electricity supply, the integration of more renewable energy into existing networks, use of large-scale development in electric vehicles, reduced carbon emissions, and providing new alternatives for customers to optimize their electricity consumption. In this article, the grid dataset has been taken from the UCI Machine Learning dataset with having 12 features and 2 dependent variables where 5400 observations are used for training and the last 600 are used for testing. ML enables binary classification of trained data into two parts such as ‘stable’ (represented as ‘1’) and ‘unstable’ (represented as ‘0’). Also, ANN has made completely successful for the evaluation of test data and provides an accuracy of 98.89% by taking 50 epochs. This model can perform by using a new electric grid test data with observations obtained from simulations. Pumped hydro is the only cost-effective solution for grid-scale energy storage at this moment. In addition to capacity, constrained due to environmental issues with water storage reservoirs, the requirement of other cost-effective energy storage technologies is much needed in the future. Therefore, the country would face issues on future energy infrastructure when using large-scale renewable integration such as (a) Controlling Ambiguity, (b) energy storage, and(c) Demand response.

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