IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Vol. 8, Issue 12, December 2021

DOI: 10.17148/IARJSET.2021.81250

ARTIFICIAL NEURAL NETWORK-BASED POWER SYSTEM RESTORATION

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Abstract - Power system restoration is a common technique used in the restoration of power by power companies. This involves laid down procedures which the system operator must follow. Due to the challenges encountered during power restoration process, the use of computer aided systems which create the power system restoration plan has become necessary. This research focuses on the use of artificial neural network in power system restoration. It throws more light on artificial neural network, the various types of artificial neural network, learning methods, its structure, strengths and its application in power system restoration. The artificial neural network develops the power system restoration plan used by the system operator for power restoration. This paper discussed majorly the Island restoration scheme which is most applicable when dealing with large transmission networks and works effectively with artificial neural network.

Key words: Power system; restoration; Island restoration scheme; artificial neural network; computer aided systems

1. INTRODUCTION

In today's world, having constant supply of electricity is critical, so adequate steps are taken to safeguard power system equipment and ensure power supply continuity. The continuity of power supply is disrupted when there is power outage. This has far-reaching implications for commerce, industry, and our daily lives. Power utility companies have taken drastic measures to mitigate the social and economic costs of blackouts. These activities include instructions and procedures that serve as a reference for the operator when restoring control. These protocols and procedures are inefficient and time consuming, necessitating the adoption of a more efficient and consistent method (Electrical Equipment, n.d.). In addition, because of the energy demand and the expansion of existing power transmission networks and lines, most of the recent power systems are operating at near-capacity. As a result, the state of the power systems must be constantly controlled in a far more comprehensive manner than was required resulting in less conservative power system function and control operation. With the advent of smart computer tools complex power problems that originate from the area of power system planning, diagnosis, operation and network can be solved easily (Nath and Balaji, 2014). One of such tool is the artificial neural network system. Hundreds of models have been created and classified as artificial neural networks, but what distinguishes them may be the functions, topology, agreed values, or learning algorithms (Gershenson, 2012)

2. NEURAL NETWORK

To understand the concept of artificial neural network, let us look at the definition of neural network. A neural network is an interconnected assembly of simple processing elements, units or nodes, whose functionality is loosely based on the animal neuron. The processing ability of the network is stored in the inter unit connection strengths, or weights, obtained by a process of adaptation to, or learning from, a set of training patterns (Gurney, 2004). It tries to mimic the natural operations of the human brain. The neural network tends to use this architecture, structure and style of processing. The nodes or units are the artificial counterparts of biological neurons. Synapses are represented by a single number or weight, so that each input is multiplied by a weight just before being sent to the cell body's equivalent. To provide a node activation, the weighted signals are added together using simple arithmetic addition (Gurney, 2004). Gershenson (Gershenson, 2012), noted that the nodes can be thought of as computing units. They take in data and process it to create an output. This processing might be basic (such as summing the inputs) or complicated (a node might contain another network). The information flow between nodes is determined by the connections. They might be unidirectional (information flows just in one direction) or bidirectional (information flows in both directions). The interactions of nodes through connections result in a network's global behavior, which is not visible in the network's elements. This global behavior is referred to as emergent behavior. This indicates that the network's capabilities outweigh those of its constituents, making networks an extremely effective tool (Gershenson, 2012). According to (Frankenfield, 2020). an artificial neural network generally contains a huge number of processors functioning in parallel and organized in tiers. The raw input data is collected by the first tier which processes it to an output which is received by a succeeding tier linked to it until the last tier creates the final data of the system. Each node has its own share of intelligence, including what it has seen and any rule it was originally designed with. One of the most remarkable attribute of artificial neural networks is that they can adapt to changes in a system. This means that they remodel themselves as they learn from the

IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Vol. 8, Issue 12, December 2021

DOI: 10.17148/IARJSET.2021.81250

earliest training and later provide more information. The most elementary learning model is focused on weighing the input sources, and as a result, each node weighs the significance of input information from each. The advantages of artificial neural network include (Burns and Burke, 2020):

a. It has parallel processing capabilities and can handle several tasks at once.
b. It not only stores information in a database, but also through a network.
c. It has the potential to form its own organization while studying.
d. It has the ability to tolerate error, so one or more defective cells will not prevent it from generating an output.
e. The artificial neural network can make decisions based on its observations after learning from events.
f. Instead of a problem causing immediate network harm, the network would gradually deteriorate over time.

A. Types of Artificial Neural Network

Various types of neural networks exist. These networks may be categorized according to their structure, information flow, density, neurons used, the level of triggering filters and their layers. They include the following (Burns and Burke, 2020 and Great Learning Team, 2020) ;

a. Perceptron Neural Network: this is the easiest and oldest models of neurons. It identifies specific attributes in the input data. It is the smallest unit of neural network. As weighted inputs are accepted, it uses the activation function to receive the output as the last result.

b. Feed Forward Neural Network: This is the simplest type of neural network and input data flows only in one direction. The input data flows through artificial neural network input nodes and exit via output nodes. Hidden node layers may or may not be present in this type of network, making their operation more interpretable.

c. Multilayer Perceptron Neural Network: This is a complex type of neural network. Input data moves via different layers of artificial neurons. It is a fully connected network because every single node is attached to all neurons in the next layer. Both input and output layers are present and having multiple hidden layers.

d. Convolution Neural Network: This is one of the most used neural networks today. It is made up of a three-dimensional configuration of neurons, as against the standard two-dimensional group. The first layer consists of the convolution layer. In the convolutional layer, data is only processed from a small portion of the visual field in each neuron, and the attributes related to the inputs are obtained batch-wise, similar to a filter.

e. De-convolutional Neural Network: This neural network uses a reversed convolutional neural network operation. The purpose of this is to find lost signals that initially may have been regarded not important to the convolutional neural network systems duty.

f. Recurrent Neural Network: This is a more complicated network. The output processed by the nodes is saved and then the result is reintroduced into the model. The recurrent neural network masters how to forecast the output of a layer by doing this. The nodes in the recurrent neural network model behave as a memory cell, continuing the calculation and execution of operations. The initial layer is made up of a feed forward neural network and then followed by a recurrent neural network.

g. Modular Neural Network: It is made up of many neural networks functioning differently from each other. During the computation process, the networks do not interact with each other's tasks during the calculation process. They work separately in achieving the output and as a result of this a large and complex calculation is done faster by breaking it down into individual components.

B. Learning Paradigms in Artificial Neural Network

The learning attribute is one of the most exceptional features of the artificial neural network. It involves altering the networks' weight with a learning algorithm. The idea behind this, is to discover a set of weight mix which when used in the network, will be able to match a correct output with any given input (Jacobson, 2014). There are basically three major learning paradigms used in artificial neural network:

a. **Supervised Learning**: It is the first and the easiest of the learning paradigms. Here, a clear and defined objective is given which is to forecast the outcome of an event using the data provided. This method is applied in solving problems involving regression or classification. The data points will have tags which provide information on the correct answer to the question proposed when using the supervised learning method. The data is split into testing data, which are grouped into hidden and learning data which is then used in training the model. By doing this, the neural network is allowed to have an answer key to the questions it asks of the training data. The model will then look for the most reliable manner to use the data to pair that answer key. We can then examine how nicely neural network performs on real-world data by permitting it to see the unseen test data and make predictions on it. This is how it learns and makes predictions. It collects the data that it has answer to, masters how to best get the right solution from this data and afterwards, applies that identical technique when it is given new data. It does not usually learn from this new data, it simply makes a prediction [9].

b. **Unsupervised Learning:** This is the second learning paradigms. Here, a set of inputs are given to the neural network and it's the duty of the neural network to discover any form of format within the inputs provided without depending on any form of assistance. The idea behind this, is to find patterns and trends inside a dataset and then apply them to predict new data (Jacobson, 2014).

c. **Reinforcement Learning**: This learning style differs from the other two in that it has a specific goal in mind that it is pushing the machine to achieve. When a specific outcome is expected, the machine selects and learns the best path to achieve it. This is accomplished by rewarding and punishing the machine based on its performance, which culminates in a long term end-goal. Only when the machine achieves a new state does it receive reward and punishment signals. This learning paradigm does not include instant feedback (Leung, 2019).

C. Artificial Neural Network Architecture

The architecture of artificial neural network comprises of the following (Kukreja et al, 2016);

a. Input Layer: This layer receives the input data or signal. The number of inputs to the neural network conforms to the number of neurons in this layer. Passive nodes are in this layer. These nodes only send the signal to the next layer and are not involved in the actual signal change.

b. Hidden Layer: this layer is in between the input layers and output layers. In this layer, the artificial neurons generate an output via an activation function by using a set of weighted inputs. They can be single or multiple layers and the nodes in this area are active.

c. Output Layer: Produces the final result which ranges from 0 to 1. It has active nodes and the amount of the output results of the neural network gives the number of neurons in the output layer

3. POWER SYSTEM RESTORATION

After a fault has been isolated, restoration is an important part of advanced distribution automation (ADA), which aims to repair non-faulted and out-of-date sections of a system. The restoration problem is a combinatorial problem that aims to maximize power supply to as many customers as possible while satisfying source, line/cable loading, and radial network constraints (Kumar, 2021) Power system restoration schemes are pre-established restoration schemes or procedures used to restore or recover the power system network to its steady-state operation. These pre-determined procedures are carried out based on certain assumptions about the power system's circumstances following a power outage. This, combined with the highly stressed conditions experienced following the power outage, could render these pre-determined restoration plans and procedures invalid. In other words, it lowers the practice's success rate. The key explanation for the low success rate is that the power systems assumed conditions when the restoration plan was established, differ significantly from the actual situation (Alsenani, 2020) Power system restoration is technically difficult and time-consuming. Meanwhile, losses to customers and the industry are fast increasing. The system bears many economic and political costs if this phase drags on, so quick and successful restoration is critical (Kumar, 2021) The restoration goals are to allow the power system to return to normal conditions in a safe and timely manner, to minimize damages and restoration time, and to reduce negative impacts on society (Liu et al, 2016).

A variety of new restoration methods have been proposed as alternatives to these widely used restoration procedures in recent years. Although the implementation details of these techniques differ, three key concepts for power system restoration (PSR) have been suggested by (Bretas and Phadke, 2003) and (ElectricalEquipment, n.d.) which are:

a. Automated Restoration: computer programs are used for the development and implementation of the PSR. It uses this computer programs to obtain system data from the supervisory control and data acquisition system (SCADA) and the energy management system (EMS). A PSR program placed in the EMS system will use the obtained system data to construct a transmission system restoration plan in the event of a wide area disturbance. Following the creation of the restoration plan, a switching sequence program, which is also part of the EMS, will be in charge of transmitting control signals through SCADA to circuit breakers and switches in order to put the plan into action. The machine operator takes on the part of a supervisor in this technique.

b. **Computer aided restoration:** In this technique, the PSR plan development and implementation is performed by the system operator. The PSR techniques that use this principle also acquire system data from the local SCADA/EMS. Following a wide area disturbance, the system operator uses power system data provided by the SCADA/EMS to develop a PSR plan. The system operator can use the PSR procedures and power system analysis programs as aids to develop the restoration plan. The system operator will also use the local SCADA/EMS to transmit control commands to circuit breakers and switches in order to implement the chosen PSR plan.

c. **Cooperative Restoration:** In this technique, following a blackout, a computer program installed at the EMS proposes a PSR plan. The system operator is in charge of putting the PSR strategy into action. Power system data collected from local SCADA/EMS is also used by PSR systems that use this technique. The PSR software installed in the EMS will use the system data to create a restoration plan when the power system experiences a wide-area disturbance. The system operator can implement the restoration plan by sending controlling signals to circuit breakers and switches via local SCADA/EMS. Rule-based expert systems and mathematical programming approaches have yielded excellent results. The time it takes to find a restoration plan is a major drawback of these techniques and in large transmission systems, rule-based techniques can take several minutes to find the plan, owing to the fact that the number of rules is

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proportional to the system size. Similar output characteristics can be found in the mathematical programming method. This method considers the system to be in a state space where it is necessary to perform a search in order to find the restored system's final configuration. A vector containing the breaker status represents the device configuration. This final system configuration can be found using a variety of search strategies. There have been tests of heuristic search algorithms, as well as breadth-first and depth-first algorithms. A load flow program is required after determining a viable system configuration to ensure that the final restoration configuration is operationally feasible. When applied to a broad transmission system, this process can take a long time. Critical issues in PSR estimation are the necessary computation time and the ability to find restoration plans under unforeseen fault conditions (Bretas and Phadke, 2003).

4. Artificial Neural Network Based Power System Restoration

In order to perform the power system restoration with better accuracy and more efficiency, artificial neural network is going to be used. The intended restoration scheme to be used is made up of a number of island restoration schemes (IRS) (Tortos and Terzija, 2012). Splitting techniques are used to break the power system into smaller subsystems, also known as islands, when the integrity of the system can no longer be preserved. This is typically done to construct stable islands with the least amount of load generation imbalance possible while maintaining generator coherences and other static and dynamic limitations (Tortos and Terzija, 2012). The work in [16] explained that, following a widespread power outage, the region is divided into small islands, each of which recovers on its own. Based on offline studies and load-generation balance, the number of islands is predetermined. For parallel restoration of large transmission systems, this is a very quick and efficient process.

The island restoration scheme employs an all open switching technique, in which all of the system's circuit breakers are open. To restore power, each IRS will create local restoration plans that include local circuit breaker switching sequences and restoration load forecasts. To generate, switching sequence and forecast load each IRS is composed of two artificial neural networks and a switching sequence program (SSP), which determines the energizing sequence of transmission paths (Rupak, 2015). An island restoration load forecast is the responsibility of the first artificial neural network of each IRS. The pre-disturbance load will be the input to this artificial neural network, which will be a normalized vector. The final island configuration and the corresponding forecast restoration load pick up percentage that will produce a feasible operating condition are determined by the second artificial neural network of each island restoration scheme.

This artificial neural networks input will be a normalized vector consisting of the forecast island restoration load supplied by the respective island restoration scheme's first artificial neural network and three elements illustrating possible unavailable transmission paths (due to outages) for use in the restoration plan (Bretas and Phadke, 2003) . According to (Bretas and Phadke, 2003) the switching sequence program is the final component of each IRS. The switching sequence program will specify the transmission path energizing sequence that will lead to the final configuration selected by the second artificial neural network. The switching sequence program input vector is made up of the island restoration scheme's second artificial neural networks final restoration island configuration and an energizing sequence database. Each island restoration scheme's energizing sequence database contains transmission path sequences that bind island generators to island loads.

Following the occurrence of a wide-area disruption, the proposed restoration scheme would present a restoration plan to the EMS operator. Before the plan can be enforced, the power system operator must use EMS/SCADA or regional control centers to execute the all-open switch strategy. The proposed scheme's restoration plan would include energizing sequences and restoration load percentage pick-up values for all islands. The machine operator will be responsible for closing the tie-lines as the final phase of the complete restoration. When all of the islands have been restored and are in a stable state, the tie-lines should be closed (Bretas and Phadke, 2003). Certain organizational limitations must be considered in order to create a practicable restoration plan that can be used as a training pattern by the island restoration schemes. Some of the restrictions considered are transmission line thermal limits, stability limits, the number of lines used in the reconstruction plan, permissible over and under voltages, and identification of locked-out circuit breakers. Once these limitations have be considered, the training of the artificial neural network can commence using a software. A training and a validation set will be created for each artificial neural network which will now be used to test its efficiency.

5. CONCLUSION

Power system restoration is an area that is gaining popularity. Since artificial intelligence has the ability to generalize and process data quickly, many techniques based on it have been proposed to enhance power system restoration. Instead of using predefined operating procedures for restoration, these methods suggest using the machine as an operator aid. From the review, Island Restoration Scheme is one of the most effective power restoration schemes especially when dealing with large networks

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DOI: 10.17148/IARJSET.2021.81250

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