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Comparison of PI and Artificial Neural Network Controller Based DVR for Compensation of Voltage Sag

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ABSTRACT

With the advent of power electronic devices, the issue of power quality has become a primary concern in today's power systems. The performance of sensitive loads is greatly affected by the inadequate power quality. The Dynamic Voltage Restorer (DVR) is a custom power device that serves as an efficient solution for safeguarding sensitive loads against voltage disturbances within power distribution systems. The efficiency of the Dynamic Voltage Restorer (DVR) depends on the effectiveness of the control technique employed to manage the switching of the inverters. The Proportional-Integral (PI) control is a commonly used technique for managing the switching of inverters in order to achieve efficient operation of the Dynamic Voltage Restorer (DVR). The application of the linear Proportional-Integral (PI) control technique to control a non-linear Dynamic Voltage Restorer (DVR) has limitations in terms of power quality restoration capabilities and leads to the generation of significant harmonics. In this paper a reliable and effective adaptive neural network based controller is used for enhancing restoration operation and harmonic suppression capabilities of DVR. Furthermore, the comparative analysis between PI controller and ANN based controller is also presented. The results of the analysis demonstrate that the ANN based DVR exhibits superior performance compared to the PI-based controller.

Keywords : Power quality, Dynamic voltage restorer, Proportional Integral, Artificial Neural Network(ANN)

I. INTRODUCTION

Modern electrical power systems are intricate networks that comprise hundreds of power generation stations and thousands of load centres, which are linked together via long power transmission and distribution networks. The widespread use of advanced electrical and electronic equipment, such as computers, programmable logic controllers, and variable speed drives, has made distribution systems highly sensitive to disturbances and non-linear loads, leading to various power quality problems like voltage sags, swells, and harmonics, and loss of sine waveform purity. Among the various power quality disturbances, voltage sags are regarded as one of the most significant. These voltage sags occur due to faults in transmission and distribution systems, the energizing of transformers, and the starting of large induction motors. Inadequate power quality can have substantial financial and operational consequences, including equipment damage and failure. These issues can result in costly repairs or replacements.

While there are several approaches available to mitigate voltage sags and swells, the utilization of a custom power device is widely recognized as the most efficient method. This paper introduces the design and implementation of a high-performance Dynamic Voltage Restorer (DVR) that utilizes an Artificial Neural Network (ANN) control strategy. At the end, the comparative analysis of PI and ANN based controller is made.

An Artificial Neural Network (ANN) is a computational model inspired by the biological neural networks found in the human brain. It is a network of interconnected nodes, known as artificial neurons or "nodes," that work together to process and transmit information. Each node takes input signals, applies a mathematical function to them, and produces an output signal that is passed to other nodes in the network. ANNs are typically organized into layers, consisting of an input layer, one or more hidden layers, and an output layer. The connections between nodes have associated weights that determine the strength or importance of the connection. During the training process, these weights are adjusted to optimize the network's performance on a specific task.

To effectively utilize ANNs for a specific task, they must undergo training using data that is relevant to the intended purpose. In this scenario, the ANN is trained using fault data and the corresponding measures needed to mitigate those instabilities. The adaptive nature of this ANN approach ensures its robustness, as it can be trained to handle all possible fault cases.

The organization of this document is as follows. In Section II, the theoretical background and Simulink model of proposed ANN controller used for mitigation of voltage sag is presented. Section III demonstrates the simulation results: which shows the DVR performance for three phase sag mitigation and compares the proposed method with PI controller. Finally, the conclusion is drawn in Section IV.

II. METHODS AND MATERIAL

The nonlinear controller is considered more appropriate for DVR due to the presence of power semiconductor switches in the inverter bridge, making it a truly nonlinear system. Commonly used nonlinear control techniques include Artificial Neural Network (ANN), Fuzzy Logic (FL), and Space Vector Pulse Width Modulation (SVPWM). Among these, the ANN control method is selected for the proposed system as it possesses adaptive and self-organizational capabilities. Furthermore, it offers inherent learning capability, enabling improved precision through interpolation. By choosing ANN, the limitations of the linear PI method can be overcome.

ARTIFICIAL NEURAL NETWORK

An Artificial Neural Network (ANN) is a computational model designed to emulate the behaviour of a biological neural network. It consists of interconnected nodes, referred to as artificial neurons or units, organized in layers. Each neuron receives input signals, processes them through a computation, and generates an output signal. These output signals are then transmitted to other neurons within the network. The connections between neurons in an ANN are established with associated weights that represent the strength of the connection. These weights undergo adjustment during a process known as training or learning. During training, the network is exposed to a set of input-output examples to acquire knowledge about patterns and relationships within the data.

By learning from the data, ANNs have the ability to make predictions or decisions based on the acquired knowledge. They can analyze input information, process it through the network's learned connections and computations, and produce an output that corresponds to the task or problem at hand. Output of the network can be calculated as follows:

Output of the node of hidden layer is given by:

$y_j = f(\sum_i w_{ji} x_i - \theta_j) - f(net_j)$

where, $netj = \Sigma_i w_{ji} x_i - \theta_j$

Computational output of the output node:

$Z_l = f(\Sigma_i v_{lj} y_j - \theta_l) = f(net_l)$

where, $net_j = \Sigma_{i\ lj}\, y_j - \theta_l$

Error of the output node:

$E = 1/2\, \Sigma_l (t_l - z_l)^2 = 1/2\, \Sigma_l (t_l - f(\Sigma_i v_{lj} y_j - \theta_l))^2$

Hypothesis:

$h\theta(x) = \theta^T x = \Sigma^n_{i=0} \theta_i x_i$

Gradient update:

$\theta_j := \theta_j - \alpha\, 1/r\ \Sigma^r_{j=1} (h_\theta(x^{(i)}) - y^{(i)}) xj^{(i)}$

where, x_i= input node, y_j = node of the hidden layer, z_l = node of output layer, w_{ji} = weight value of network between the input node and node of hidden layer, v_{lj} = weight value of network between the nodes of hidden layer and output layer, t_l = expected value of the output node, α = learning rate, r = total sample, θ = weight.

This research utilizes an advanced controller that is built upon a multilayer backpropagation artificial neural network (ANN) to improve the performance of the compensating device. The ANN is trained using the Matlab toolbox, employing the LM backpropagation method as the training algorithm for the ANN controller. To optimize the training process, the Gradient Descent (GD) method is employed, which is a first-order optimization technique used to locate local minima of functions.

The main goal of the ANN controller is to reduce errors. The ANN controller's output produces modulation signals that are used to generate pulses for the Insulated Gate Bipolar Transistor (IGBT). These output signals are obtained through the dq0-to-abc transformation. Figure 1 illustrates the overall structure of the multi-layer feed-forward neural network, showing how the layers are organized within the ANN training block.

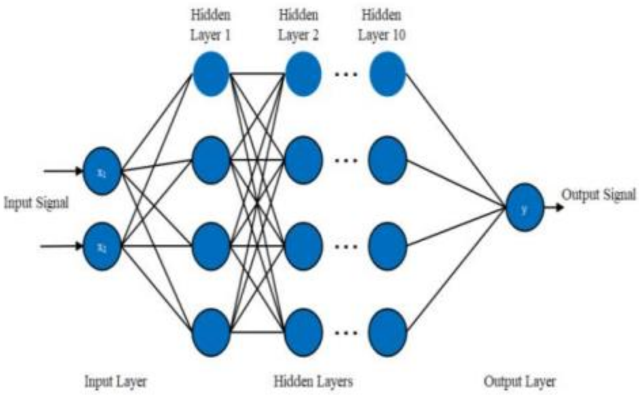

Fig.1 Multi-layer feedforward structure

The control circuit with ANN controller used in Dynamic voltage restorer is depicted in fig.2.

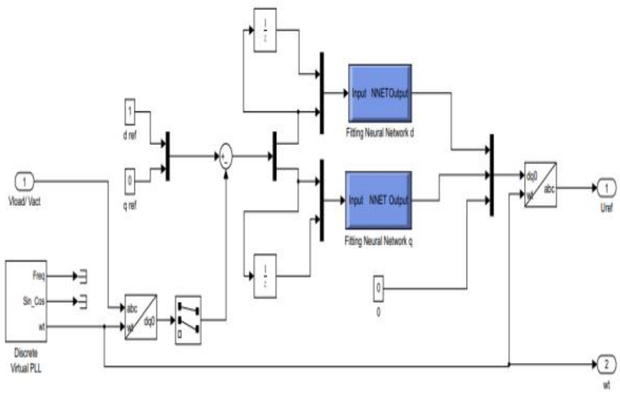

Fig.2 Control circuit with ANN Controller

III. RESULTS AND DISCUSSION

To evaluate the suggested compensation technique, a designed setup consisting of a three-phase power system with a source, a transmission line, two transformers located at each end of the line, and a nonlinear load, has been implemented. Fig.3 shows the Matlab Simulink model with ANN controller.

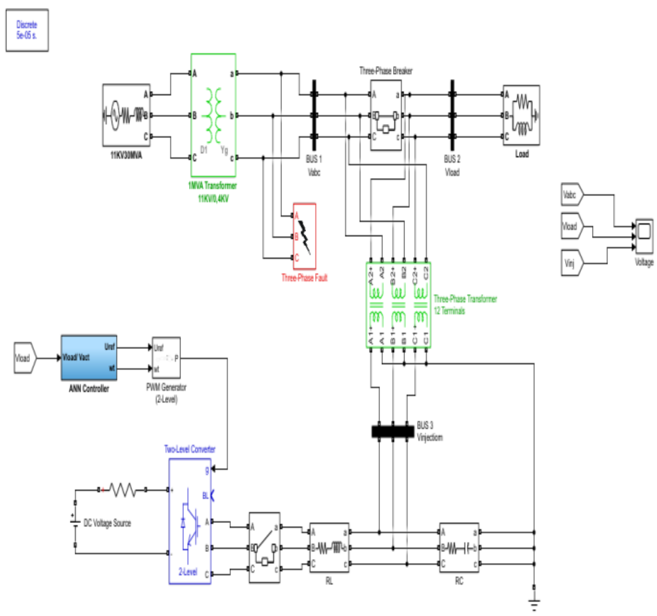

Fig.3 Simulink model of DVR with ANN Controller

The fig. 4 shows the source voltage, load voltage and injected voltage waveforms of DVR under three line to ground fault condition. A TLGF occurs and resulting in a decrease of voltage from their nominal values. The total fault duration is 0.1 s from 0.2 s to 0.3 s. The voltage sag is corrected using ANN controller by injecting appropriate voltage that is missing during the fault condition.

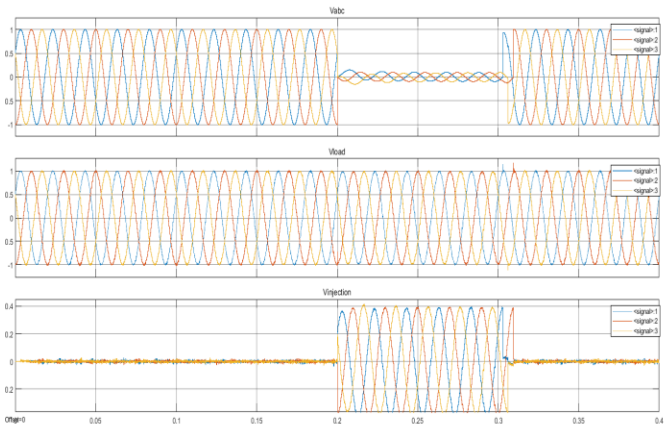

Fig.3 Three line to ground fault with ANN controller

FFT analysis of sensitive load voltage shows the load voltage is perfect sinusoid with very low THD of 2.04% as shown in Fig.4.

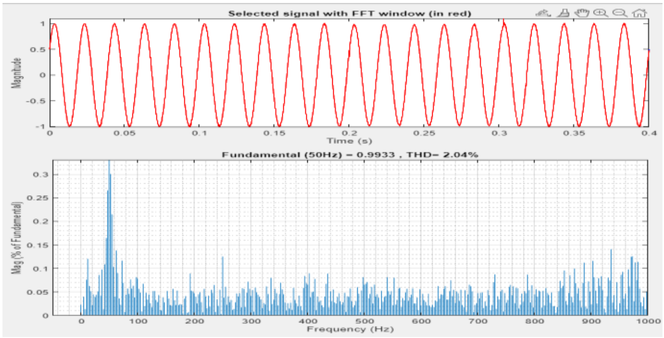

Fig.4 THD analysis for three line to ground fault with ANN controller

Fig. 5 shows the voltage restoration by PI controller under same loading and faulting condition. The output of the PI controller exhibits a notable presence of harmonics and noticeable distortion in the waveform.

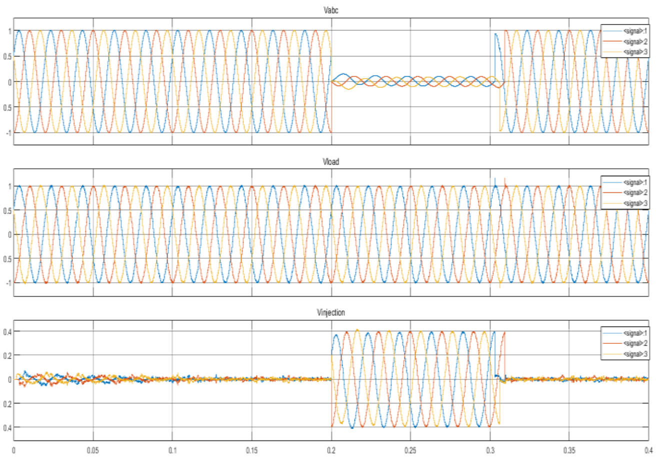

Fig.5 Three line to ground fault with PI controller

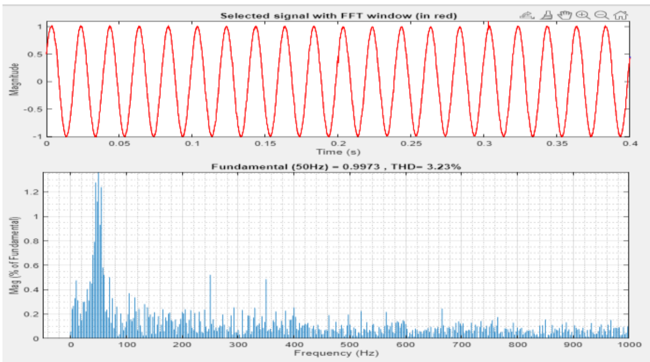

Fig.6 THD analysis for three line to ground fault with PI controller

FFT analysis of sensitive load voltage using PI-based DVR shows THD of about 3.23% as shown in figure 6.

IV. CONCLUSION

The comparative analysis of the simulation outcomes has confirmed that the proposed system, employing an artificial neural network (ANN) controller, delivers superior power quality performance compared to an existing model utilizing a Proportional-Integral (PI) controller. The DVR with ANN control ensures smooth, stable, and rapid response for mitigating imbalances and voltage sags. The simulation result shows that the fundamental values of load voltages have been maintained above 97.96% of the nominal value, and the Total Harmonic Distortion (THD) of load voltages has been kept around 2.04% of the nominal value. Comparatively, the results indicate that the ANN-based DVR surpasses the performance of the PI-based controller, which achieved a load voltage of 96.77% and a THD of 3.23%. Therefore, the ANN-based controller for the DVR proves to be a viable solution for mitigating power quality disturbances.

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