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Power Quality Improvement using Artificial Neural Network Controller based Dynamic Voltage Restorer

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ABSTRACT

The importance of power quality (PQ) concerns amplifies as the number of voltage-sensitive loads rises within distribution systems. Industrial distribution systems commonly face voltage disturbances, which primarily include voltage sags, voltage swells, and voltage unbalances. Voltage sags or swells can occur throughout the entire system or affect a substantial portion of it due to faults occurring at either the transmission or distribution level. Additionally, when the system experiences high demand, a notable voltage reduction, or drop, can take place. Voltage sag and swell can lead to the failure or shutdown of sensitive equipment found in industries like semiconductor or chemical plants. These voltage disturbances can also result in a significant current imbalance, potentially causing fuses to blow or breakers to trip. The consequences of these effects can be financially burdensome for customers, ranging from minor fluctuations in quality to costly production downtime and equipment damage. The DVR (Dynamic Voltage Restorer) is a power electronic converter-based mitigation device that is connected in series. It is widely recognized as an effective custom power device for mitigating the adverse effects of voltage disturbances originating from upstream sources on sensitive loads. While the primary purpose of the DVR is to mitigate voltage sags and swells, there are instances where additional functionalities, such as harmonic compensation and reactive power compensation, are incorporated into the device. When it comes to controlling the DVR, the most commonly employed option is the PI (Proportional-Integral) controller. It offers a straightforward structure and can deliver satisfactory performance across a broad operational range. However, the main challenge with this simple controller lies in selecting the appropriate PI gains. Fixed gains may not always provide the desired control performance when there are changes in system parameters and operating conditions. Therefore, an online tuning process is necessary to ensure that the controller can effectively handle all variations in the system. The paper introduces the Dynamic Voltage Restorer (DVR) and

explains its operating principle. Additionally, it presents a proposed controller based on Artificial Neural Network. The performance of ANN controller has been analysed using MATLAB Simulink model in this paper.
Keywords: Power quality, Dynamic voltage restorer, Proportional Integral, Artificial Neural Network (ANN)

I. INTRODUCTION

Power quality problems in industrial applications refer to various disturbances that can occur in the electrical power supply. These disturbances include voltage sags and swells, flicker, interruptions, and harmonic distortion. In industrial settings, where automation is extensively utilized across various processes, it becomes crucial to prevent such phenomena. Voltage sags are considered a prominent power quality issue among various disturbances. They arise from faults in transmission and distribution systems, the energization of transformers, and the initiation of large induction motors. 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 these disturbances and non-linear loads. Insufficient power quality can lead to significant financial and operational implications, which may include equipment damage and failures. Such problems can result in expensive repair or replacement requirements.

Traditional power quality compensation methods have several drawbacks, such as electromagnetic interference, potential resonance issues, fixed compensation capabilities, and bulky equipment. As a result, power system and power electronic engineers are required to explore adjustable and dynamic solutions using custom power devices to improve power quality. The Dynamic Voltage Restorer (DVR) is recognized as the most efficient and effective modern custom power device employed in power distribution networks to minimize voltage sags.

In this paper, MATLAB Simulink-based test systems for the Dynamic Voltage Restorer (DVR) are presented. The objective is to minimize voltage sag through the implementation of control strategy which utilizes Artificial Neural Network.

The basic configuration of the dynamic voltage restorer (DVR) is illustrated in fig.1 which comprises several components. These components include an Injection/Booster transformer, a Harmonic filter, a Voltage Source Converter (VSC), a DC charging circuit, and a Control and Protection system. In this configuration, the DVR system is connected in series with the main system using the secondary winding of the injection transformer. When a voltage sag occurs in the main system, the DVR responds by injecting a controlled voltage produced by a Voltage Source Converter (VSC) in series with the bus voltage. This injection is carried out through an injecting/booster transformer, effectively reducing the magnitude of the sag. Typically, the Dynamic Voltage Restorer (DVR) is positioned within a distribution system, situated between the power supply and the critical load feeder. Its main purpose is to swiftly enhance the voltage on the load side during disturbances, thereby preventing any power disruptions to the connected load. The efficiency of the DVR relies on the effectiveness of the control technique employed to switch the inverter. There are multiple circuit topologies and control schemes available for implementing a DVR.

Apart from compensating for voltage sags and swells, the DVR can also undertake additional functions, including compensating for line voltage harmonics, mitigating transient voltage fluctuations, and limiting fault currents.

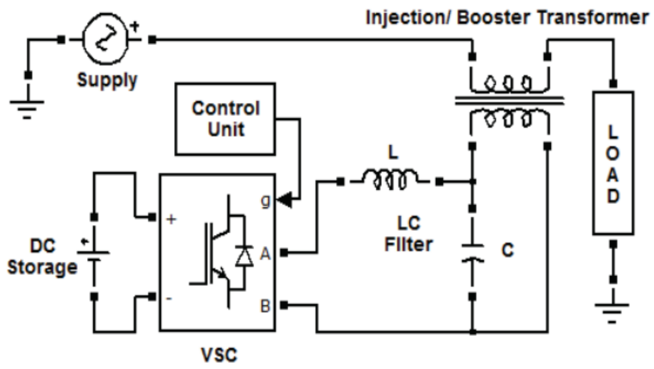

Fig.1 Basic configuration of DVR

In many sag correction techniques, the Dynamic Voltage Restorer (DVR) is responsible for injecting active power into the distribution line during the compensation period. As a result, the capacity of the energy storage unit within the DVR can become a limiting factor, particularly when dealing with sags of long duration.

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 under different fault conditions. Finally, the conclusion is drawn in Section IV.

II. METHODS AND MATERIAL

The presence of power semiconductor switches in the inverter bridge makes the Dynamic Voltage Restorer (DVR) a truly nonlinear system, necessitating the use of a nonlinear controller. Nonlinear control techniques such as Artificial Neural Network (ANN), Fuzzy Logic (FL), and Space Vector Pulse Width Modulation (SVPWM) are commonly employed. For the proposed system, the ANN control method is chosen due to its adaptive and self-organizational capabilities. Additionally, it possesses inherent learning capability, allowing for improved precision through interpolation.

ARTIFICIAL NEURAL NETWORK

The Artificial Neural Network (ANN) is a network designed to mimic the structure and functioning processes of the human brain. It comprises multiple interconnected processing elements or neurons. The behaviour of the entire network in an Artificial Neural Network (ANN) is determined by the arrangements and strengths of interneuron connections, also known as weights. These weights play a crucial role in determining how information is processed and propagated throughout the network. Fundamentally, an Artificial Neural Network (ANN) can estimate relationships between variables without relying on a predefined mathematical model. It achieves this by learning from representative data provided during the training process. The training of an Artificial Neural Network (ANN) involves presenting an adequate number of input-output examples to the network. This allows the network to learn and adjust its internal parameters, such as connection weights, in order to approximate the desired relationship between the inputs and outputs.

Through the process of learning from data, Artificial Neural Networks (ANNs) acquire the capability to make predictions or decisions based on the knowledge they have gained. ANNs can effectively analyze input information, process it using the learned connections and computations within the network, and generate an output that corresponds to the specific task or problem being addressed. This ability to generalize from the acquired knowledge enables ANNs to perform tasks such as pattern recognition, classification, regression, and other forms of data-driven analysis. 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, $netj = \sum_i w_{ji} x_i - \theta_j$

Computational output of the output node:

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

where, $net_j = \sum_i {}_{lj} y_j - \theta_l$

Error of the output node:

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

Hypothesis:

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

Gradient update:

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

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.

Fig.2 shows the flowchart of training procedure for ANN controller of DVR.

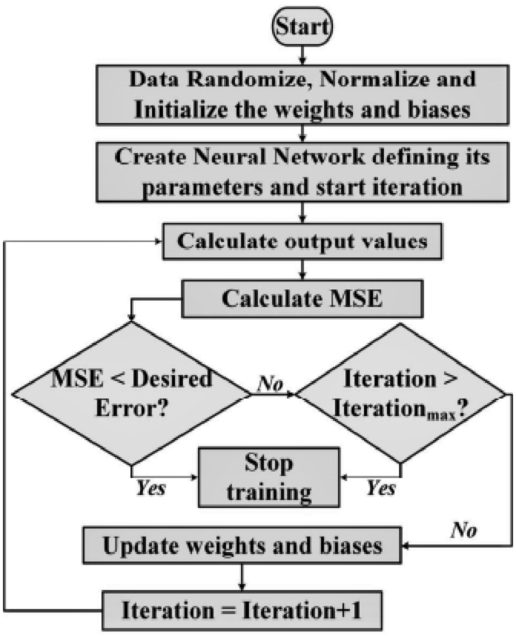

Fig.2 Flowchart of training procedure of ANN controller

In this research, an enhanced controller is employed to enhance the performance of the compensating device, and it is based on a multilayer backpropagation artificial neural network (ANN). The ANN is trained using the LM backpropagation method as the training algorithm, utilizing the Matlab toolbox. The primary objective of the ANN controller is to minimize errors. By processing the input data, the ANN controller generates modulation signals, which are then utilized to generate pulses for the Insulated Gate Bipolar Transistor (IGBT). These output signals are obtained through the dq0-to-abc transformation.

Fig.3 illustrates the overall structure of the multi-layer feed-forward neural network, showing how the layers are organized within the ANN training block.

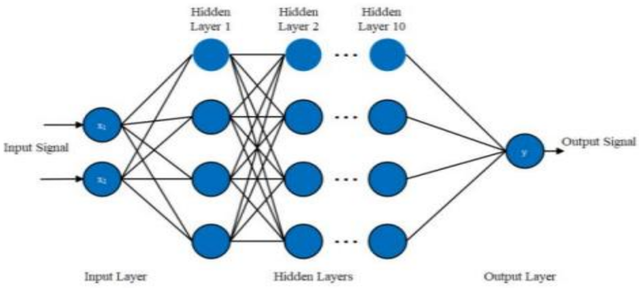

Fig.3 Multi-layer feedforward structure

Controller Circuit:

The control circuit of DVR based on ANN controller is depicted in fig.4. It employs Park's transformation (dq0 transformation. It is primarily employed in the analysis of three-phase systems to convert three-phase time-domain variables into a two-phase rotating reference frame, often referred to as the dq reference frame. It allows the representation of the three-phase system in a simplified form, making it easier to analyze and control.

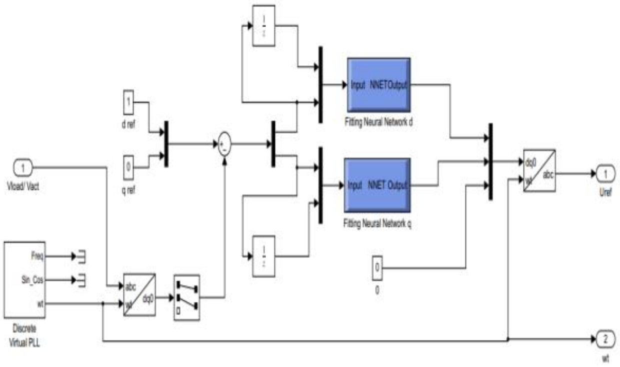

Fig.4 Control circuit with ANN Controller

The abc_to_dq0 transformation block is used to convert the supply voltage and reference voltage signals from the abc coordinate system to the dq0 coordinate system. This transformation is accomplished by splitting the dq0 signals of both the supply voltage and reference voltage using the demux block. The direct (d) and quadrature (q) components of the supply signal are then compared to the corresponding components of the reference signal. The resulting d and q values are subsequently sent to the dq0_to_abc transformation block using the mux block. The dq0_to_abc transformation block performs the inverse transformation, converting the resultant dq0 coordinates back to the abc coordinate system. This transformation is crucial for generating the pulse signals required for further processing. The output of this block is then transmitted to the Voltage Source Converter (VSC) with Harmonic Filter unit. Additionally, a discrete 3-phase PLL (Phase-Locked Loop) block is employed to generate an output signal whose phase is related to the phase of the input signal.

III. RESULTS AND DISCUSSION

To evaluate the proposed 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.5 shows the Matlab Simulink model of DVR with ANN controller.

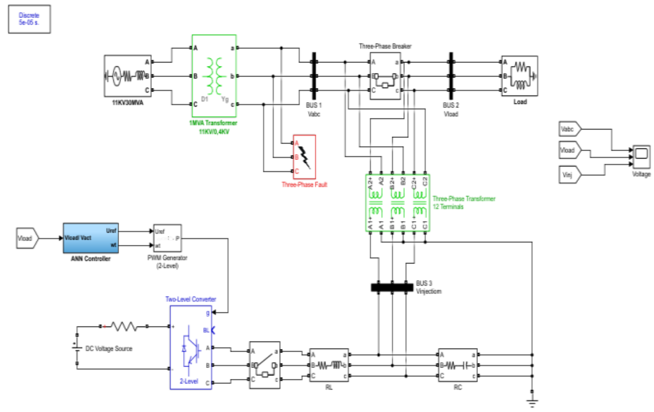

Fig.5 Simulink model of DVR with ANN Controller

The fig. 6 shows the source voltage, load voltage and injected voltage waveforms of DVR under single line to ground fault condition. A SLGF 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.

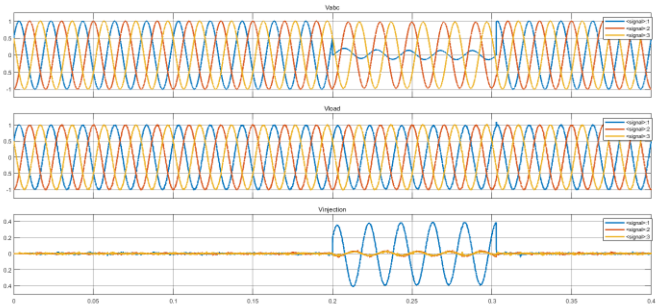

Fig.6 Single line to ground fault with ANN controller

FFT analysis of sensitive load voltage shows the load voltage is perfect sinusoid with very low THD of 2.08% as shown in Fig.7.

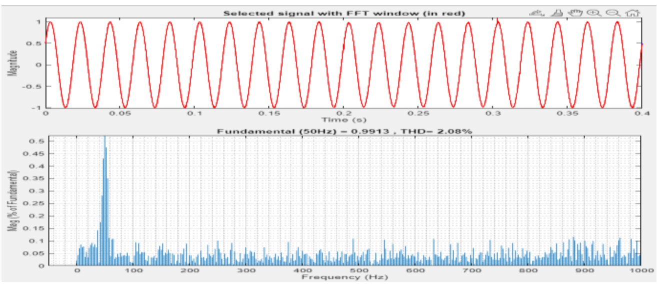

Fig.7 THD analysis for Sigle line to ground fault with ANN controller

Fig. 8 displays the source voltages, load voltages, and injected voltages observed during this DLGF event. A double-line to ground fault (DLGF) occurs on both phase A and phase B, causing a decrease in voltage from their nominal values. The fault persists for a total duration of 0.1 seconds, specifically from 0.2 seconds to 0.3 seconds.

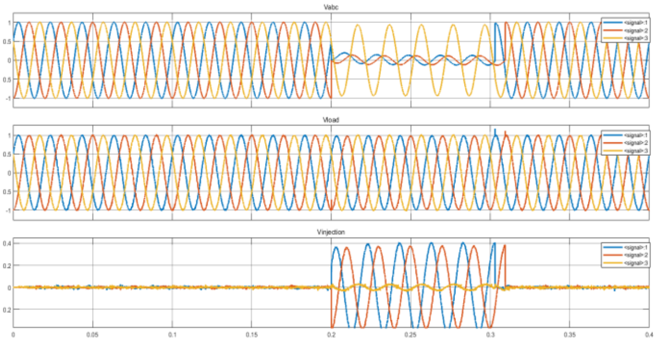

Fig.8 Double line to ground fault with ANN controller

FFT analysis of sensitive load voltage using PI-based DVR shows THD of about 2.04% as shown in figure 9.

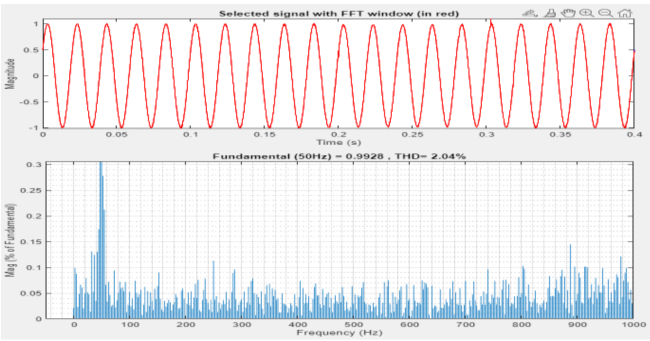

Fig.9 THD analysis for Double line to ground fault with ANN controller

In case 3, a three line to ground fault (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. Figure 10 depicts the source, load, and injected voltages in a TLGF situation.

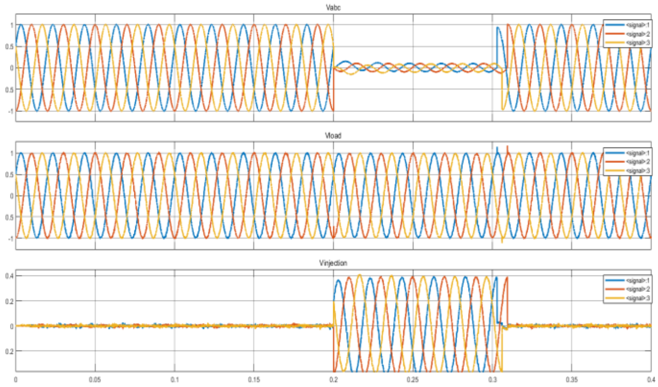

Fig.10 Three line to ground fault with ANN controller

FFT analysis of sensitive load voltage shows the load voltage is perfect sinusoid with very low THD of 2.04% as shown in Figure 11.

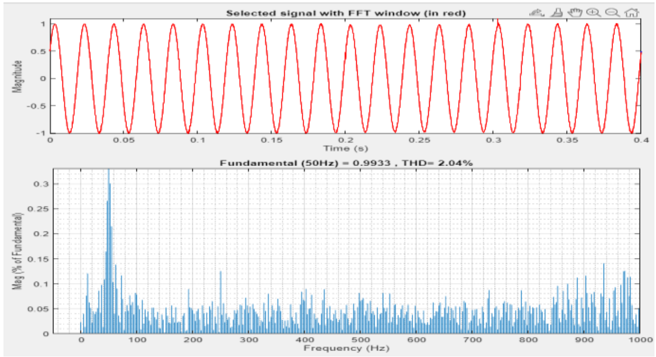

Fig.11 THD analysis for Three line to ground fault with ANN controller

IV. CONCLUSION

DVRs are widely recognized as a popular option for enhancing the quality of power in power systems. There is a wide range of control systems available to effectively operate and control these devices. The simulation results have validated that the suggested system, incorporating an artificial neural network (ANN) controller, achieves enhanced power quality performance when compared to alternative existing techniques. 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 under different faulting conditions.

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