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ENHANCE POWER QUALITY USING DSTATCOM AND DVR WITH ARTIFICIAL NEURAL NETWORKS (ANN)

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ABSTRACT:
Poor power quality in the electric grid manifests as variations in terminal voltage, transients, and waveform distortions. The widespread use of non-linear loads, such as adjustable speed drives, traction drives, and power converters, has significantly contributed to this decline in power quality, leading to substantial economic losses. Therefore, it is crucial to develop equipment capable of mitigating these issues. Custom power devices play a vital role in improving both the reliability and quality of power supplied to consumers. Among the most effective flexible AC transmission devices based on the Voltage Source Inverter (VSI) principle are the Distribution Static Compensator (DSTATCOM) and the Dynamic Voltage Restorer (DVR). This paper presents a comparative analysis of DSTATCOM and DVR based on their performance in addressing power quality issues in the power system at the load bus. Additionally, an artificial neural network is applied for detecting power quality disturbances, such as voltage sags and swells.
Key words: DSTATCOM, DVR, Power Quality, Voltage source inverter

INTRODUCTION:

Power quality has significant economic consequences for consumers, utility providers, and electrical equipment measurement. Issues such as voltage dips, voltage swells, high levels of current harmonic distortion caused by non-linear loads, and reduced power factor pose major challenges for both electrical utilities and industrial consumers. To ensure the delivery of high-quality electrical power, efficient planning, management, and control of the power system are essential, with a focus on cost-effective solutions. A simulation platform has been developed using MATLAB, incorporating a simulation model to analyze practical cases. This platform evaluates the performance of the proposed method and detects transient voltage disturbances.
The DSTATCOM, a shunt device, and the DVR, a series device, are two types of VSI-based compensators commonly used to mitigate voltage sags and swells while regulating load voltage. These devices effectively address power quality issues such as load voltage harmonics, source current harmonics, and unbalanced conditions, ensuring improved performance under steady-state operation. The DSTATCOM and DVR, developed within the designed system, play a crucial role in mitigating power quality disturbances, including voltage sags, voltage swells, and other related issues.

DSTATCOM:

The D-STATCOM is a three-phase, shunt-connected power electronics-based device designed for reactive power compensation. It can generate or absorb reactive power as needed to regulate specific parameters within the electric power system. As a fast-response, shunt-connected solid-state power controller, the D-STATCOM provides flexible voltage control, enhancing power quality in utility distribution feeders.

The key components of a D-STATCOM include a coupling transformer with leakage reactance, a voltage source inverter (VSI), a DC capacitor, and three-phase insulated gate bipolar transistors (IGBTs). Its operation begins when an AC voltage difference occurs across the leakage reactance and the power system. Additionally, a secondary damping function can be integrated into the D-STATCOM to improve power system oscillation stability. The device utilizes solid-state power switching components and enables rapid control of three-phase voltages in both magnitude and phase angle.

Functionally, the D-STATCOM can be regarded as either a voltage-controlled source or a current-controlled source. It employs an inverter to convert the DC link voltage (Vdc) stored in the capacitor into a voltage source with adjustable magnitude and phase, allowing dynamic compensation for voltage disturbances.

The single line diagram of D-STATCOM is shown in figure 1 (a).

The VSI is designed to convert DC voltage into a sinusoidal AC voltage with minimal harmonic distortion. The power compensation and voltage regulation capability of the D-STATCOM depend on the rating of the DC storage device. When the AC bus voltage magnitude exceeds that of the VSI, the AC system perceives the D-STATCOM as an inductive element connected to its terminals. Conversely, if the AC bus voltage is lower than the VSI voltage, the system views the D-STATCOM as a capacitive element, indicating the absorption or generation of reactive power. No reactive power exchange occurs when both voltage magnitudes are equal..

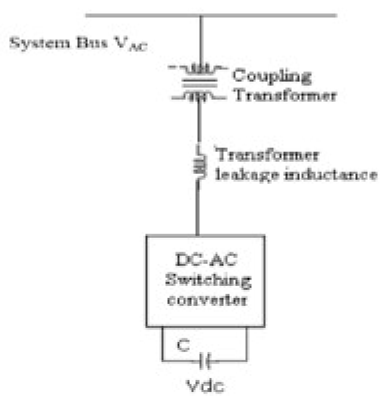


Figure (a): Single line diagram of a D-STATCOM

ARTIFICIAL NEURAL NETWORK:

Artificial neural networks have demonstrated remarkable speed, fault tolerance, and adaptability. Simple, highly connected processing units called neurones make up artificial neural networks. Each neurone aggregates inputs from other neurones and generates an output based on the aggregated inputs.

The most popular technique for training networks is the back propagation learning algorithm, which this article suggests as a power quality output for voltage sag and swell. The feed forward neural network architecture and the artificial neural network concept are depicted in Fig. 1(b). A multilayer network with a hidden layer—a unit that is neither an input nor an output unit—as seen in this illustration.

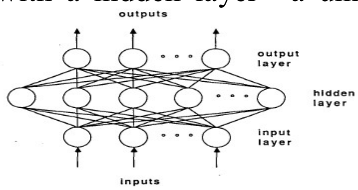


Fig .(b): Feed forward neural network

DYNAMIC VOLTAGE RESTORER, (DVR) :

The load and the series voltage controller are linked in series. A transformer including a PWM inverter circuit and a DC voltage source coupled to VSI is used to establish a direct connection with power electronics. While the active power is drawn from energy storage, the reactive power is produced by the VSC converter. A solid state device called a DVR controls the load side voltage by injecting voltage into the system. The schematic diagram of a DVR that is comparable to thevenin is displayed in Figure 2.0.

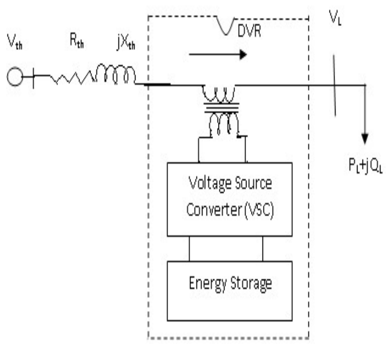


Figure Schematic diagram of a DVR

$V_{DVR} = V_L + Z_{th}I_L - V_{th}$

Where V_L = load voltage magnitude desired

Z_{th} = impedance (Thevenin'simpedance)

$= R_{th} + jX_{th}$

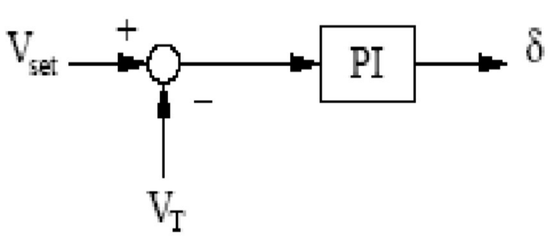
I_L = Load Current

Vth= system voltage during fault condition

The load current is given by:

$I_L = \frac{(P_L+ZQ_L)}{V_L}$, When V_L is considered as a reference.

The control technique measures the r.m.s. voltage at the load point where a sensitive load is connected and maintains a constant voltage magnitude during system disruptions. The proportion integration (PI) controller utilised in Facts devices is depicted in figure 3.1 below.



The sinusoidal PWM approach, which is the foundation of the VSC switching strategy, offers simplicity and improved response. PWM approaches are preferred in FACTS applications because they provide a more versatile choice than Fundamental Frequency Switching (FFS) techniques. The PWM controller utilised to generate reference control signals in the designed system in fact devices is depicted in Figure 3.2.Figure Controller for DSTATCOM and DVR

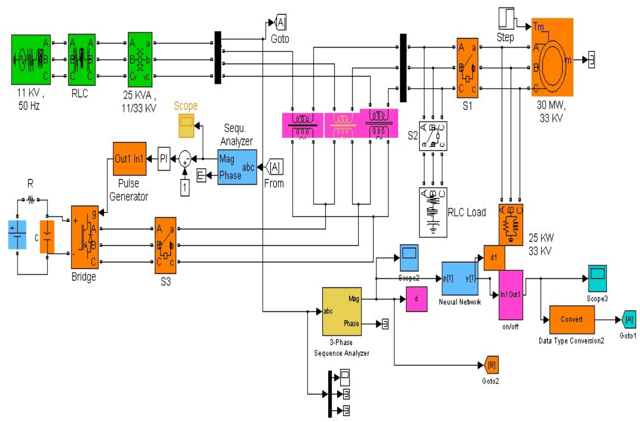


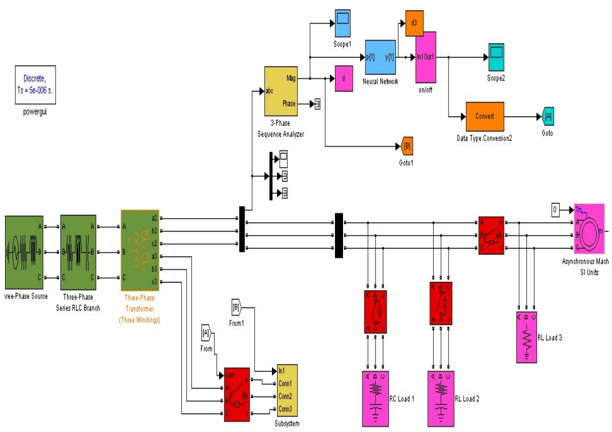
Figure Generation of reference control signals for PWM controller

MODELING AND SIMULATION RESULTS:

The MATLAB simulation model of the DVR is illustrated in Figure 5.3. In this setup, a three-phase supply is connected to a three-phase load through the DVR to introduce sag, swell, and harmonics on the supply side. The dynamic voltage restorer consists of a PWM inverter circuit and a DC voltage source connected to the DC link of the VSI.

The IGBT-based PWM voltage source inverter is implemented using the universal bridge block from the power electronics subset of the power system block set. The load considered in the model operates at a lagging power factor. Additionally, a ripple filter is placed across the secondary terminals of the transformer to eliminate switching ripple from the terminal voltage. The reference load voltages are derived using the sensed terminal voltages, load supply voltages, and the DC bus voltage of the DVR.

Figure Simulink model of DVR test system.



A pulse width modulation (PWM) controller is used
to compensate for voltage sags by comparing the reference and sensed load voltages to generate gate signals for the IGBTs in the VSI. The complete Simulink model of the DVR is shown in Figure 4.1.

In the first simulation, the system operates without the DVR, and power quality issues such as voltage sag and swell are introduced during a 320 ms period. The voltage sag at the load point is observed to be

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20% relative to the reference voltage. Using MATLAB simulation tools, the DVR is configured to operate specifically for mitigating voltage sag and swell.
In the second simulation, the same conditions are applied, but this time with the DVR in operation to analyze its effectiveness in compensating for these power quality disturbances. The MATLAB simulation model for the test system of the DSTATCOM is shown in Figure 4.2. In this setup, the output of the proposed model is applied to the DSTATCOM through a breaker controlled by external switches. The results of the test system are presented in Figure 5.0, corresponding to the first simulation, which is conducted under normal conditions without any power quality issues.
Fig 4.2: Simulink model of DSTATCOM test system to measure Power Quality problems.
Three-phase induction motors increase the load over 300–700 ms, resulting in a 30% voltage sag at the load point relative to the reference voltage. The second simulation is run using the identical situation as before without DSTATCOM, and the third simulation is run now that DSTATCOM is operational. Figure 5.1 shows the voltage sag duration, which was recorded during the 0.32–0.72 s period during which DSTATCOM began to operate. Within 20 ms, the sag and swell were reduced to less than 10% of the sag before the system recovered to 1.0 p.u., as seen in figure 5.2. The simulation lasts for 1200 ms in total. ANN sees the measuring system's output and applies it to DSATCOM and DVR to improve power quality.

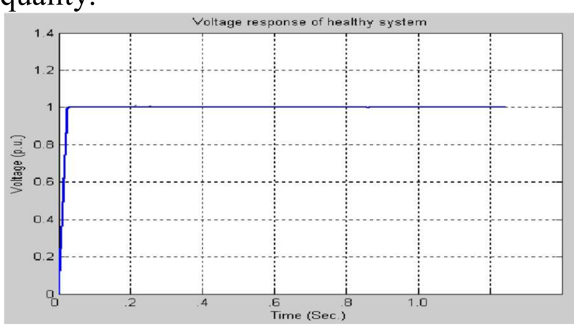

Figure 5.0 Voltage response in p.u. when no power quality problems occurs.

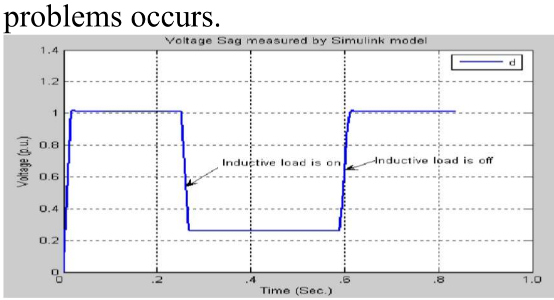

Figure 5.1. Voltage response of the test system without DSTATCOM

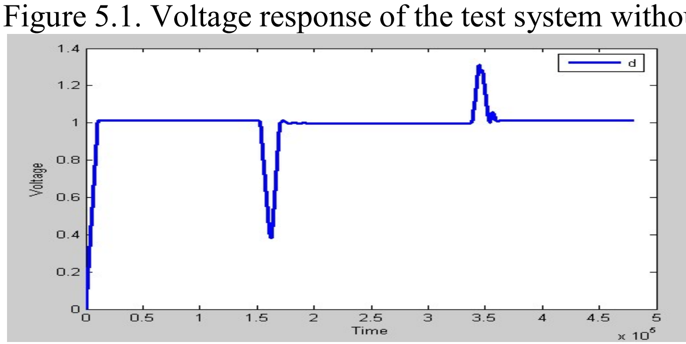

Figure 5.2 Voltage response of the test system with DSTATCOM

THD Analysis: Improving power quality necessitates reducing total harmonic distortion. The THD of the load side voltage and current is shown in Table 1. The harmonic comparison between DVR and DSTATCOM is displayed in this table. Figure 5.4 shows the DSATCOM load voltage THD study during voltage sag, and Figure 5.5 shows the DVR load voltage THD analysis during voltage sag for 0.3 to 0.7 seconds. The load voltage THD analysis for DVR during voltage sag is shown in Figure 5.4, whereas the load voltage THD analysis for DSTATCOM is shown in Figure 5.5.

Table 1

	DSTATCOM				DVR			
	Supply Voltage THD	Load Voltage THD	Load Current THD	THD When DSTACOM ON	Supply Voltage THD	Load Voltage THD	Load Current THD	THD when DVR ON
Voltage Sag & Swell	3.39%	1.63%	5.53%	1.6%	22.35%	31.45%	1.6%	31.4%

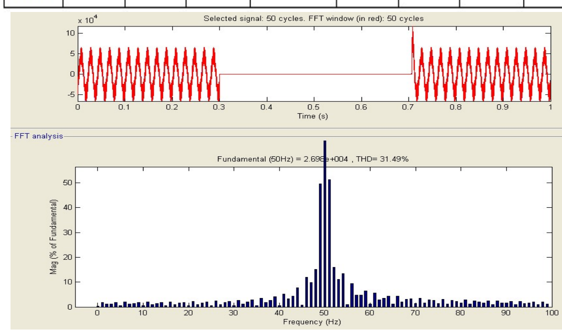

Figure Load Voltage THD during voltage sag for DVR

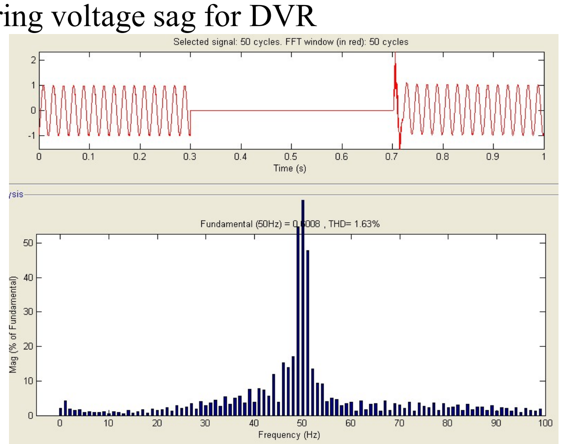

Figure Load Voltage THD during voltage sag and swell for DSTACOM

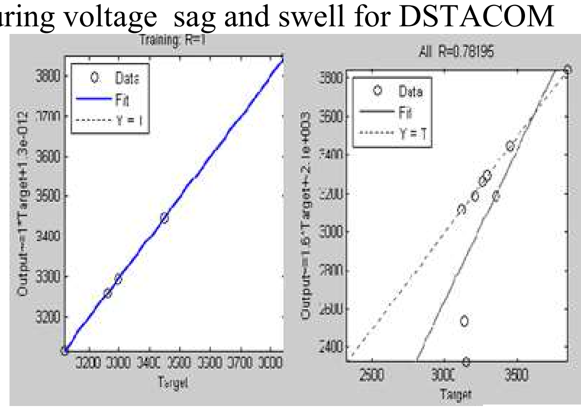

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Fig.Regression plot of power quality measurement.

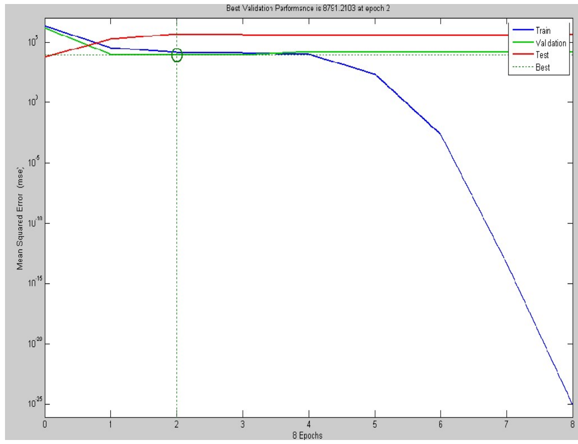

Fig. Performance of the network1 for power quality measurement.

Figure displays the power quality measurement regression plot, and Figure 5.6 displays the network's performance as an error. The greatest performance evaluation metric for forecasting is mean absolute percentage error, or MAPE. The most widely used and recognised error metric for evaluating various forecasting techniques is the MAPE value. Three data sets are created from the input data: 70% for training, 15% for testing, and 15% for validation.

CONCLUSION:

Using a Matlab simulating model, this study develops solutions for power quality issues including voltage sags and swells and presents mitigation strategies for custom power electronic devices, such as DVR and DSTACOM, with thorough results. The VSI utilised in customised power devices has a PWM-based control mechanism. A voltage source inverter (VSI) linked in shunt with the ac system provides improved voltage regulation, reactive power compensation, power factor correction, and the elimination of line harmonics. The offered simulation results demonstrate good accuracy and aid in our comprehension of the DVR and DSATCOM comparison. In comparison to DVR, DSATCOM offers comparatively superior voltage regulation, according to the THD study of the suggested model. The findings of the ANN demonstrate that the network performs well and makes fair predictions. Ultimately, this neural network may prove to be a useful instrument for measuring and enhancing power quality.

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