Artificial Intelligence Controlled Three-Phase Four-Wire DSTATCOM for Improved Power Quality in Distribution Network

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Abstract- This is because the nonlinear and unbalanced loads of modern distribution systems are the primary contributors to power quality problems that include harmonics, low power factor, and voltage imbalance. To overcome these difficulties, in this paper, I propose an Artificial Intelligence (AI)-controlled three-phase four-wire DSTATCOM. It has sophisticated controllers, such as, Synchronous Reference Frame Theory (SRFT), Instantaneous Reactive Power Theory (IRPT) and Adaptive Neuro-Fuzzy Inference System (ANFIS), to improve the performance. The comparison of the three methods discussed above based on simulation results in MATLAB/Simulink indicates that although SRFT and IRPT can help reduce harmonics and increase the power factor, the ANFIS-based controller is the most successful, producing virtually sinusoidal balanced currents, a power factor approaching one, and a Total Harmonic Distortion (THD) within the IEEE-519 limits. The suggested AI-based solution shows quick reaction and ensures stable quality power improvement at different load levels.

Keywords- DSTATCOM, Power Quality, Harmonic mitigation, compensate neutral current, AI controller, ANFIS, MATLAB/ Simulink.

I. INTRODUCTION

Power quality in the current power-systems has emerged as a major concern because of increased nonlinear and unbalanced loads. Harmonics, low power factor, voltage distortion, and unbalanced currents are problems that impact utilities as well as a consumer, which causes energy loss and damages equipment. To address these issues, specifically crafted power apparatus such as Distribution Static Compensators (DSTATCOM) is prevalent, since it offers prompt reactive power nourishment, eradication of harmonics, and load balancing in distribution systems.

The past studies compared various control techniques of DSTATCOM including Instantaneous Reactive Power (IRP) theory, Symmetrical Component (SC) theory and Improved Instantaneous Active and Reactive Current Component (IARCC) theory. It was found that all three perform well under balanced conditions but the IARCC approach has more favorable results in the case of distorted and unbalanced voltages especially in THD reduction and power factor improvement [1]. It has also been reviewed that DSTATCOMs would cope with the voltage sags, swells and harmonics, and are, therefore, strong tools in improving PQ in PQ enhancement in a distribution system [2].

Intelligent controllers have been suggested in order to enhance dynamic performance. As an example, the use of fuzzy or wavelet-based neural controllers instead of conventional PI controllers led to better DC-link voltage control, lower harmonics and quicker transient response to load changes [3]. On the same note, issues such as voltage increase through extensive penetration of distributed generation (DG) have been researched, and active network management enabled by DSTATCOMs was reported to be an effective approach to ensure stable operation [4].

More recent publications also demonstrate the use of Artificial Neural Networks (ANN) and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) in the control of DSTATCOM. Those strategies realistically produce reference currents, recompense reactive power, and matching currents in the source even in harsh unbalanced nonlinear circumstances [5]. The AI-controlled controllers have been shown to be more reliable and stable as it reduces the THD and ensures almost a unity power factor in distribution networks [6]. Likewise, better control schemes like SRF and refined AI- based strategies have proved to work in the removal of harmonics and enhance the overall efficiency of the system [7] [8].

This paper proposes an AI-controlled three- phase four-wire DSTATCOM to enhance the quality of power. We developed Synchronous Reference Frame Theory (SRFT), Instantaneous Reactive Power Theory (IRPT), and ANFIS-based intelligent control, and tested them using MATLAB/Simulink. As the results demonstrate, in the absence of DSTATCOM, the distortion of source current is high (THD = about 24-28%). THD drops to 6-7% and 5-6% respectively with SRFT and IRPT controllers and better power factor. The ANFIS-based controller however, performs better than both, to the extent that the THD is minimized to 3-4%, and the power factor is corrected to near unity (0.99). The simulation pictures are a clear confirmation that our proposed AI-based DSTATCOM is capable of providing quicker response, balanced sinusoidal currents, and very reliable PQ improvement during nonlinear and unbalanced load conditions.

II. LITERATURE SURVEY

The issues of power quality in the distribution system are of great concern due to harmonics, bad power factor and poor shape of the load. A comparison of three control methods of DSTATCOM was between Instantaneous reactive power (IRP) theory, Symmetrical component (SC) theory, and Improved Instantaneous active and reactive current component (IARCC) theory. It was demonstrated that all the techniques work excellent under balanced conditions, but IARCC works superior in distorted and unbalanced supply voltages [1]

DSTATCOMs have found extensive application as a resolution to popular PQ issues such as voltage sags, swells, harmonic pollution, etc. Their capability to balance reactive power, harmonic suppression, and enhance voltage stability is brought to the limelight by reviews. The different topologies and control strategies have been studied and the findings indicated that DSTATCOMs can dramatically enhance the quality of power within the whole system [2].

In a bid to improve the performance of PQs, scientists have come up with sophisticated controllers of DSTATCOM. A new methodology substituted a classical PI controller with a fuzzy neural network controller based on the wavelet. This technique offered superior transient operation, enhanced DC-link voltage control and lower distortion at different loads and was more dependable than traditional techniques [3].

The second issue in the contemporary distribution networks is the emergence of distributed generation (DG). Although DG helps to satisfy the increasing energy needs, it can cause such problems as reverse power flow and increase in the voltage. Research indicates that network reinforcement strategies and proactive management techniques with the help of compensators such as DSTATCOMs are required in order to deal with such issues. Comparison of these tools reveals that there are variations in cost, deployment, and effectiveness in ensuring the stability of the system [4].

Artificial Neural Network (ANN)-based control within DSTATCOM has also been used in more recent work. Such techniques are used to form correct reference currents, balance loads, and reduce harmonics even in very unbalanced and nonlinear situations. ANN-based controllers are also capable of maintaining the DC-link voltage constant during dynamic load variation and enhance the overall system reliability and performance [5].

In this paper, we build on this aspect of research and perform a comparative study of three DSTATCOM control strategies, namely IRP, SC and IARCC, using MATLAB/Simulink. The experiment tests them under a variety of operating conditions. Findings indicate that, at balanced conditions, both IRP and SC will work satisfactorily, but at unbalanced and distorted voltages, IARCC method obviously outperforms as the resulting THD, power factor, and optimized compensator ratings are lower. This underscores IARCC as the best strategy that can be used in the real world to enhance PQ enhancement [6].

III. PROPOSED METHOD

The block diagram for proposed method is as shown in below:

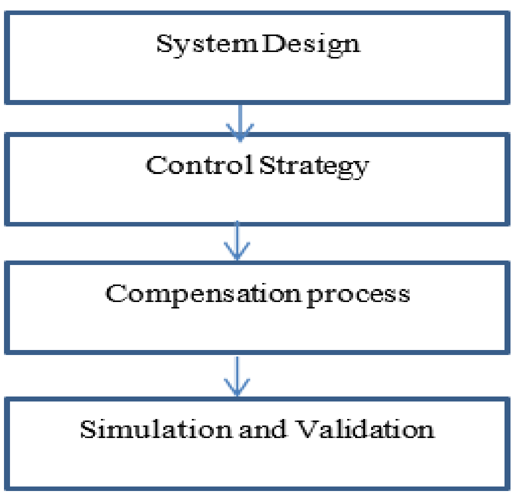

Fig.3.1 Block diagram

3.1 System Design: Three-phase four-wire DSTATCOM is produced to enhance power quality in the distribution systems. The system is linked at the Point of Common Coupling (PCC) to address current issues like harmonics, low power factor and neutral current. The voltage source converter (VSC) uses a DC-link capacitor, and is connected with the grid by coupling inductors.

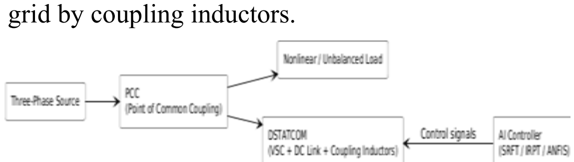

Fig.3.1 Block diagram of proposed three-phase four-wire DSTATCOM with AI-based controller,

3.2 Control Strategy: Various control methods are used to produce reference currents to the DSTATCOM. These are Synchronous Reference Frame Theory (SRFT), Instantaneous Reactive Power Theory (IRPT) and an Artificial Intelligence (AI)-based controller. The AI controller employs an Adaptive Neuro-Fuzzy Inference System (ANFIS), which integrates the learning capabilities of neural networks with fuzzy reasoning to enhance accuracy and flexibility when the load varies.

3.3 Compensation Process: Comparison of the reference currents generated by the selected control algorithm and real load currents is made. The error is fed to a current controller which produces switching pulses to the VSC. This provides a way of ensuring harmonic mitigation, neutral current compensation and power factor correction, resulting in balanced and sinusoidal source currents.

3.4 Simulation and Validation: The proposed system is simulated and experimented in MATLAB/Simulink in nonlinear and unbalanced loading conditions. Performance is considered based on the analysis of Total Harmonic Distortion (THD), current balancing in the source, neutral current, and enhancement of power factor. The effectiveness of the AI-based approach is confirmed by the results of the SRFT, IRPT, and ANFIS controllers.

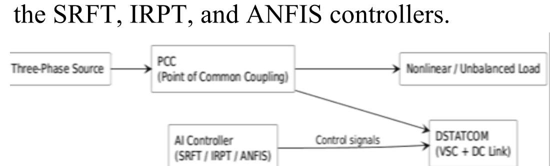

Fig.3.2 Flowchart of proposed methodology

IV. RESULTS

4.1 Simulation Setup

The system under study consists of a three-phase source, a nonlinear load, and a shunt-connected DSTATCOM. The simulation parameters are as follows:

- Source voltage: 230 V (rms), 50 Hz
- DC link capacitor: 3650 µF
- DC link voltage reference: 430 V
- Coupling inductor: 1 mH
- Nonlinear load: Three-phase uncontrolled rectifier with RL load
- Simulation platform: MATLAB/Simulink

The nonlinear load introduces harmonic currents into the distribution system, and the DSTATCOM is controlled using SRFT, IRPT, and ANFIS techniques for comparative analysis.

4.2 Test Cases

The following test cases are considered:

- Case 1: Source supplying nonlinear load with DSTATCOM using ANN controller
- Case 2: Source supplying nonlinear load with DSTATCOM using ANFIS controller

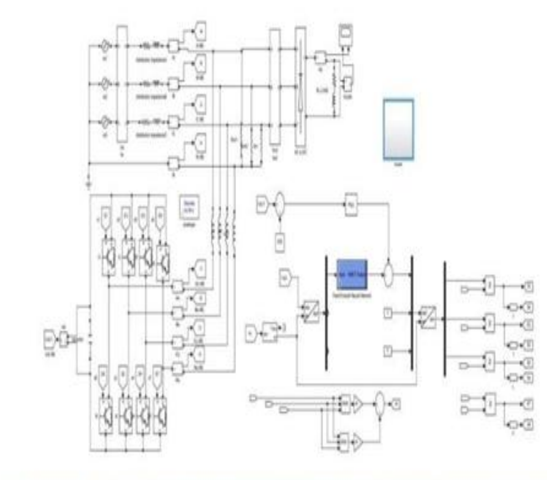

Fig. 6.1 Simulation diagram of three phase four wired DSTATCOM using ANN controller

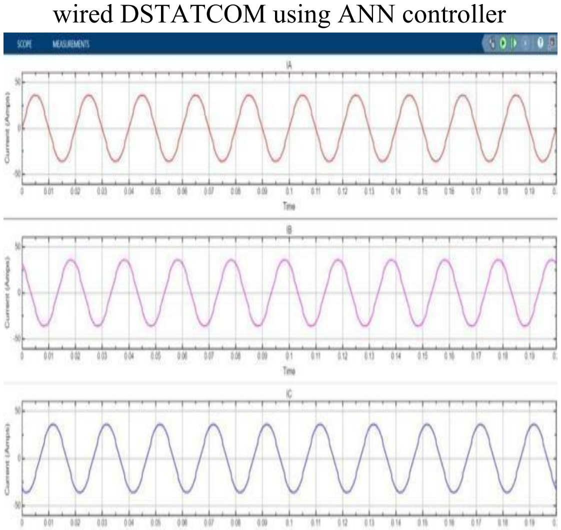

Fig. 6.2 Three phase supply current waveforms of three phase four wired DSTATCOM using ANN controller

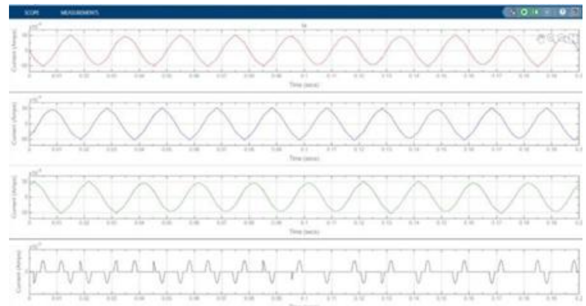

Fig. 6.3 Three Phase Compensating Current of three phase four wired DSTATCOM using ANN controller

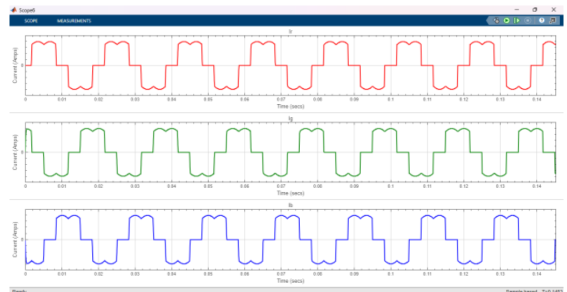

Fig. 6.4 Three Phase load Currents of three phase four wired DSTATCOM using ANN controller

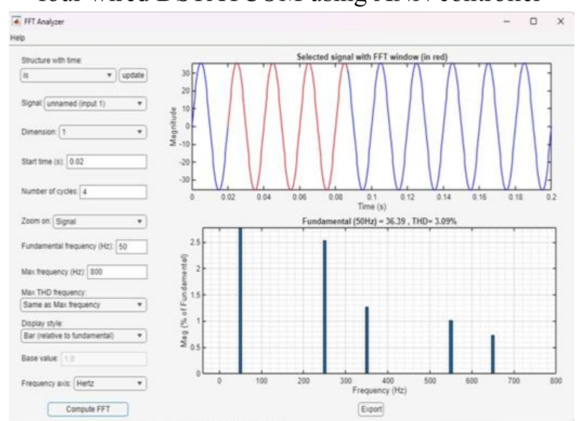

Fig. 6.5 THD value of A Phase source current with DSTATCOM using ANN controller

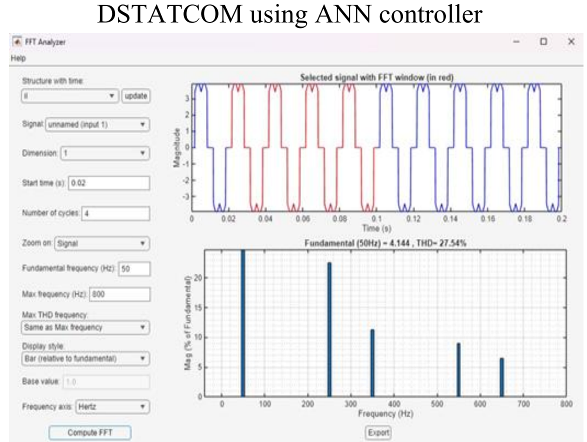

Fig. 6.6 THD value of load current DSTATCOM using ANN controller

6.3.2 Source supplying nonlinear load with DSTATCOM using ANFIS controller

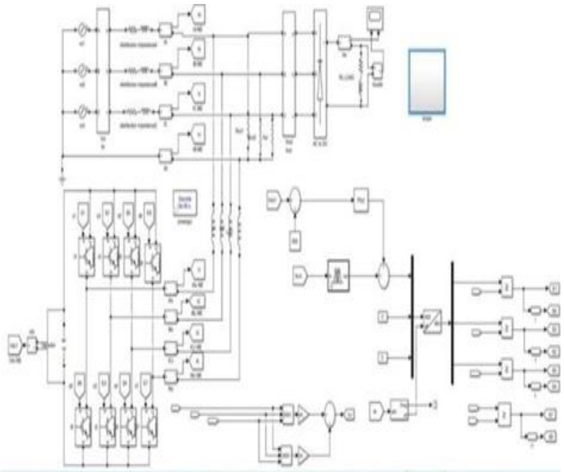

Fig. 6.7 Simulation diagram of three phase four wired DSTATCOM using ANFIS (Adaptive Neuro-Fuzzy Interference System)

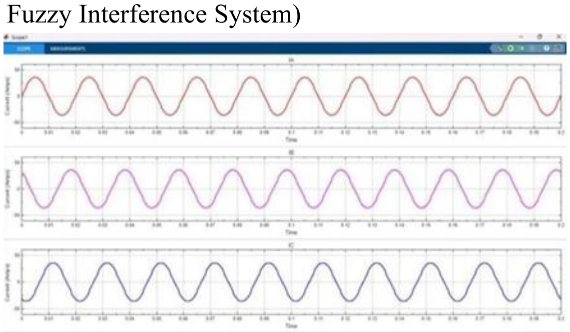

Fig. 6.8 Three Phase Source Current of three phase four wired DSTATCOM using ANFIS (Adaptive Neuro-Fuzzy Interference System)

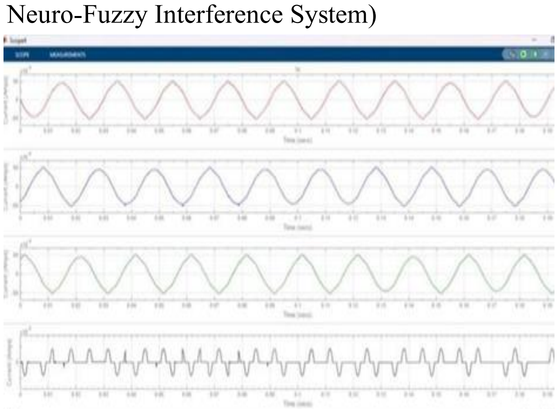

Fig. 6.9 Three Phase Compensating Currents of three phase four wired DSTATCOM using ANFIS (Adaptive Neuro-Fuzzy Interference System)

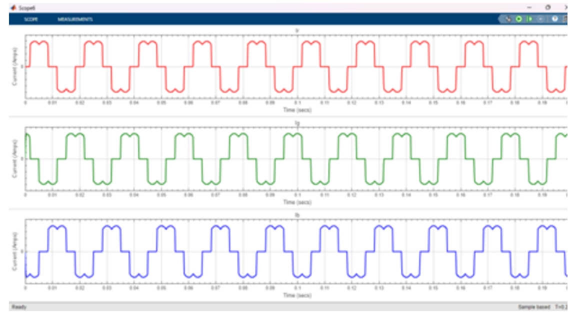

Fig. 6.10 Three Phase Load Currents of three phase four wired DSTATCOM using ANFIS(Adaptive Neuro-Fuzzy Interference System)

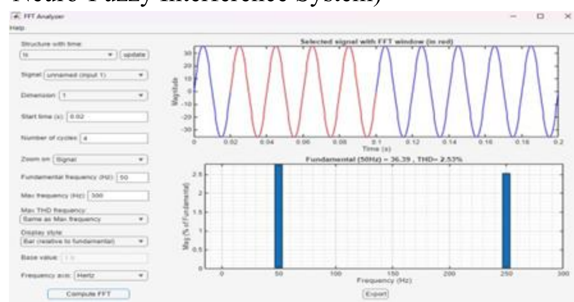

Fig. 6.11 Phase A Source Current THD value with DSTATCOM using ANFIS (Adaptive Neuro-Fuzzy Interference System)

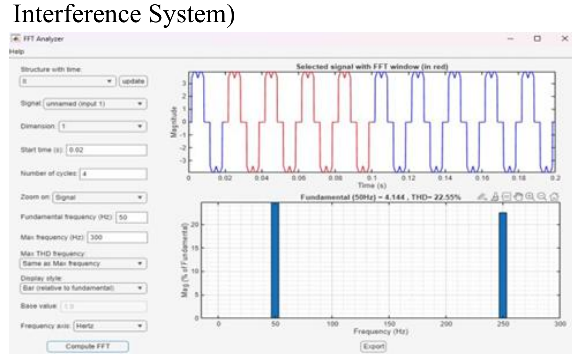

Fig. 6.12 Phase A load current THD value with DSTATCOM using ANFIS (Adaptive Neuro-Fuzzy Interference System)

V. CONCLUSION

This paper introduced a three phase four wire DSTATCOM using AI to control the quality of power in distribution systems. The results of simulation studies proved that SRFT and IRPT controllers enhance the performance of the system by decreasing THD and increasing the power factor. The ANFIS-based controller however, performed better with faster dynamic response, reduced harmonic distortion (2-3.2%), and a power factor that was close to unity (~0.99). The findings confirm that AI-based control plans, particularly ANFIS, are quite useful in harmonics reduction, current balancing, and safe operation of the distribution system in nonlinear and unbalanced loads.

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