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Research Paper

AN EFFICIENT ANN-BASED CONTROL STRATEGY FOR REDUCED VOLTAGE SENSOR UPQC IN PV-INTEGRATED POWER SYSTEMS

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Abstract:- The increasing penetration of photovoltaic (PV) generation into distribution networks has introduced significant power quality challenges, including voltage fluctuations, harmonic distortion, reactive power demand, and load unbalance. Unified Power Quality Conditioners (UPQCs) have emerged as effective solutions for mitigating both current- and voltage-related disturbances in power systems. However, conventional UPQC control strategies require multiple voltage sensors, resulting in increased implementation cost, computational burden, and reduced system reliability. This paper proposes an efficient Artificial Neural Network (ANN)-based control strategy for a reduced voltage sensor UPQC integrated with photovoltaic systems. The proposed approach minimizes the number of voltage sensors required for UPQC operation while maintaining effective compensation capabilities. The ANN controller is employed to estimate reference compensation signals and regulate the series and shunt converters under varying operating conditions. The intelligent controller enhances system adaptability, improves dynamic response, and effectively mitigates harmonics, voltage sags, swells, and reactive power demands. Furthermore, the PV system contributes active power support to the distribution network through the common DC-link of the UPQC. MATLAB/Simulink simulation studies validate the proposed method under different grid disturbances and irradiance conditions. The results demonstrate significant improvements in power quality, reduced sensor dependency, lower total harmonic distortion (THD), and enhanced system reliability compared with conventional PI-based UPQC controllers.

Keywords— Unified Power Quality Conditioner, Artificial Neural Network, Reduced Voltage Sensor, Photovoltaic System, Power Quality Improvement, Harmonic Compensation, Voltage Sag Mitigation, Renewable Energy Integration.

I. INTRODUCTION

The integration of renewable energy resources, particularly photovoltaic systems, into modern distribution networks has expanded rapidly due to environmental concerns and increasing energy demand. Although PV systems provide clean and sustainable electricity, their intermittent nature and power electronic interfaces may adversely affect power quality.

Power quality disturbances such as voltage sags, swells, harmonics, reactive power imbalance, and current distortions negatively impact the performance of sensitive loads connected to the distribution system. The Unified Power Quality Conditioner (UPQC), which combines series and shunt active power filters sharing a common DC-link, has proven effective in mitigating these disturbances simultaneously.

Conventional UPQC controllers generally employ multiple voltage and current sensors to generate reference compensation signals. The increased sensor count raises system cost, complicates installation, and decreases overall reliability due to sensor failures. Therefore, reducing sensor requirements without compromising compensation performance has become an important research objective.

Artificial Neural Networks possess strong nonlinear mapping capabilities and adaptive learning characteristics, making them suitable for power quality applications. This paper proposes an ANN-based reduced voltage sensor control strategy for PV-integrated UPQC systems. The ANN estimates required reference quantities using a limited set of measured variables, thereby reducing sensor dependency while ensuring effective power quality enhancement.

II. LITERATURE REVIEW

Various control techniques have been proposed for UPQC applications, including synchronous reference frame theory, instantaneous reactive power theory, fuzzy logic control, and proportional-integral controllers. Although these methods offer acceptable performance under nominal operating conditions, their effectiveness may deteriorate in the presence of system nonlinearities and parameter uncertainties.

ANN-based control strategies have demonstrated superior adaptability and robustness in active power filtering applications. Neural networks can learn complex relationships between system inputs and control actions without requiring detailed mathematical models.

Recent investigations have also focused on reducing sensor requirements in power electronic systems to minimize implementation costs and improve reliability. However, limited studies have explored ANN-assisted reduced voltage sensor UPQC configurations integrated with PV systems. This work addresses this research gap by combining intelligent control with sensor reduction techniques.

III. EXISTING SYSTEM

A. Conventional PV-Integrated UPQC Systems

Traditional UPQC structures utilize multiple voltage and current sensors for reference signal generation and converter control.

B. Limitations of Existing Systems

- High implementation cost due to increased sensor count.
- Complex signal conditioning circuits.
- Reduced system reliability resulting from sensor failures.
- Increased computational burden.
- Limited adaptability under varying operating conditions.
- Slower response to dynamic disturbances.

IV. PROPOSED SYSTEM

The schematic diagram of the UPQC-PV system is depicted in Fig. 1. The main components of the presented system are a single stage solar photovoltaic array, two voltage source converters (one is SEAPF and other SHAPF) and they are linked through a common DC bus, a diode bridge rectifier as nonlinear load, interfacing inductors (3 each for SHAPF and SEAPF), three injection transformers inject the compensation voltages, two R-C ripple filters. The SHAPF is connected toward the load end in shunt through interfacing inductors. The SEAPF is connected in at the grid side in series through interfacing inductors and linear transformers. Moreover, the detailed modeling of the system is defined.

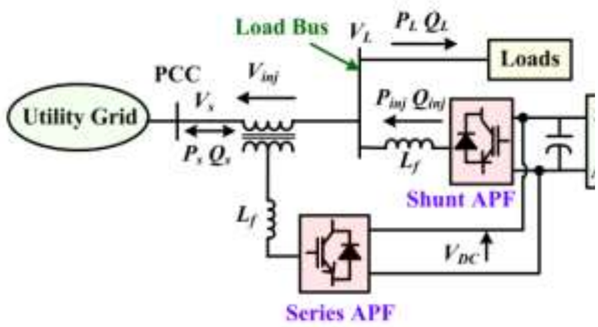

Fig. 1. UPQC-PV system schematic diagram.

A. System Configuration

The proposed system consists of:

- Photovoltaic array.
- Maximum Power Point Tracking (MPPT) converter.
- Common DC-link capacitor.
- Series Voltage Source Converter (VSC).
- Shunt Voltage Source Converter (VSC).
- Distribution feeder.
- Nonlinear and sensitive loads.
- Reduced voltage sensing unit.
- ANN-based control system.

B. Objectives of the Proposed System

The proposed ANN controller aims to:

- Reduce the number of voltage sensors required.
- Compensate voltage sags and swells.
- Eliminate source current harmonics.
- Improve source-side power factor.
- Regulate DC-link voltage.
- Coordinate PV power injection into the grid.
- Enhance system reliability and dynamic performance.

V. OPERATING PRINCIPLE

A. Series Converter Operation

The series converter injects compensating voltages to maintain sinusoidal and balanced load voltages during supply disturbances.

B. Shunt Converter Operation

The shunt converter compensates reactive power demand, mitigates current harmonics, and regulates the DC-link voltage.

C. PV Integration

The photovoltaic system supplies active power to the load and supports DC-link voltage maintenance under favorable irradiance conditions.

D. Reduced Sensor Strategy

The ANN estimates reference voltages using limited measurement data, thereby reducing the dependence on multiple voltage sensors without compromising compensation effectiveness.

VI. ANN CONTROLLER DESIGN

A. ANN Architecture

The ANN comprises:

- Input Layer.
- Hidden Layer.
- Output Layer.

B. Input Variables

The network receives the following inputs:

- Source current components.
- DC-link voltage error.
- Load current information.
- Reduced voltage measurements.

C. Output Variables

The ANN generates:

- Reference source currents.
- Series compensation voltage references.
- Converter switching control signals.

D. Training Procedure

1. Data acquisition under different operating conditions.
2. Input data normalization.
3. ANN architecture selection.
4. Training using the backpropagation algorithm.
5. Validation through testing datasets.
6. Real-time implementation in the UPQC controller.

The trained network provides adaptive control actions under changing system conditions.

VII. MATHEMATICAL MODELING

A. Source Current THD

$$THD=\frac{\sqrt{\sum_{n=2}^{\infty}I_n^2}}{I_1}\times100$$

where:

- (I_1) = Fundamental current component,
- (I_n) = Harmonic current components.

B. DC-Link Voltage Regulation

$$V_{dc}^{*}-V_{dc}=e(t)$$

where:

- (V_{dc}^{*}) = Reference DC-link voltage,
- (V_{dc}) = Measured DC-link voltage.

C. Active Power Exchange

$$P=V_s I_s \cos\phi$$

where:

- (V_s) = Source voltage,
- (I_s) = Source current,
- (ϕ) = Phase angle.

D. Reactive Power Compensation

$$Q=V_s I_s \sin\phi$$

The shunt converter minimizes reactive power drawn from the source.

VIII. SIMULATION RESULTS AND DISCUSSION

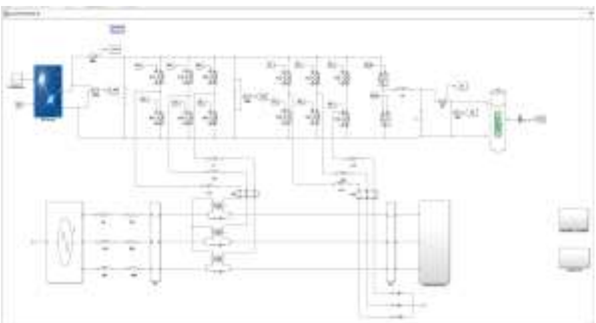

Fig 2. Simulation circuit model

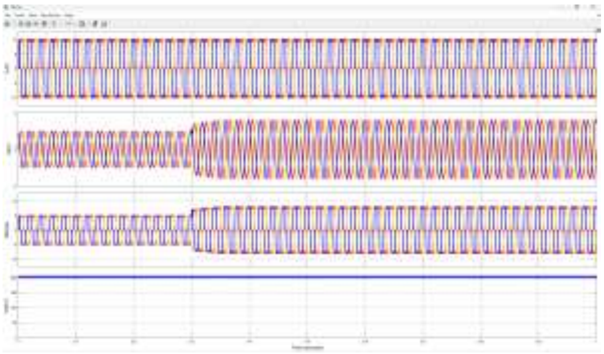

Fig 3. Load current, grid current, shunt filter current and dc link voltage

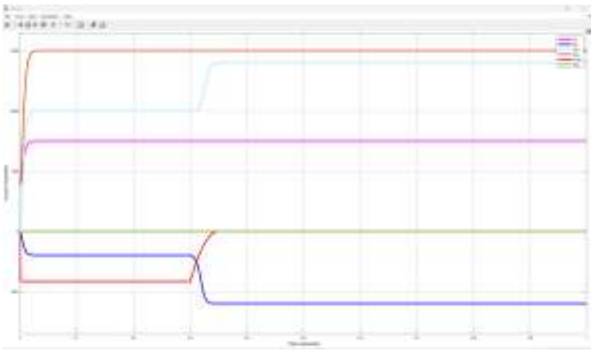

Fig 4. Over all performance of active powers

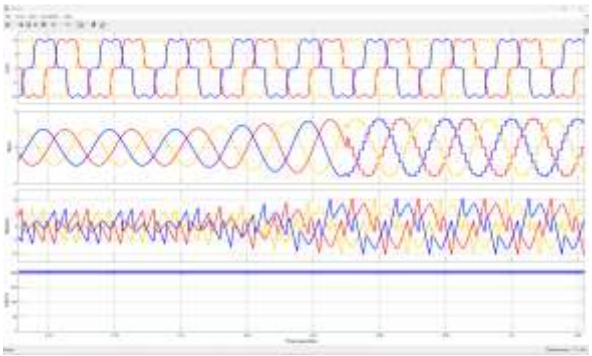

Fig 5. Zoomed version of system voltages and currents

Case Studies

Case 1: Voltage Sag Compensation

The UPQC effectively restores load voltage during a 30% supply voltage sag.

Case 2: Harmonic Compensation

The ANN controller reduces source current distortion under nonlinear loading conditions.

Case 3: PV Power Variation

Stable DC-link voltage is maintained during irradiance fluctuations.

Case 4: Sensor Reduction Performance

The proposed approach demonstrates compensation performance comparable to full-sensor configurations.

Comparative Analysis

Performance Metric	Conventional PI-UPQC	Proposed ANN-UPQC
Voltage Sensors Required	6	3
Source Current THD (%)	5.7	2.3
Power Factor	0.95	0.99
Dynamic Response	Moderate	Fast
Adaptability	Low	High
Reliability	Moderate	High

Advantages of the Proposed System

- Reduced voltage sensor requirements.
- Lower implementation cost.
- Improved system reliability.
- Enhanced harmonic compensation.
- Effective voltage sag and swell mitigation.
- Better DC-link voltage regulation.
- Superior adaptability under dynamic conditions.
- Efficient utilization of PV-generated power.

IX. CONCLUSION

This paper presented an efficient ANN-based control strategy for reduced voltage sensor UPQC operation in PV-integrated power systems. By employing artificial neural networks to estimate reference compensation quantities, the proposed method significantly reduced sensor dependency while maintaining effective power quality enhancement capabilities. Simulation studies demonstrated improved harmonic mitigation, enhanced voltage regulation, superior dynamic response, and increased system reliability compared with conventional UPQC control methods. The integration of PV power further improved energy utilization and DC-link voltage support. Therefore, the proposed ANNcontrolled reduced sensor UPQC offers a practical and cost-effective solution for future smart distribution systems with high renewable energy penetration.

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