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Smart ANN based Inverter Control for Reducing Harmonics in PV Assisted EV Charging Station

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ABSTRACT: This research is focused and targeted at improving power quality at a solar photovoltaic (PV) array-fed electric vehicle (EV) charging station. The station can function independently, charging EV batteries on solar energy, as well as exporting any excess energy for connection with the utility network. It also enhances grid power quality through reactive compensation and elimination of harmonics with a controller based on an artificial neural network (ANN). The charger station can perform various operations: 1. harmonic reduction with ANN-based control, 2. regulating EV battery charging and discharging, 3.performing EV charging and harmonic current compensation simultaneously, and 4.enabling EV discharging with harmonic current compensation. The control strategy, with the help of ANN-based controller, can maintain stable operation even at unbalanced voltage conditions at the grid. With ANN control, total harmonic distortion (THD) on grid currents is minimized effectively by 0.81%, with levels below 1%. The charging station primarily operates in grid-connected mode but can switch into standalone mode in case there is a loss of synchronization at the grid, allowing the PV array to continue charging at the EV battery.

KEYWORDS: Solar Photovoltaic (PV) Array, Electric Vehicle (EV) Charging Station, Utility Grid Connection, Artificial Neural Network (ANN) Control, EV Battery recharging and Discharging, Harmonic Filter, power quality.

I. INTRODUCTION

It is essential in the present power systems that the supply reliability must be improved and the total harmonic distortion should be minimized for successful energy transformation. In this paper, a new approach based on the application of an Artificial Neural Network (ANN)-based a controller has been introduced to enhance power quality and the minimization of the total harmonic distortion in the three-phase inverter system. The ANN controller dynamically optimizes the switch strategy of the inverter in order to provide better voltage stability and elimination of the harmonics. The controller based on machine learning characteristics efficiently adapts the load changes and provides better performance in comparison to the conventional controls. Simulation results validation the superiority of the ANN-based control method by providing better quality of the power and elimination of the harmonics.

Total harmonic distortion (THD) reduction and power quality improvement have grown in importance in presentday power systems in recent years. Multiple studies focused on how Artificial Neural Networks (ANN) might enhance inverter performance and optimise control schemes.Singh et al. [1] proposed a power quality improvement technique for a PV- based EV charging station with a three-phase grid connection, highlighting the necessity of efficient harmonic mitigation techniques. Quawi et al. [2] proposed an ANN-based controller for hybrid power distribution systems, demonstrating its performance in harmonic elimination and system stability enhancement. Mohamed et al. [3] developed a neural-network-based model predictive control (MPC) strategy for three-phase inverters with an LC filter, ensuring better voltage stability and reduced harmonic distortion .El Iysaouy et al. [4] suggested an effective singlephase DC-DC microinverter with passive filters for harmonic mitigation. Their approach emphasized the importance of





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advanced filtering techniques for power quality improvement. Furthermore, El-Hawary [5] reviewed the state-of-the-art developments in smart grids, emphasizing the necessity of intelligent control strategies for quality enhancement and energy management. A hybrid ANN and fuzzy logic switching model (FLSM) to predict tidal currents was suggested by El-Hawary [6], indicating the versatility of ANN-based control systems for adapting to changing environments. Also, Mishra and Panda [11] suggested an ANN-based shunt active power filter to enhance power quality, which performed better in harmonic elimination compared traditional methods.Rahmani et al. [12] suggested a thyristor-controlled reactor-based shunt hybrid power filter for power quality enhancement, highlighting the necessity for hybrid solutions. Singh and Sharma [13] implemented a neural network-controlled three-level neutral-point-clamped (NPC) inverter for shunt active power filtering, with significant THD reductions. Rashid et al. [14] and Awal et al. [15] also developed ANN-based shunt active power filters for harmonic compensation and power factor correction, proving their efficiency for real-time power quality enhancement.Abu-Mouti and El-Hawary [16] examined an artificial bee colony algorithm for the optimal allocation of distributed generation, which again emphasized the applicability of AI-based methods for modern power distribution systems.

II. PROPOSED CONFIGURATION

The system proposed uses the implementation of an Artificial Neural Network (ANN) controller for the improvement of the quality of the power and the elimination of Total Harmonic Distortion (THD) in the three-phase inverter system. All the components have very critical roles in the successful transformation of the energy and elimination of the harmonics. Below is the explanation of the components and the roles they have in the system.

1. Power Source (AC grid or alternative energy source)

Powers the system. Either the utility grid or photovoltaic system or any other renewable source. Provides uninterrupted and consistent supply of power for inverter operation.

2. Rectifier (AC to DC Conversion)

It converts the AC voltage from the source into the steady DC voltage the inverter requires. Acts as the intermediary between the AC source and the inverter for the smooth supply of DC voltage.

3. DC Link (Energy Storage or Capacitor Bank)

It holds the fixed DC voltage before sending it into the inverter. It provides a steady source of energy that is not subject to voltage swings and makes the inverter operate smoothly.



Fig.1 POWER CONTROLLED THREE PHASE INVERTER FOR PV SYSTEMS





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4. Three-Phase Inverter (Switching Circuit using IGBT

It converts the controlled DC voltage into three-phase AC output at the wanted voltage level and frequency. It generates a pulse-width modulated PWM waveform that gets filtered to provide a sinusoidal output.

5. The load, also referred to as the three-phase inductive or resistive load

Represent the actual electrical load that consumes power from the system. They could be any three phase device, such as motor or industrial machinery

6. Feedback-producing voltage and current sensors

Together with other system factors, measures the output volatge, current, and THD. provide real time data to the ANN controller for adaptive control.

7.Control System (Artificial Neural Network Controller)

Controls the inverter switching through the assistance of an ANN controller.Dynamically adjusts the switching strategy to optimize power quality and reduce Total Harmonic Distortion (THD).

8.PV-EV Integration

The system supports the charging station of the PV-based Electric Vehicle, enabling it to utilize renewable energy. The inverter ensures effective grid-to-vehicle (G2V) and vehicle-to-grid (V2G).

III. PROPOSED METHODOLOGY

Replaces the conventional controllers (e.g., PID or PI) for optimal switching and reducing the THD. Learns inputoutput mappings and adjusts the switching dynamically .Enhances the output quality of the power by reducing the harmonics and voltage regulation Offers more adaptability towards load changes.



FIG.2 NEURAL NETWORKING PROCESSING AND LAYER

Power quality analysis(Techniques for THD measurement and Improvement)

It confirms that the output satisfies IEEE standards by measuring the output waveform's harmonic content. The system becomes more efficient and equipment heating losses are reduced when the THD is reduced. ANN-based control outperforms conventional controllers in terms of harmonic mitigation.

Input voltage and current inputs:

It takes V_{abc} (per unit voltage) and ILabc (Load currents) as inputs. They are transformed into the dq0 frame using a Park Transform.

Artificial Neural Network (ANN) Controller:

ANN takes input signals and generates corrective control actions. It improves dynamic performance and avoids the issues of power quality such as harmonics, voltage unbalance, and reactive imbalance. ANN output also finds application in current reference generation (Io _Ref) for the sake of maintaining the stability in the power. DQ0 to ABC transformation: These processed dq0 signals are transformed into abc components in order that there will be suitable control in the three-phase system. Controlled current is fed into PWM (Pulse Width Modulation) Generator for switch-on/off pulse generation.

PWM-Based Switching Control:

PWM generator generates the pulses used for optimal current injection for compensation. These pulse gates are fed into the controlling switches of the compensator and help in minimizing the problems associated with the power quality.





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FIG.3 ANN CONTROL AND WEIGHT PROCESSING

IV. EQUATIONS FOR THD REDUCTION USING ANN CONTROLLER:

The ANN generates optimal control signals to reduce THD in current/voltage wave forms. The following mathematical expressions are used:

Error Signal Calculation

e(t) = I ref(t) - I load(t) ----- (1) * e(t) = Error signal * I ref(t) = Reference current produced by ANN * I load(t) = Load current

Weight Update Rule in ANN Training: Back propagation Algorithm

Wnew = Wold + n.e(t).X Where: * W new = New weights * W new = New weights * W old = Old weights * n= Learning rate * X = Input

Harmonic Compensation (Reference Current Generation):

I comp=I load-I ref

----(3)

----(2)

> Park transformation (abc to dq0) for current extraction

The a b c frame current load is converted into the dq0 frame using the Clarke-Park transformation:

$$\begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix} = \tfrac{2}{3} \begin{bmatrix} \cos(\theta) & \cos(\theta - 120^\circ) & \cos(\theta + 120^\circ) \\ \sin(\theta) & \sin(\theta - 120^\circ) & \sin(\theta + 120^\circ) \\ \tfrac{1}{2} & \tfrac{1}{2} & \tfrac{1}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

where:

-----(4)

Ia, Ib, Ic = Load currents in abc frame

Id, Iq, Io = Direct, quadrature, and zero-sequence currents

 $\theta = \omega^* t = Phase angle$

This process separates basic components (Id, Iq) from harmonics and enables accurate compensation.





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ANN-Based Reference Current Generation

The ANN controller generates the reference current I ref by adaptive learning from the error between desired and load currents:

I ref = ANN(Idq0, Vdq0)

----(5)

Where: Idq0 = Transient load current Vd0 = Voltage in the d0 frame ANN adjusts weights dynamically based on training and live-time error. The ANN weighting update rule is the gradient descent rule:

Wnew = WOld + n.e(t).X

Where: * Wnew, Wold = New and old weights * n = Learning rate *e(t) = I ref - I load = Error signal * X = Input vector

dq0 to abc Transformation for PWM Control

After ANN correction, the reference current is converted back to the abc frame using inverse Park transformation:

$$\begin{bmatrix} I_a^{ref} \\ I_b^{ref} \\ I_c^{ref} \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 1 \\ \cos(\theta - 120^\circ) & \sin(\theta - 120^\circ) & 1 \\ \cos(\theta + 120^\circ) & \sin(\theta + 120^\circ) & 1 \end{bmatrix} \begin{bmatrix} I_d^{ref} \\ I_q^{ref} \\ I_0^{ref} \end{bmatrix} -\dots -(6)$$

These currents drive the PWM generator, producorate signals the inverter.

THD Management and Estimation to Achieve ≤0.81%

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \times 100\%$$
 ----(7)

*In=The RMS value of the nth harmonics component I1 is the RMS value of the fundamental frequency. To maintain THD $\leq 0.81\%$, the ANN dynamically minimises the error between I load and I ref by adjusting weights and bias values.





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Weighted Training Equations for Artificial Neural Networks to Improve Power Quality Calculating weighted sums in the hidden layer

$$z_j = \sum_{i=1}^n W_{ji} a_i + b_j$$

----(8)

Where:

* zj = net input to neuron j *wji= Weight of Neurone į to Neurone j * ai = Activation value of Neurone I

* bj = the bias term of neurone j

Activation Function (for ReLU, Sigmoid, or Harmonic Reduction) aj=f(zj) For the sigmoid's activation:

$$f(z_j)=rac{1}{1+e^{-z_j}}$$
 -----(9)

Concerning the activation of Re LU: f(zj) = max(0,zj)

V. BATTERY PARAMETERS AND STATE OF CHARGE OF LEAD ACID BATTERY



FIG.6 BATTERY BLOCK PARAMETERS AND STATE OF CHARGING MONITORING

A lead-acid battery Simulink simulation model is displayed in the image. Under various operating circumstances, the model examines battery behaviour, voltage, current, and State of Charge (SOC).

Important Factors and Their Values

1. Type of Battery: Lead-Acid

2. 300V is the nominal voltage (V).

3. 6.5Ah is the rated capacity (Ah).

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4. Starting SOC (percentage): 99%

5. 6.825Ah is the maximum capacity (Ah).

6. Voltage (V) at Full Charge: 3180.5082V

7. 0.2054925A is the nominal discharge current (A).

Several parameters are used to model the battery in order to ascertain its dynamics and charge/discharge characteristics

BATTERY SIMULATION EQUATIONS:

State of Charge (SOC) calculation:

where:

* SOC(t) = State of Charge at time t
* SOC(0) = Initial SOC of 99%
The battery's rated capacity, or Cr, is 6.5Ah.
* Current in the battery (A) = I bat

Equation for Battery Terminal Voltage
 Taking internal resistance into account, the battery's terminal voltage is:

$$V_{bat} = V_{oc} - I_{bat} R_{int}$$
(11)

where:

* V bat = voltage at the battery's terminal

* Open circuit voltage (voc) is dependent on SOC.

* I bat = current in the battery

* R int = Battery internal resistance

Battery-Stored Energy

The battery's total stored energy can be found using the following method:

$$E_{stored} = V_{bat} \times Q$$

----(12)

where:

* Wh (energy stored) = stored E * Q is the battery's stored charge (Ah). Due to: Q=SOC * Cr It is possible to rewrite the stored energy as: E stored = V bat * (SOC* Cr)

VI. SIMULATION RESULTS AND DISCUSSION

1. Achieved Power Quality Improvement: The ANN-based controller reduces THD to 0.81% in Comliance with IEEE 519 standards.

2. Effective Harmonic Mitigation: By combining SPWM techniques with the recommended ANN-Based control strategy, a steady and smooth waveform is generated.

3. Practical Use: This research could have a significant impact on electric vehicle inverters, industrial power electronics, and the Integration of renewable energy sources.





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|DOI: 10.15680/IJIRSET.2025.1405268| ted signal O Display Display se Selected signal: 75 cycles, FFT window (in red): 7 cycles 50 0 -50 Time (s) nal to analyze -O Display FFT window 7 of 8.852 cycles of selected signal FFT window: 0 02 0.04 0.06 0.08 0 12 Time (s) FFT analysis

FIG.7 TOTAL HARMONIC DISTORTION AND FUNDAMENTAL FREQUENCY ANALYSIS

Important Findings from the Simulation:

I .Amplitude of Fundamental Frequency (50 Hz) = 73.49

II. 0.81% is the total harmonic distortion (THD).

III .Harmonic Spectrum: Displays individual frequencies up to 1000 Hz.

IV. THD Compliance: The THD is kept below 1%, in accordance with IEEE 519 power quality standards.

1. The Artificial Neural Network (ANN) Controller adjusts the control parameters after learning the system dynamics. helps reduce harmonics dynamically by using active filtering.



2. Sinusoidal pulse width modulation, or SPWM

SPWM optimises switching pulses to reduce higher orderharmonics.

3. The strategy for D-Q Transform control

The control system converts ABC components to the DQ0 reference frame in order to provide Precise harmonics compensation.

4. Active Power Filter (APF) Implementation eliminates undesirable harmonics through the use of PWM control methods.



FIG .9 VOLTAGE, CURRENT, AND FREQUENCY ANALYSIS USING SIMULINK





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We can look at the different current and voltage components from the waveform output to assess the power quality. **I.Source of Voltage** (Top Waveform) :



FIG.10 SOURCE VOLTAGE WAVEFORM

The waveform displays a balanced three-phase sinusoidal voltage .Minimal distortion indicates stable grid conditions before any harmonics or disturbances occur.

If there are harmonic levels, a Fast Fourier Transform (FFT) analysis is recommended to measure them.



I. The converter current:

FIG.12 CONVERTER CURRENT WAVEFORM

switching pulses to illustrate how the converter works. illustrates active harmonic compensation, which supports power quality improvement methods such as Shunt Active Power Filters (SAPF). A power factor analysis is required to confirm the efficacy if the device is intended for reactive power compensation.

III. Neutral Current (Yellow Signal, fourth waveform):

Unbalanced or harmonic-rich loads are indicated by high-frequency oscillations .The existence of zero-sequence components, which are usually caused by unbalanced nonlinear loads, is confirmed by the presence of neutral current The performance of the filter/controller would be confirmed by a decrease in neutral current after compensation.



FIG.13 NEUTRAL CURRENT WAVEFORM





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IV. Source Current:



Contains harmonics at first, but after 0.5 seconds, it seems to be more sinusoidal, suggesting that the filtering was successful .The effectiveness of the implemented control strategy will be demonstrated by comparing THD before and after compensation .The decrease in peak values after compensation implies less strain on grid elements, improving overall effectiveness.

• The suggested system effectively reduces harmonics form 5% to 0.81% by using the ann controller and neutral current imbalance.



V. Dc voltage:

FIG.15 DC VOLTAGE WAVEFORM

A nearly constant voltage with slight fluctuations (ripple), with stable DC voltage with some ripple or noise. The initial section has slight transient behavior, possibly caused by power-on effects. The waveform stabilizes with some slight oscillation, may be some lingering ripple from the power supply.

VII .CONCLUSION

This study focuses on improving power quality in an electric vehicle (EV) charging station powered by a solar photovoltaic (PV) array. The station can run independently, charging EV batteries using solar energy while also feeding any extra power into the utility grid. Beyond just providing energy, it helps improve grid stability by reducing harmonics and offering reactive power support, thanks to an artificial neural network (ANN)-based controller. The charging station is designed to handle multiple tasks: 1. Minimizing harmonics through an ANN-driven control system, 2. Managing the charging and discharging process of EV batteries, 3. Enabling EV charging while simultaneously compensating for harmonic currents, 4. Allowing EV discharging while also addressing harmonic distortions. With its ANN-based control strategy, the system remains stable even when the grid voltage is unbalanced. The ANN ensures that total harmonic distortion (THD) in the grid currents is kept as low as 0.81%, staying well below 1%. While the

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station mainly operates when connected to the grid, it can automatically switch to standalone mode if grid synchronization is lost, ensuring uninterrupted operation using solar power.

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