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Original Article

Analysis of Harmonic Reduction Using An Intelligent Control Active Filter in A Solar Grid with Variable Load

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Abstract - *Electricity quality maintenance is severely hampered by the integration of solar electricity into the grid, especially when there are changing loads and harmonic disturbances. This study suggests an intelligent control active filter for harmonic reduction in a solar grid with changeable load conditions as a way to address these issues. The efficacy and adaptability of traditional passive filters are limited, so innovative control strategies must be used to mitigate harmonics effectively. This study looks at a grid-connected photovoltaic system's static variable load. The integration of grid-photovoltaic assembled a reversible converter to make the suggested system more efficient in power disturbances. The power circuit consists of two 75-watt series photovoltaic panels connected to a DC-DC static variable load. Additionally, an intelligent control active filter with a basic design is intended for harmonic reduction. Current control of the reversible inverter to reduce fluctuation under static load variations and synchronize the output current to the alternate grid voltage. The current photovoltaic grid system is capable of switching the direction of active powers in the alternative grid for static changeable loads brought on by reversible converter design, according to results obtained using MATLAB/Simulink for easy access, a categorized list of 38 publications on the subject is also provided.*

Keywords - *Advanced Control Active Filter (ACAF), Harmonic Reduction (HR), Varying Load (VL), Transient Response (TR), Adaptive Control (AC), Predictive Control (PC), Fuzzy Logic Control (FLC), Neural Network Control (NNC), Model Predictive Control (MPC).*

1. Introduction

An intelligent control active filter represents a significant advancement in power quality management and grid stability. Active filters are devices used to mitigate harmonic distortion, compensate for reactive power, and improve the overall quality of electrical power in distribution systems.

Unlike passive filters, active filters can dynamically respond to changing load conditions and disturbances, making them highly effective in modern power systems with variable loads and renewable energy sources like solar and wind. The introduction of intelligent control to active filters elevates their functionality by incorporating sophisticated algorithms, advanced sensors, and real-time data processing capabilities.

1.1. Adaptability

Intelligent control algorithms allow active filters to adapt to changing grid conditions, load profiles, and power quality requirements. They can dynamically adjust filter parameters and operating modes to optimize performance in real time.

1.2. Harmonic Mitigation

By analysing grid voltage and current waveforms, intelligent control algorithms can accurately detect and mitigate harmonic distortions caused by nonlinear loads, power electronics, and other sources. This helps maintain compliance with international power quality standards and regulations.

1.3. Reactive Power Compensation

Active filters with intelligent control can effectively compensate for reactive power, improving power factor and voltage stability in distribution networks. This capability is particularly valuable in systems with fluctuating loads and renewable energy integration.

1.4. Grid Resilience

Intelligent control enables active filters to enhance grid resilience by quickly responding to disturbances such as voltage sags, swells, and fluctuations in frequency. They can inject or absorb reactive power as needed to stabilize the grid and prevent voltage instability.

1.5. Optimization

By continuously analysing grid parameters and load characteristics, intelligent control systems optimize the operation of active filters to minimize energy losses, maximize efficiency, and reduce operational costs over time.

1.6. Integration with Smart Grids

Active filters with intelligent control can seamlessly integrate with smart grid infrastructures, enabling communication, remote monitoring, and coordination with other grid assets. This facilitates grid-wide optimization and enhances overall system reliability and performance.

1.7. Fault Detection and Diagnostics

Advanced diagnostic capabilities embedded in intelligent control systems enable proactive fault detection, troubleshooting, and predictive maintenance of active filters. This helps minimize downtime and ensures the long-term reliability of power quality enhancement equipment.

The introduction of intelligent control to active filters represents a significant advancement in power quality management, grid stability, and energy efficiency. By leveraging advanced control algorithms and real-time data processing, these systems offer unparalleled flexibility, adaptability, and performance in modern electrical distribution networks of VR.

- Investigate the performance of different intelligent control algorithms, such as fuzzy logic, neural networks, and AC, in reducing harmonic distortion in the solar grid.
- Assess the impact of variable load characteristics on harmonic generation and propagation within the grid and analyze how the active filter responds to these variations.
- Optimize the parameters of the intelligent control active filter to maximize Harmonic Reduction (HR) efficiency while minimizing losses and costs.
- Evaluate the overall impact of the active filter on grid stability, power quality, and system reliability in the presence of solar PV generation and variable loads.

2. Objective of Analysis

The primary objective of this analysis is to investigate the effectiveness and feasibility of employing an intelligent control active filter for harmonic reduction in a solar grid with Varying Load (VR) conditions.

- Harmonic Reduction Assessment
- Adaptability to variable loads
- Grid stability enhancement
- Comparative analysis

2.1. Scope of Research

The following are the points of scope of research work.

2.1.1. Harmonic Reduction Techniques

Harmonic Reduction (HR)techniques aim to mitigate or eliminate harmonic distortion in electrical systems, improving power quality and ensuring the reliable operation of electrical equipment [1]. Here are some commonly used harmonic reduction techniques:

- Passive Filters
- Active Filters
- Hybrid Filters
- Variable Frequency Drives (VFDs)
- Phase-Shifting Transformers
- Resonant Filters
- Active Front-End Converters
- Notch Filters
- Digital Signal Processing (DSP) Techniques
- Load Management

2.1.2. Intelligent Control Algorithms

Intelligent control algorithms utilize advanced computational techniques to make decisions and adjustments in real-time, often based on feedback from sensors or predictive models. These algorithms are particularly useful in complex systems with nonlinearities, uncertainties, and dynamic operating conditions [2]. In the context of HR in a solar grid with variable load, several intelligent control algorithms can be applied:

- Fuzzy Logic Control (FLC)
- Neural Network Control (NNC)
- Adaptive Control (AC)
- Model Predictive Control (MPC)
- Genetic Algorithms (GA)
- Particle Swarm Optimization (PSO)
- Reinforcement Learning (RL)
- Hybrid intelligent control

2.1.3. Solar Grid Integration

Solar grid integration involves the incorporation of solar Photovoltaic (PV) systems into existing electrical grids, enabling the generation of electricity from solar energy and its injection into the grid for distribution and consumption [3]. Here are some key aspects of solar grid integration:

- Interconnection Standards
- Grid Impact Studies
- Grid Code Compliance
- Power Electronics Interfaces
- Voltage and Frequency Regulation
- Grid-Forming Inverters
- Energy Management Systems
- Grid Resilience and Flexibility
- Energy Storage Integration
- Smart Grid Technologies

By delving into these aspects, the research analysis aims to provide comprehensive insights into the effectiveness, feasibility, and practical implications of utilizing intelligent control active filters for HR in solar grids with variable load conditions.

2.2. Working of an Intelligent Control Active Filter

The working of an intelligent control Advanced Control Active Filter (ACAF) involves several key steps and components to manage power quality in electrical distribution systems effectively [4]. Here is a simplified overview of how it operates:

- Sensing and Monitoring: The active filter continuously monitors the electrical parameters of the grid, such as voltage, current, frequency, and power factor [5, 6]. This is typically done using high-precision sensors and meters installed at strategic locations in the distribution network.
- Signal Processing and Analysis: The raw data collected from sensors are processed and analysed in real-time by the intelligent control system. Advanced algorithms, such as Digital Signal Processing (DSP) techniques and machine learning algorithms, are employed to extract relevant information and identify power quality issues, such as harmonic distortion, reactive power imbalance, and voltage fluctuations [7].
- Reference Generation: Based on the analysis of grid parameters, the intelligent control system generates reference signals that define the desired behaviour of the active filter [8]. These reference signals specify the amount of compensation needed to mitigate power quality problems and maintain grid stability [9].
- Control Algorithm Execution: The intelligent control algorithm calculates the appropriate control signals required to achieve the desired compensation. This involves determining the magnitude, phase, and frequency of the compensation currents injected by the active filter [10, 11].
- Current Injection: The active filter, typically implemented using power electronics devices such as Insulated Gate Bipolar Transistors (IGBTs), injects compensating currents into the grid in real-time [12]. These currents are precisely controlled to cancel out harmonics, balance reactive power, and stabilize voltage fluctuations.
- Feedback Control Loop: The active filter continuously receives feedback from the grid through sensors, allowing the intelligent control system to dynamically adjust its operation in response to changes in load conditions and grid disturbances [13]. This closed-loop control mechanism ensures that the active filter maintains optimal performance under varying operating conditions [14].
- Adaptive Operation: The intelligent control system employs AC strategies to dynamically adjust filter parameters and operating modes based on changing grid conditions and power quality requirements [15]. This adaptability ensures that the active filter remains effective and efficient over time, even as the grid evolves.
- Communication and Integration: In modern power systems, intelligent control active filters are often equipped with communication interfaces (e.g., Modbus, Ethernet) to facilitate integration with Supervisory Control and Data Acquisition (SCADA) systems, Distributed Energy Resources (DERs), and smart grid infrastructure [16]. This enables remote monitoring, control, and coordination of active filter operation across the grid.

By combining advanced sensing, signal processing, control algorithms, and power electronics, intelligent control active filters play a crucial role in improving power quality, enhancing grid stability, and enabling the seamless integration of renewable energy sources in electrical distribution systems [17].

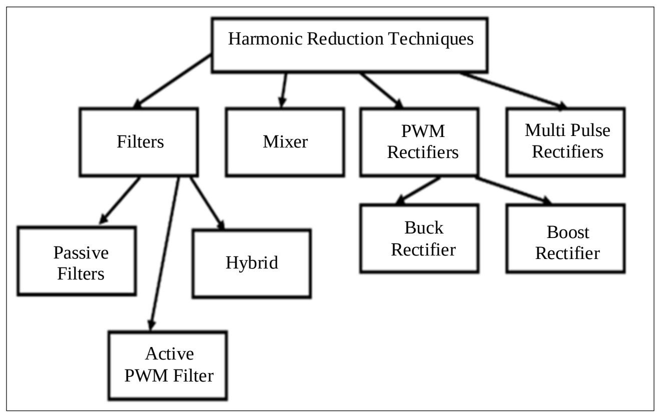

Fig. 1 Configuration block diagram of harmonic reduction techniques

2.3. Role of Harmonic Reduction

Harmonic Reduction (HR) is a crucial function of an intelligent control active filter, as it helps to mitigate harmonic distortions in electrical power systems. Here is a breakdown of the role of harmonic reduction in the context of an intelligent control active filter:

- Harmonic Distortion Mitigation: Electrical power systems often suffer from harmonic distortions caused by non-linear loads such as power electronics, variable frequency drives, and other equipment. These harmonics can lead to various issues, including voltage distortion, increased losses, overheating of equipment, and interference with sensitive electronic devices [18]. The primary role of harmonic reduction through an intelligent control active filter is to mitigate these harmonic distortions effectively [19].
- Detection and Analysis: The intelligent control system continuously monitors the electrical signals in the power system to detect the presence of harmonics. Sophisticated algorithms analyze the waveform of the current and

voltage signals to identify the harmonic frequencies, magnitudes, and phases present in the system [20].

- Reference Generation: Based on the analysis of the harmonic content in the electrical signals, the intelligent control system generates reference signals that define the desired compensation for mitigating the harmonics. These reference signals specify the magnitude and phase of the compensating currents that need to be injected by the active filter to cancel out the harmonic distortions.
- Current Injection: The active filter, under the control of the intelligent control system, injects compensating currents into the electrical system to cancel out the harmonic currents generated by non-linear loads [21]. These compensating currents are precisely controlled to have the opposite phase and magnitude of the harmonic currents, effectively reducing their impact on the system.
- Closed-Loop Control: The active filter operates in a closed-loop control scheme, continuously receiving feedback from the electrical system through sensors. This feedback allows the intelligent control system to dynamically adjust the compensating currents to adapt to changes in the harmonic content of the system and maintain effective harmonic reduction under varying operating conditions [22].
- Compliance with Standards: Harmonic reduction is essential for ensuring compliance with international power quality standards and regulations, which impose limits on the levels of harmonic distortion allowed in electrical power systems. By effectively reducing harmonics, an intelligent control active filter helps utilities and end-users meet these regulatory requirements and avoid penalties [23].
- Improvement of Power Quality: By reducing harmonic distortions, an intelligent control active filter improves the overall quality of electrical power in the system. This results in a more stable voltage waveform, reduced losses in electrical equipment, improved efficiency of power distribution, and enhanced reliability of sensitive electronic devices connected to the system.

Harmonic reduction is a critical function of an intelligent control active filter, helping to mitigate the adverse effects of harmonic distortions in electrical power systems and improve overall power quality and system performance [24].

3. Intelligent Control Using Active Filters

Intelligent control in the context of Advanced Control Active Filter (ACAF) involves using advanced algorithms to dynamically adjust the operation of the active filter in response to changing system conditions and load characteristics. Here is how intelligent control can be implemented in an active filter:

- Real-Time Monitoring
- Data Processing and Analysis
- Intelligent Control Algorithms
- Fuzzy Logic Control (FLC): Fuzzy logic-based controllers can be used to interpret the system's operating conditions and adjust the active filter's parameters accordingly. Fuzzy rules can be defined to map input variables (e.g., harmonic levels, load variations) to appropriate control actions (e.g., adjusting filter parameters, switching frequencies) [25].
- Neural Network Control: Neural networks can learn complex mappings between system inputs and desired outputs, allowing the active filter to adapt its operation based on historical data and past experiences. Neural network controllers can predict optimal control actions for harmonic reduction based on the system's current state.
- Model Predictive Control (MPC): MPC utilizes a dynamic model of the electrical system to predict future system behaviour and compute optimal control inputs that minimize harmonic distortion. MPC algorithms optimize the active filter's parameters over a finite time horizon while satisfying system constraints and performance criteria.
- Control Action Generation: Based on the output of the intelligent control algorithm, the active filter generates control signals to adjust its parameters, such as switching frequencies, filter coefficients, and compensation currents.
- Feedback Loop: The active filter's output is fed back to the system, and the effectiveness of the control action is evaluated based on the reduction in harmonic distortion and improvement in power quality.
- Iterative Adjustment: The intelligent control algorithm iteratively adjusts the active filter's parameters based on feedback from the system, continuously optimizing its performance to achieve the desired level of harmonic reduction [26].
- Solar Grid with Variable Loads: In a solar grid with variable loads, intelligent control techniques play a crucial role in ensuring efficient energy management, maintaining grid stability, and optimizing the utilization of renewable energy sources.
- Load Forecasting: Utilize machine learning algorithms to forecast load demand based on historical data, weather patterns, and other relevant factors. Load forecasting helps anticipate fluctuations in demand and allows for proactive energy management.
- Solar Power Forecasting: Similarly, employ predictive models to forecast solar power generation based on weather forecasts, solar irradiance data, and historical performance. Accurate solar power forecasting enables better planning and integration of solar energy into the grid.
- Demand Response: Implement demand response strategies to adjust energy consumption in response to changes in solar generation and grid conditions. Intelligent algorithms can automatically control appliances, HVAC systems, and other loads to optimize

energy use and minimize grid imbalances.

- Battery Energy Storage Systems (BESS) Control: Integrate battery energy storage systems to store excess solar energy during periods of high generation and discharge it during times of peak demand or low solar output. Intelligent control algorithms manage battery charging/discharging based on real-time grid conditions and load requirements [27].
- Active Power Filtering: Use active power filters with intelligent control algorithms to mitigate harmonic distortion caused by nonlinear loads and fluctuations in solar generation. These filters dynamically adjust their operation to maintain power quality and ensure compliance with grid standards.
- MicroGrid Management: Implement intelligent microgrid management systems to coordinate the operation of distributed energy resources, including solar PV systems, energy storage, and flexible loads [28]. These systems optimize energy flows within the micro grid, balance supply and demand, and ensure grid stability.
- Optimal Dispatch Strategies: Develop optimization algorithms to determine the optimal dispatch of generation sources (solar, battery storage, conventional generators) to minimize operating costs, maximize renewable energy utilization, and meet load demand while considering constraints such as grid capacity and energy storage limitations [29].
- Fault Detection and Self-Healing: Utilize intelligent algorithms for fault detection and self-healing in the grid. These algorithms monitor system parameters, detect anomalies or faults, and automatically reconfigure the grid topology or isolate faulty components to restore normal operation [30].
- Adaptive Control and Learning: Implement Adaptive Control (AC) techniques that learn from historical data and adapt to changing grid conditions over time. Machine learning algorithms can continuously optimize control parameters based on real-time feedback, improving system efficiency and performance.
- Grid Connectivity and Communication: Ensure robust communication infrastructure for real-time data exchange and control signals between grid components, including solar inverters, energy storage systems, smart meters, and control devices. Intelligent communication protocols facilitate coordinated operation and optimization of the solar grid [31].

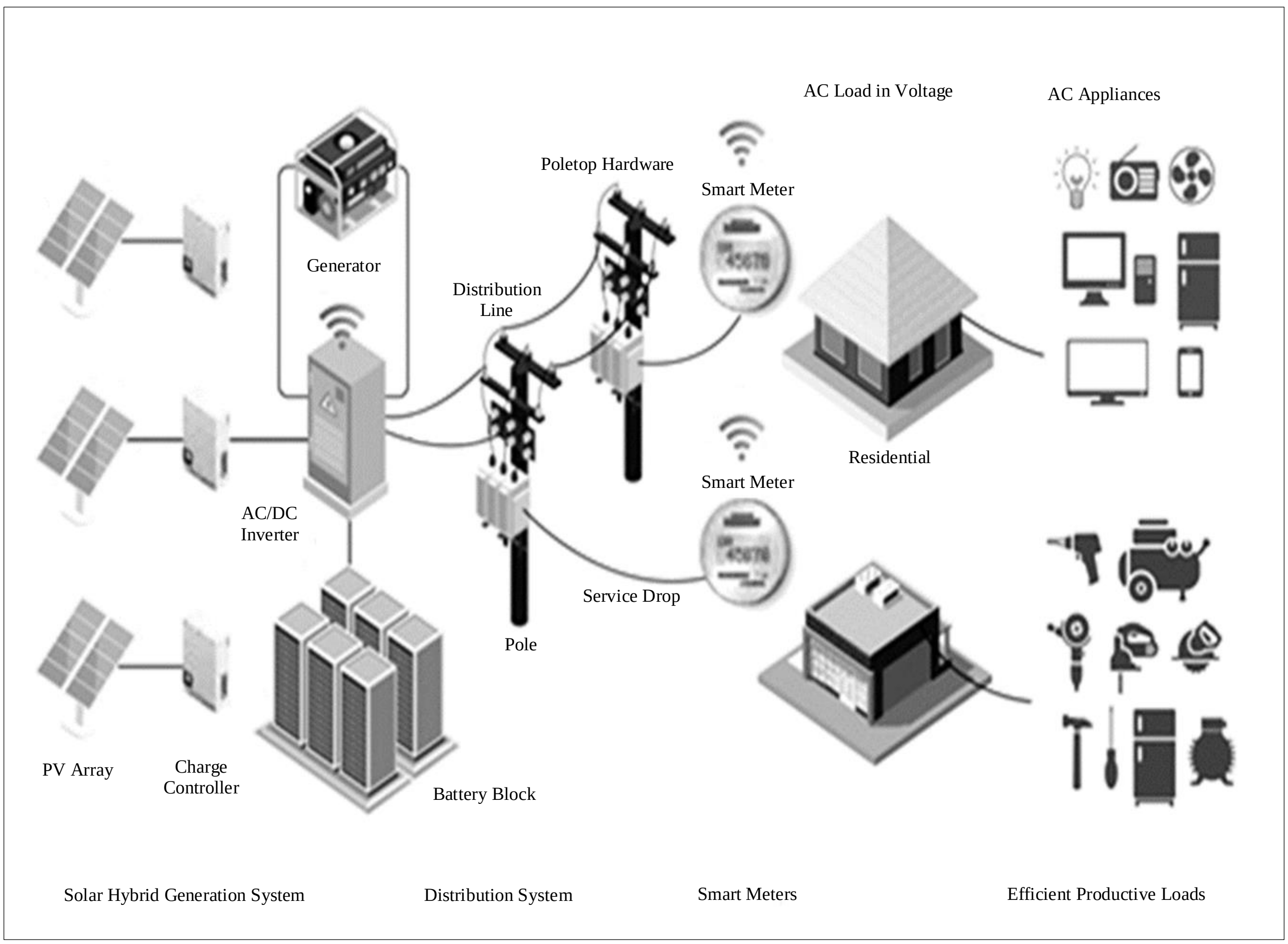

Fig. 2 Solar grid with variable loads

4. Circuit Diagram

A comparison study of harmonic reduction using an intelligent control Advanced Control Active Filter (ACAF) in a solar grid with variable load is given below.

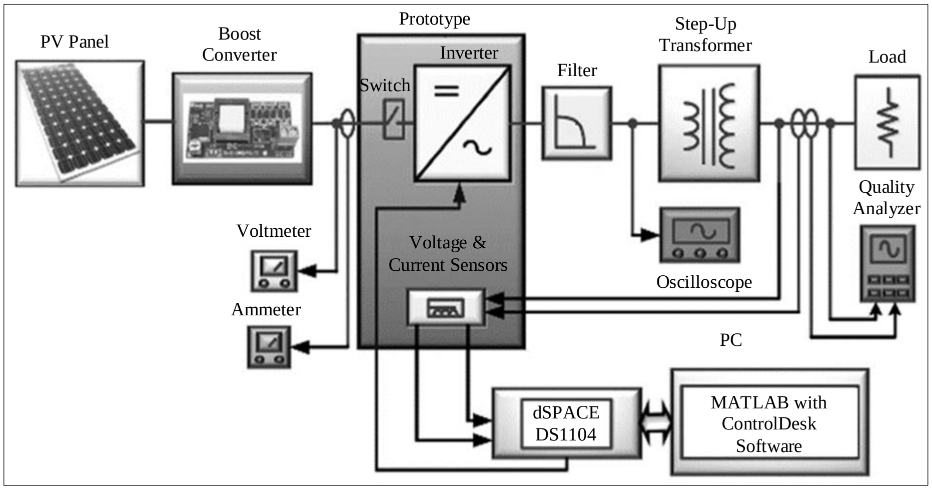

Fig. 3 Fuzzy Logic Control (FLC) active filter in a solar grid for harmonic reduction with variable load

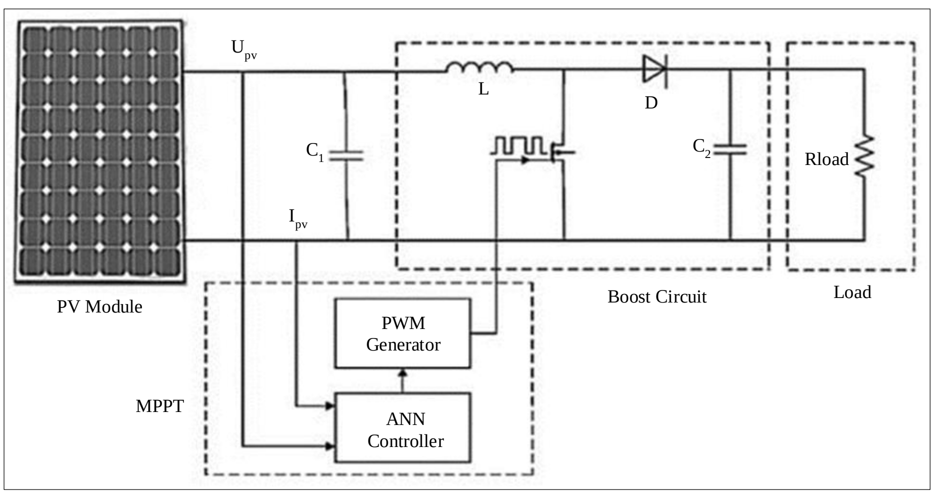

Fig. 4 Neural Network Control (NNC) active filter in a solar grid for harmonic reduction with variable load

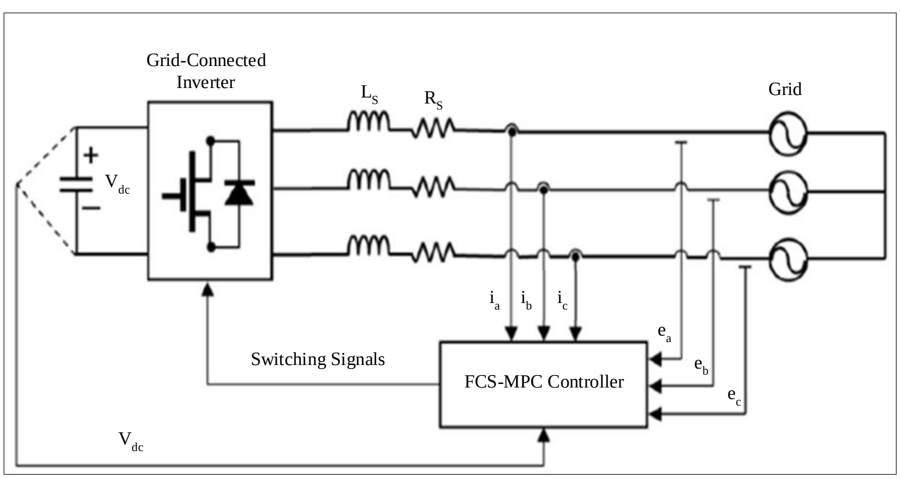

Fig. 5 Model Predictive Control (MPC) active filter in a solar grid for harmonic reduction with variable load

5. Simulation Results

Simulation results of Fuzzy Logic Control (FLC), Neural Network Control (NNC) and Model Predictive Control (MPC) are given below with waveforms.

5.1. Fuzzy Logic Control Method Simulation Results

Simulating the fuzzy logic control method for harmonic reduction in a solar grid with variable loads can provide valuable insights into its performance.

While simulations are conducted directly, the typical results are outlined that you might expect to see:

- Harmonic Reduction: The primary objective of the fuzzy logic control method is to reduce harmonic distortion in the grid current. Simulation results would demonstrate the effectiveness of the control algorithm in mitigating harmonic components across different load and solar power scenarios.
- Voltage and Current Waveforms: The simulation would show the voltage and current waveforms at various points in the solar grid system, both before and after the application of the fuzzy logic control method. Reduction in harmonic distortion should be evident in the post-control waveforms.
- Power Quality Indices: Metrics such as Total Harmonic Distortion (THD), Voltage Total Harmonic Distortion (VTHD), Current Total Harmonic Distortion (ITHD), and Power Factor (PF) can be calculated from the simulation results to quantify the improvement in power quality achieved by the fuzzy logic control method [31].
- Transient Response: The simulation would also assess the TR of the system, particularly how quickly the fuzzy logic controller adapts to changes in solar power output and load conditions. Fast response times are desirable for maintaining power quality under dynamic operating conditions.
- Stability Analysis: Stability analysis will be conducted to ensure that the fuzzy logic control method does not introduce instability or oscillations in the system. Simulation results would demonstrate the stability of the controlled system over a range of operating conditions.
- Robustness: The robustness of the fuzzy logic control method against uncertainties such as variations in solar irradiance, load fluctuations, and parameter uncertainties would be evaluated through simulation experiments. The results would show the system’s ability to maintain harmonic reduction performance under different operating scenarios.
- Comparison with Other Methods: If applicable, the simulation results could include comparisons with other control methods for harmonic reduction in solar grids, such as traditional PID control or Model Predictive Control (MPC), highlighting the advantages of the fuzzy logic approach.

Overall, simulation results would provide valuable evidence of the efficacy, stability, and robustness of the fuzzy logic control method for harmonic reduction in solar grids with variable loads. These results can inform the design and implementation of real-world control systems for improving power quality in renewable energy systems.

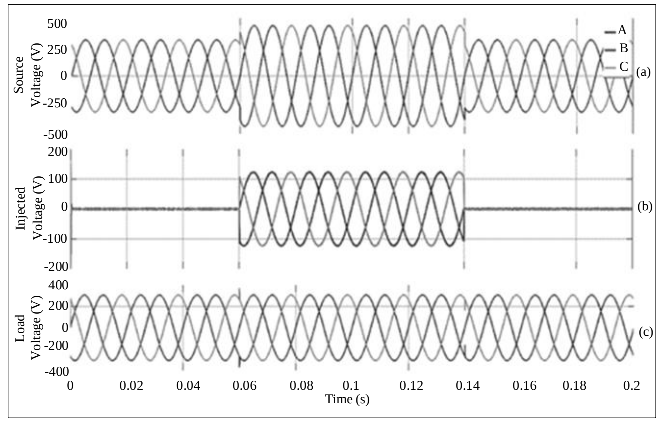

Fig. 6 Simulated waveform of Fuzzy Logic Control (FLC) active filter in a solar grid for harmonic reduction with variable load

5.2. Neural Network Control Method Simulation Results

Simulating the neural network control method for harmonic reduction in a solar grid with variable loads can yield valuable insights into its performance. Here is what might be expected to be observed in the simulation results:

- Harmonic Reduction: Similar to the fuzzy logic control method, the primary objective of the neural network control method is to reduce harmonic distortion in the grid current. Simulation results would demonstrate the effectiveness of the neural network in learning and implementing control actions to mitigate harmonic components across various load and solar power scenarios.
- Voltage and Current Waveforms: The simulation would depict the voltage and current waveforms at different points in the solar grid system before and after applying the neural network control method. Reduction in harmonic distortion should be evident in the post-control waveforms compared to the pre-control ones.
- Power Quality Indices: Metrics such as Total Harmonic Distortion (THD), Voltage Total Harmonic Distortion (VTHD), Current Total Harmonic Distortion (ITHD), and Power Factor (PF) can be calculated from the simulation results. These indices would quantify the improvement in power quality achieved by the neural network control method.
- Transient Response: The simulation would assess the Transient Response (TR) of the system, indicating how quickly the neural network adapts to changes in solar power output and load conditions. Fast response times are desirable for maintaining power quality under dynamic operating conditions.

- Training and Learning Curves: If the neural network is trained using historical data or through reinforcement learning, the simulation results may include training and learning curves. These curves show the convergence of the neural network training process and its ability to predict control actions based on input data accurately.
- Stability Analysis: Stability analysis will be conducted to ensure that the neural network control method does not introduce instability or oscillations in the system. The simulation results would demonstrate the stability of the controlled system across different operating conditions.
- Robustness: The robustness of the neural network control method against uncertainties such as variations in solar irradiance, load fluctuations, and parameter uncertainties will be evaluated. The simulation results would showcase the system's ability to maintain harmonic reduction performance under diverse operating scenarios [33].

Comparison with Other Methods: The simulation results could also include comparisons with other control methods, such as fuzzy logic control or traditional PID control, highlighting the advantages of the neural network approach in terms of accuracy, adaptability, and performance.

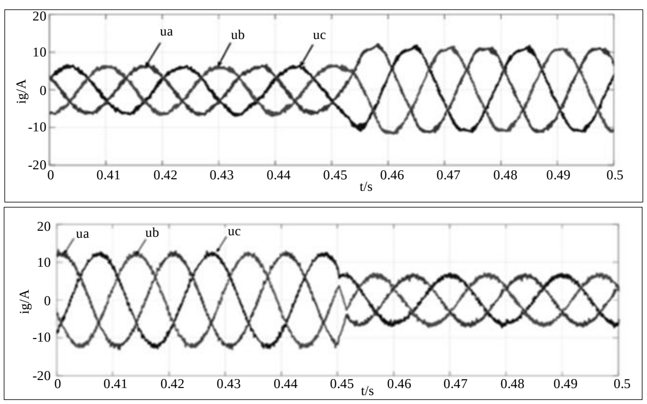

Fig. 7 Simulated waveform of Neural Network Control (NNC) active filter in a solar grid for harmonic reduction with variable load

By analyzing these simulation results, researchers and engineers can gain insights into the efficacy, stability, and robustness of the neural network control method for harmonic reduction in solar grids with variable loads, thereby informing the design and implementation of real-world control systems for improving power quality in renewable energy systems [32].

5.3. Model Predictive Control Method Simulation Results

Simulating the Model Predictive Control (MPC) method for harmonic reduction in a solar grid with variable loads can provide valuable insights into its performance. Here is what you might expect to see in the simulation results:

- Harmonic Reduction: The primary objective of the MPC method is to reduce harmonic distortion in the grid current. Simulation results would demonstrate the effectiveness of the MPC algorithm in minimizing harmonic components across various load and solar power scenarios.
- Voltage and Current Waveforms: The simulation would show the voltage and current waveforms at different points in the solar grid system before and after applying the MPC method. Reduction in harmonic distortion should be evident in the post-control waveforms compared to the pre-control waveforms.
- Power Quality Indices: Metrics such as Total Harmonic Distortion (THD), Voltage Total Harmonic Distortion (VTHD), Current Total Harmonic Distortion (ITHD), and Power Factor (PF) can be calculated from the simulation results. These indices quantify the improvement in power quality achieved by the MPC method.
- Transient Response: The simulation would assess the Transient Response (TR) of the system, indicating how quickly the MPC algorithm adapts to changes in solar power output and load conditions. Fast response times are desirable for maintaining power quality under dynamic operating conditions.
- Control Trajectories: MPC generates control trajectories for the active filter or other control devices over a prediction horizon. The simulation results would show these trajectories and how they adjust in response to changes in operating conditions.
- Constraint Handling: MPC considers system constraints such as voltage and current limits, as well as control device constraints. The simulation results would demonstrate how MPC dynamically adjusts the control actions while respecting these constraints [34].
- Stability Analysis: Stability analysis will be conducted to ensure that the MPC method does not introduce instability or oscillations in the system. The simulation results would demonstrate the stability of the controlled system across different operating conditions.
- Robustness: The robustness of the MPC method against uncertainties such as variations in solar irradiance, load fluctuations, and parameter uncertainties will be evaluated. The simulation results would showcase the system's ability to maintain harmonic reduction performance under diverse operating scenarios [35].
- Comparison with Other Methods: The simulation results could include comparisons with other control methods, such as fuzzy logic control, neural network control, or traditional PID control. This would highlight the advantages of the MPC approach in terms of accuracy, adaptability, and performance.

By analyzing these simulation results, researchers and engineers can gain insights into the efficacy, stability, and robustness of the MPC method for harmonic reduction in solar grids with variable loads. This information can inform the design and implementation of real-world control systems for improving power quality in renewable energy systems [36].

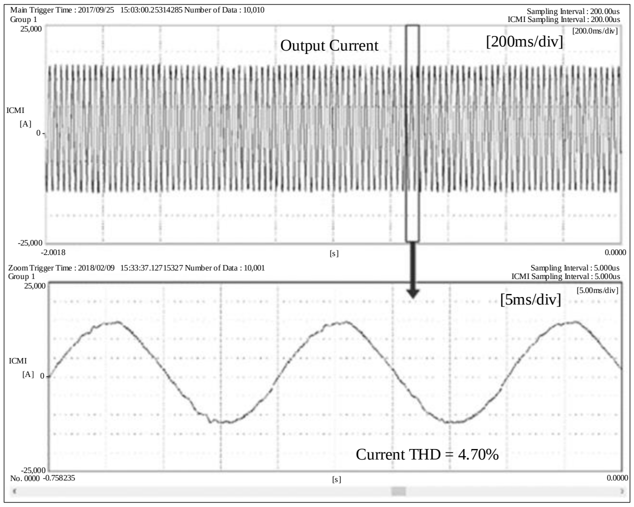

Fig. 8 Simulated waveform of Model Predictive Control (MPC) active filter in a solar grid for harmonic reduction with variable load

Table 1. THD improvement chart and discussion

S.No.	Parameters	Without Filter	With Active Filter
1.	Current (THD)	57.41	4.15
2.	Voltage (THD)	110.42	12.16

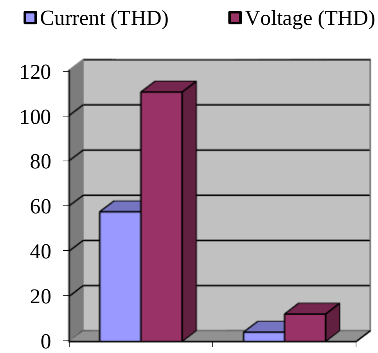

Table 2. Compare chart of FLC, NNC & MPC

Field	Fuzzy Logic Control Method	Neural Network Control Method	Model Predictive Control Method
Harmonic Reduction Performance	The effectiveness of FLC in reducing harmonic distortion depends on the accuracy of the linguistic rules and the precision of the control actions.	NNC relies on learning patterns from data to predict optimal control actions. Thus, its performance depends on the quality and representativeness of the training data.	MPC considers future system behaviour within a prediction horizon, enabling it to optimize control actions for harmonic reduction. Its performance depends on the accuracy of the model predictions and the optimization algorithm.
Response Time	FLC typically has fast response times since it relies on simple linguistic rules for decision-making.	NNC response times depend on the complexity of the neural network architecture and the computational resources available.	MPC can have moderate to fast response times depending on the prediction horizon length and the computational resources available for optimization.
Robustness	FLC may lack robustness if the linguistic rules are not comprehensive enough to cover all operating scenarios.	NNC can be robust if trained on a diverse dataset that captures a wide range of operating conditions.	MPC is inherently robust due to its ability to handle constraints and adapt to changing conditions within the prediction horizon.
Stability	FLC is generally stable if the linguistic rules are well-defined and do not lead to oscillatory behaviour.	NNC stability depends on the architecture of the neural network and the training process.	The optimization algorithm ensures MPC stability and the constraints imposed on the control actions.
Computational Complexity	FLC has low computational complexity since it relies on simple linguistic rules and does not require extensive computational resources	NNC can have high computational complexity depending on the size and architecture of the neural network.	MPC can have moderate to high computational complexity, especially if the prediction horizon is long or if complex optimization algorithms are used.

6. Conclusion

According to Tables 1 and 2, Analysis of harmonic reduction using an intelligent control active filter in a solar grid with variable load. The entire database has been taken on a real-time basis and has been modeled in MATLAB Simulink software.

The simulation results are compared. The current/voltage profile of the system has been successfully improved under varying loads, and the THD of both voltage and current has been significantly improved as per IEEE recommendations. The current THD has increased from 57.41% to 4.15%, and voltage THD has improved from 110.42% to 12.16%.

Hence, this control strategy is an effective solution for harmonic reduction using an intelligent control active filter in a solar grid with variable load and waveforms. The choice between FLC, NNC, and MPC depends on factors such as the specific requirements of the application, computational resources available, and the level of adaptability and robustness desired. Each control method has its strengths and weaknesses. FLC is the optimal choice as per the general specific characteristics of the solar grid system and the preferences of the designer. ANN control method simulation results are near to slandered value. It is also more affected.

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