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Development of Intelligent Smart Inverter With Harmonic Reduction With Renewable Energy Applications

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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.*

Index Terms*—Harmonic Reduction (HR), Varying Load (VL), Transient Response (TR),Adaptive Control (AC), Predictive Control (PC), Fuzzy Logic Control (FLC).*

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I. 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.

The interest of photovoltaic (PV) power generation has been steadily increasing, as evidenced by the substantial market growth from the last two decades [1]. To improve the commercial viability, the effects of high PV penetration of the grid must be addressed. Stability is a critical issue when considering a high PV-penetrated grid [2]. Voltage swelling can occur as a result of rapid increases in PV power generation/solar irradiance, referred to as *overloading* [3]. Further issues occur when the PV system transitions to islanded mode in the event of grid faults [1]. It is desirable to seek alternatives to disconnection during grid faults. The concept of low-voltage ride through (LVRT) is a proposed method of grid voltage support, where the grid-connected inverter will inject reactive power prior to disconnection upon sensing a dip in grid voltage. By applying such a control feature, the smart inverter can turn PV generation from a stability hazard to a stability asset. In recent years, there has been discussion to update grid codes pertaining to PV inverters to include this capability, and has been implemented in some grid codes [4-6]. However, adjusting the active and reactive power set-points to produce these advanced grid-support features makes for a more difficultcontrol problem.

This paper is the first to consider an LVRT-enabled smart PV inverter for this topology via the proposed AMPC. This work is considered an extension of the work in [7], with additional analysis, experimental verification, and more advanced predictive control which features the auto-tuning weight factor technique. The tracking improvements from the auto-tuning feature are demonstrated experimentally, comparing to the original, static weight factor ratio in [8]. Additionally, this proposed control scheme implements an index variable, *s*, in the cost function. This variable is used to eliminate iterative computations associated with redundant next-state predictions. Without any degradation of tracking capabilities, five of the ten next-state prediction calculations are removed using this technique, enhancing the control's computational efficiency.

a. 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.

b. 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.

c. 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.

II. Design Methodology

This section presents the design, development and working principles of the developed smart modular solar Inverter system. The system comprises two parts: software and hardware. The voice control unit and mobile application control mechanism (a touch control interface for smartphones) are used to control the modular inverter, while the hardware is made up of numerous units that make up the modular inverter system. The technique is divided into three sections: solar inverter development, metering, and energy allocation; voice module control unit creation, and mobile application for the modular inverter. The aim of this research is to develop a smart energy metering and switching modular inverter which is controlled by the voice of a user and also through the mobile application software. The system is a solar inverter where energy from the sun is harvested using a Photovoltaic Solar panel and boosted using a buck-boost converter. The harnessed energy is then stored in a battery through the charge controller as shown in Figure 1.

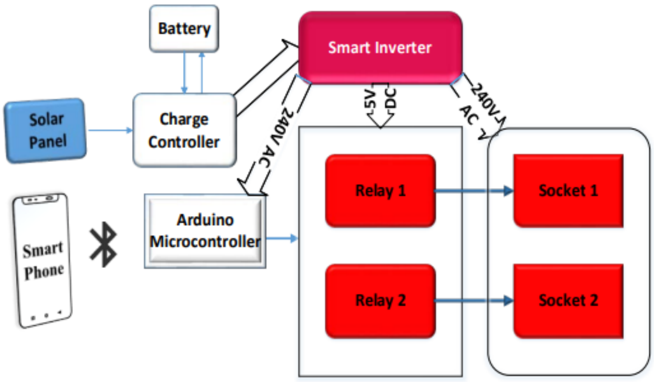

Figure 1. System Block Diagram.

The energy stored in the battery is in form of direct current (DC) and there is a need for conversion into alternating current (AC) because home appliances use alternating current (220V to 240V). This is done through the inverter. The meter controller monitors the power dissipated on the nodes to ensure that each user uses a considerable amount of power and does not affect the load usage of other nodes (users) connected to the inverter. The switching controller monitors the connected load on each of the inverter nodes, alert the user if there is an erratic current dissipated in any node and switch off that node to ensure that there is no excess current from any of the connected loads. The voice-based controller for the system allows the user to control the inverter through an IoT medium (mobile app). The mobile application serves as a means of single-user authorization access and security for inverter usage. The system's controlling functions include power on/off the whole circuit, or the individual circuits connected to the system respectively. The mobile application is also the medium by which the user previews the monitoring function of the inverter. Figure 2 shows the data flow chart of the system.

III. Development of the Switching and Metering Module

The switching and metering module consist majorly of a current sensor which is set to measure DC and AC for 20A. The three-output pin of the current sensor is connected to the microcontroller while the wire in and wire out pin are connected to the inverter battery to measure the current being drawn by an external device. The module is connected in series with the relay to avoid short circuits and to accurately monitor the current going to each channel on the relay.

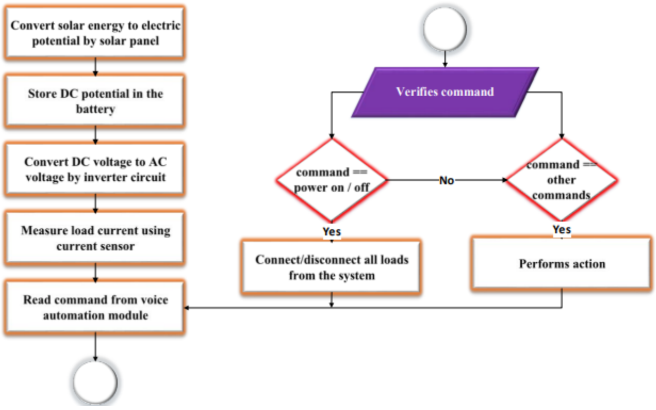

Figure 2. System Flow Chart.

IV. 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 postcontrol 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.

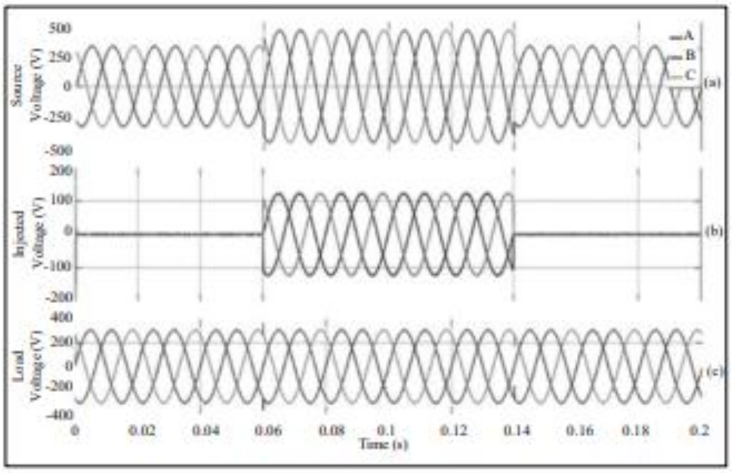

Fig.3 Simulated waveform of Fuzzy Logic Control (FLC) active filter in a solar grid for harmonic reduction with variable load.

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.

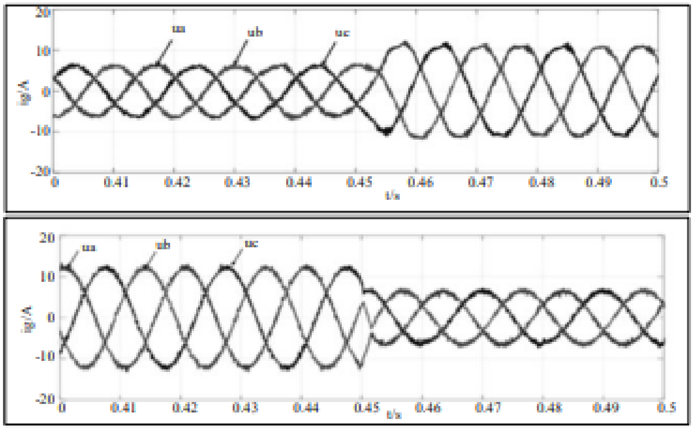

Fig.4 Simulated waveform of Neural Network Control (NNC) active filter in a solar grid for harmonic reduction with variable load.

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 .

V. CONCLUSION

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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