DESIGN AND CONTROL OF A GRID-CONNECTED DUAL VSI FOR ENHANCED POWER QUALITY

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Abstract: The increasing penetration of renewable energy sources into the power grid, maintaining power quality has become a significant concern. Voltage Source Inverters (VSIs), commonly used for interfacing renewable energy systems like solar PV and fuel cells, must not only inject active power but also mitigate power quality issues such as harmonics, unbalanced loads, and reactive power demands This paper presents the design and control strategy for a grid-connected Dual Voltage Source Inverter (Dual VSI) aimed at enhancing power quality in distributed generation (DG) systems. The system utilizes two interlinked VSIs operating in coordination to manage both active/reactive power flow and mitigate power quality issues such as harmonic distortion, voltage sag, and unbalanced loads. A synchronized control algorithm based on decoupled d-q reference frame theory and a novel feed-forward compensation mechanism is employed to improve dynamic response and reduce total harmonic distortion (THD). Simulation results in MATLAB/Simulink and experimental validations confirm the effectiveness of the proposed Dual VSI configuration in achieving superior power quality compared to conventional single VSI setups.

Keywords: VSI, Power Quality, MATLAB/Simulink

1.Introduction

In the present scenario the technological advancements and environmental concerns lead the power system to a typical shift with more renewable energy sources integrated to the network by means of distributed generations (DG). These DG units with consequent control of local generation and storage facilities from a micro grid. In a micro grid, power from variable renewable energy sources such as fuel cells, photovoltaic (PV) systems, and wind energy systems are connected to grid and loads with power electronic converters. A grid interactive inverter plays a dominant role in interchanging power electronic converters. A grid connected inverter plays a main role in exchanging power from the micro grid to the grid and the connected load. This micro grid inverter can either work in a grid sharing mode while delivering a part of local load or in grid injecting mode, by injecting power to the main grid. Power quality maintenance is another major aspect that has to be concerned while main grid is connected by micro grid system. The growth of power electronic devices and electrical loads with unbalanced nonlinear currents has degraded the power quality in the power distribution network. Furthermore, if there is a significant amount of feeder impedance in the distribution network, the propagation of these harmonic currents distorts the voltage at the point of common coupling (PCC). A Technological progress and environmental concerns drive the power system to a paradigm shift with more renewable energy sources integrated to the network by means of distributed generation (DG). These DG units with coordinated control of local generation and storage facilities form a microgrid [1]. In a microgrid, power from different renewable energy sources such as fuel cells, photovoltaic (PV) systems, and wind energy systems are interfaced to grid and loads using power electronic converters. A grid interactive inverter plays an important role in exchanging power from the microgrid to the grid and the connected load [2], [3]. This microgrid inverter can either work in a grid sharing mode while supplying a part of local load or in grid injecting mode, by injecting power to the main grid. Maintaining power quality is another important aspect which has to be addressed while the microgrid system is connected to the main grid. The proliferation of power electronics devices and electrical loads with unbalanced nonlinear currents has degraded the power quality in the power distribution network. Moreover, if there is a considerable amount of feeder impedance in the distribution systems, the propagation of these harmonic currents distorts the voltage at the point of common coupling (PCC). At the same instant, industry automation has reached to a very high level of sophistication, where plants like automobile manufacturing units, chemical factories, and semiconductor industries require clean power. For these applications, it is essential to compensate nonlinear and unbalanced load currents [4]. Load compensation and power injection using grid interactive inverters in microgrid have been presented in the literature [5], [6]. A single inverter system with power quality enhancement is discussed in [7]. The main focus of this work is to realize dual functionalities in an inverter that would provide the active power injection from a solar PV system and also works as an active power filter, compensating unbalances and the reactive power required by other loads connected to the system. In [8], a voltage regulation and power flow control scheme for a wind energy system (WES) is proposed. A distribution static compensator (DSTATCOM) is utilized for voltage regulation and also for active power injection. The control scheme maintains the power balance at the grid terminal during the wind variations using sliding mode control. A multifunctional power electronic converter for the DG power system is described in [9]. This scheme has the capability to inject power generated by WES and also to perform as a harmonic compensator. Most of the reported literature in this area discuss the topologies and control algorithms to provide load compensation capability in the same inverter in addition to their active power injection. When a grid-connected inverter is used for active power injection as well as for load compensation, the inverter capacity that can be utilized for achieving the second objective is decided by the available instantaneous microgrid real power [10].

2.Literature review

Recently, the use of grid-connected hybrid renewable energy resources (like solar, wind, and hydro) increases rapidly because of the huge expansion in the load demand on the distributed generating system (Kim et al., 2008). But on the other hand, it prompts significant issues and consequences by the intermittent nature of these hybrid energy resources (Salimi et al., 2021; Sun et al., 2021). Despite the availability of energy resources, grid modernization and consumers interest are increasing in the energy market (Amir and Khan, 2021). To meet the desired electricity demand, the most effective solution is to use affordable sustainable energy sources (Armghan et al., 2020; Sanguesa et al., 2021;). According to the energy reports (MNRE, 2019), in India, 56 percent of wind energy and 34 per cent of solar power supplies fulfill the consumer’s electricity demand. That was generated by a key factor in promoting sustainable energy sources such as PV and wind-based resources and their interconnection with the on/off the grid (ToghaniHolari et al., 2020). The solar and wind energy hybrid power generation systems (HPGS) were primarily extended because the solar power plant’s common accessibility and output generating power are dependent on the following environmental factors: individual irradiance accessibility, ambient temperature, and wind velocity These resources produce a discontinuous and irregular voltage as a consequence of the substantial impact of hybrid RES by the climate and weather variation (Ni et al., 2021; Praveen Kumar et al., 2021). To help with these issues, the hybrid renewable energy network is integrated with the grid network to identify resource reliability. Furthermore, the MPPT control technique is required to maximize the generation and control the most unusual power sources (BhatNempu and Jayalakshmi, 2020). Various generation control methods have comprised MPPT control ((perturbation and observation (P and O), hill-climbing, etc.), intelligent-based genetic hybrid system, fuzzy-based control, artificial neural network (Amir and Zaheeruddin, 2019), and other machine learning approaches to maximize the distributed power from variable renewable resources (Chandrasekaran et al., 2021). On the other hand, various research studies proposed the optimal controller design and their optimization approach for the grid-connected photovoltaic (PV) power generation system. Although the control approach was presented and mainly focused on the hybrid development of the wind-photovoltaic-based stand-alone system (Soliman et al., 2018), there is a huge challenge in the practical control design for large stand-alone photovoltaic and wind-based hybrid power generation systems. The dynamic stability of a grid-connected distributed generation station is coupled with different stages of the power transformer (Urooj et al., 2021) and converter mechanism, which is having a simultaneous diesel dynamo, and dynamic energy storage to utilize the maximum generation curve for the development of remote emergency backup systems.

3.Methodology

This section outlines the step-by-step approach employed in the design, modeling, and control of a dual Voltage Source Inverter (VSI) system connected to the grid. The main goal is to deliver active power while improving power quality under various load conditions. The dual-VSI configuration consists of an Active VSI (AVSI) and a Mitigating VSI (MVSI) operating in coordination.

3.1 Design of DVSI Parameters AVSI:

The important parameters of AVSI like dc-link voltage (Vdc), dc storage capacitors (C1 and C2), interfacing inductance (Lf x), and hysteresis band (±hx) are selected based on the design method of split capacitor DSTATCOM topology The dc-link voltage across each capacitor is taken as 1.6 times the peak of phase voltage. The total dc-link voltage reference (Vdcref) is found to be 1040 V. Values of dc capacitors of AVSI are chosen based on the change in dc-link voltage during transients. Let total load rat-ing is S kVA. In the worst case, the load power may vary from minimum to maximum, i.e., from 0 to S kVA. AVSI needs to exchange real power during transient to maintain the load power demand. This transfer of real power during the transient will result in deviation of capacitor voltage from its reference value. Assume that the voltage controller takes n cycles, i.e., nT seconds to act, where T is the system time period. Hence, maximum energy exchange by AVSI during transient will be nST . This energy will be equal to change in the capacitor stored energy

3.2 DUAL VOLTAGE SOURCE INVERTER

The proposed DVSI circuit is shown in fig. It consists of 2 inverters which are connected to the grid at point of common coupling and suppling unbalanced loads. A neutral point clamped (NPC) inverter is used as a auxilary voltage source inverter that compensates reactive, harmonic and unbalanced components in load currents. Capacitors C1 and C2 represents the split capacitor topology of dc-link of the AVSI. Five level inverter is used as the main voltage source. inverter that supplies the power generated from the distributed energy resources (DER) to grid. The DER can be either dc source or ac source. The load connected in this system is unbalanced and nonlinear load.

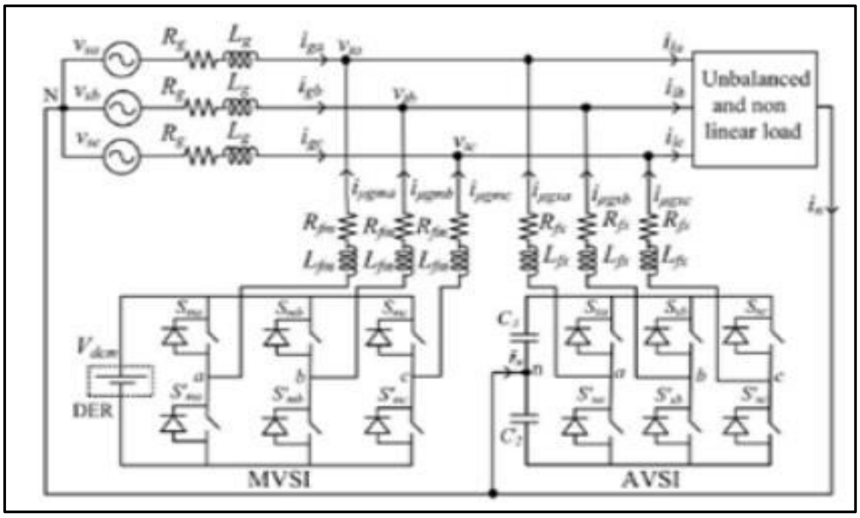

Figure 1: DVSI system configuration

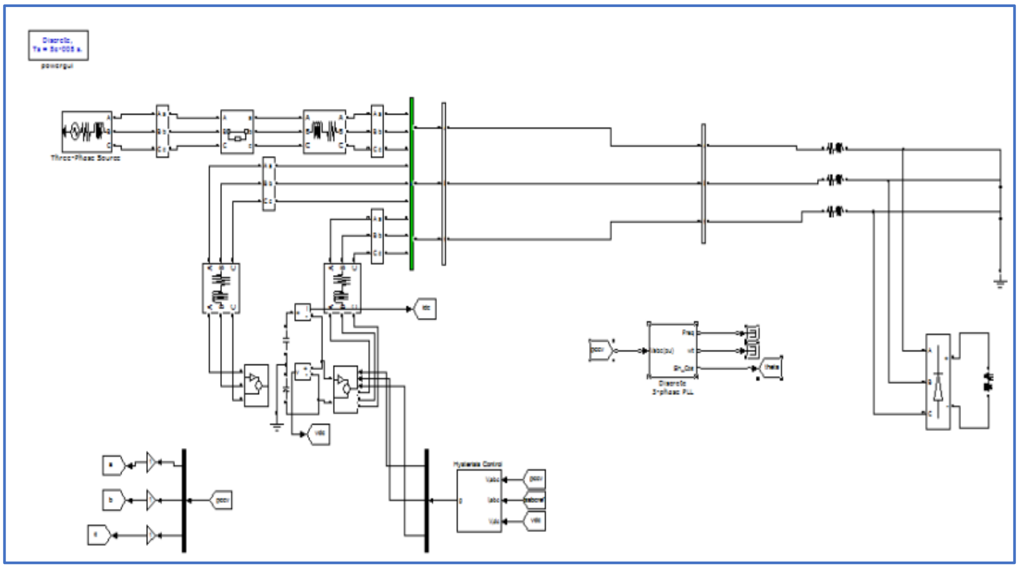

Figure 2: Control diagram of DVSI scheme

4. SIMULATION STUDIES

The simulation model of DVSI method is developed in MATLAB 7.12.0 to evaluate the performance. The simulation results explain the grid sharing and grid injecting modes of operation of DVSI method in steady state as well as in transient condition and also unbalanced load compensation technique by AVSI. The voltages at the point of common coupling are distorted due to the feeder impedance. If these distorted voltages are used for the generation of reference current of AVSI, the compensation of unbalanced components in load currents is not proper. Therefore, balanced sinusoidal voltages are required for the reference current generation.

Table: The simulation study demonstrates the grid sharing and grid

Parameters	Values
Grid voltage	400 V(L–L)
Fundamental frequency	50 Hz
Feeder impedance	R_g = 0.5 Ω, L_g = 1.0 mH
AVSI	$C_1 = C_2$ = 2000 μF V_{dcref} = 1040 V Interfacing inductor, L_{fx} = 20 mH Inductor resistance, R_{fx} = 0.25 Ω Hysteresis band ($\pm h_x$) = 0.1 A
MVSI	DC-link voltage, V_{dcm} = 650 V Interfacing inductor, L_{fm} = 5 mH Inductor resistance, R_{fm} = 0.25 Ω Hysteresis band ($\pm h_m$) = 0.1 A
Unbalanced linear load	$Z_{la} = 35 + j19$ Ω $Z_{lb} = 30 + j15$ Ω $Z_{lc} = 23 + j12$ Ω
Nonlinear load	3 ϕ diode bridge rectifier with DC side current of 3.0 A
DC voltage controller gains	K_{Pv} =10, K_{Iv} = 0.05

injecting modes of operation of DVSI scheme in steady state as well as in transient conditions.

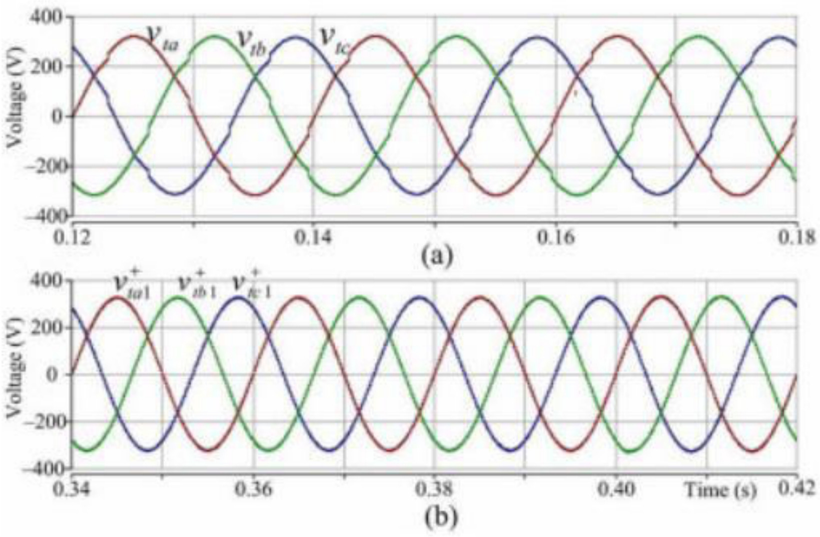

Figure 3: Without DVSI scheme: (a) PCC voltages and (b) fundamental positive sequence of PCC voltages

The distorted PCC voltages due to the feeder impedance without DVSI scheme are shown in Fig 3. (a). If these distorted voltages are used for the reference current generation of AVSI, the current compensation will not be proper Therefore, the fundamental positive sequence of voltages is extracted from these distorted voltages using the algorithm explained in Section III-A. These extracted voltages are given in Fig. 3(b). These voltages are further used for the generation of inverter reference currents.

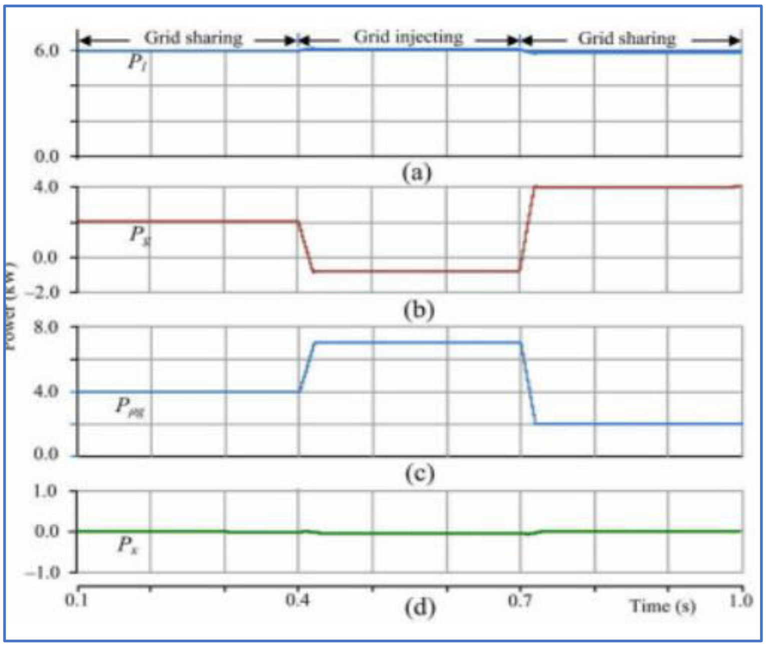

Fig 4. (a)–(d) represents active power demanded by load (P l), active power supplied by grid (P g), active power supplied by MVSI (P µg), and active power supplied by AVSI (P x), respectively. It can be observed that, from t =0.1 to 0.4 s, MVSI is generating 4 kW power and the load demand is 6 kW. Therefore, the remaining load active power (2 kW) is drawn from the grid.

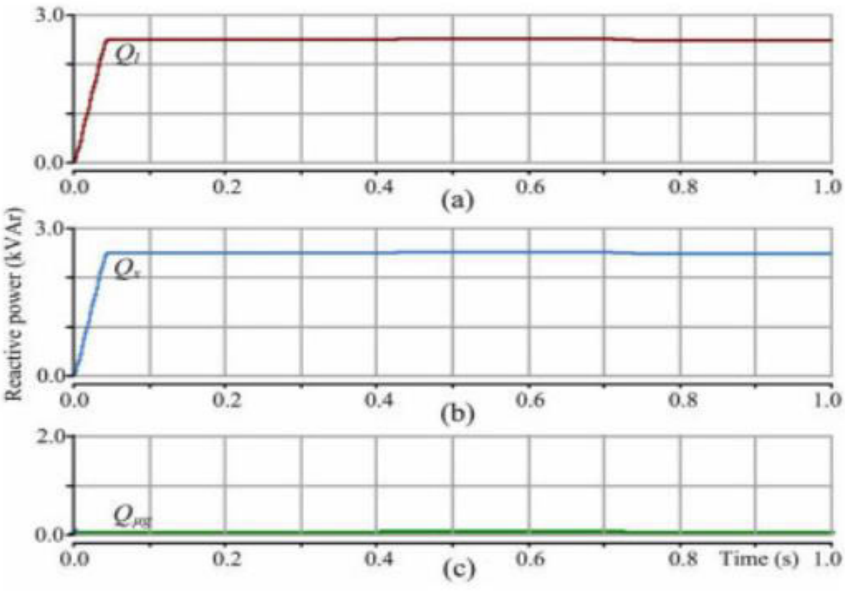

Figure: 5(a)–(c) shows the load reactive power (Q l), reactive power supplied by AVSI (Q x), and reactive power supplied by MVSI (Q µg), respectively. It shows that total load reactive power is supplied by AVSI, as expected.

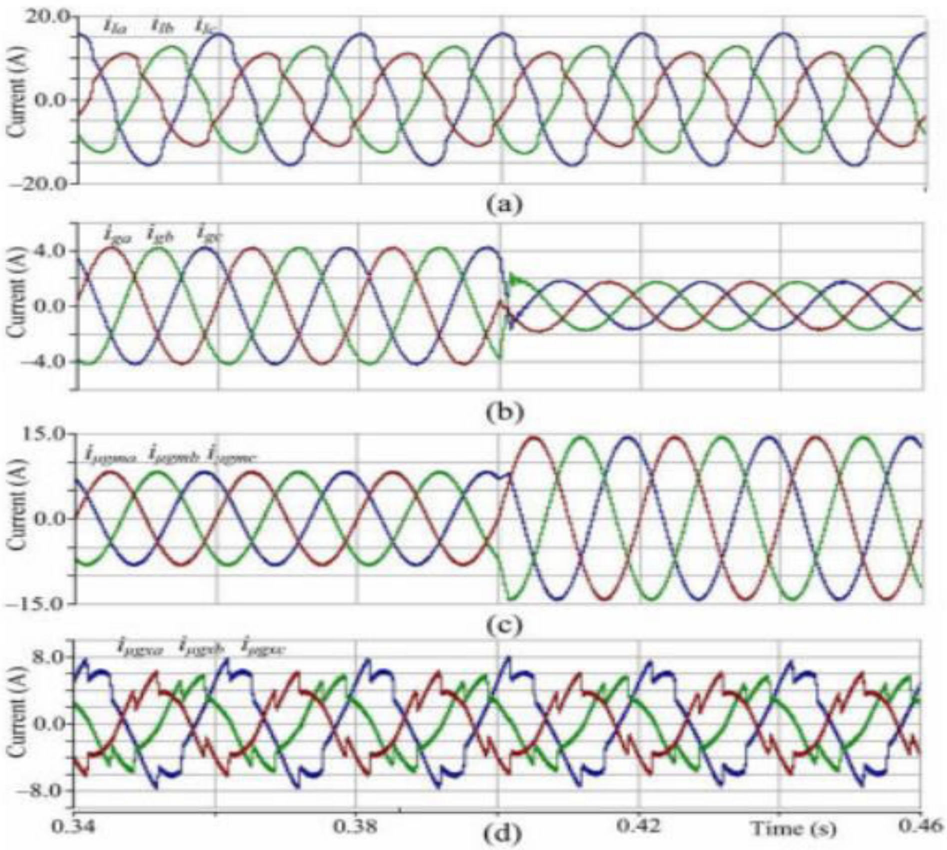

Figure 6: Simulated performance of DVSI scheme: (a) load currents; (b) grid currents; (c) MVSI currents; and (d) AVSI currents.

The load currents are unbalanced and distorted. The MVSI supplies a balanced and sinusoidal currents during grid supporting and grid injecting modes. The currents drawn from grid are also perfectly balanced and sinusoidal, as the auxiliary inverter compensates the unbalance and harmonics

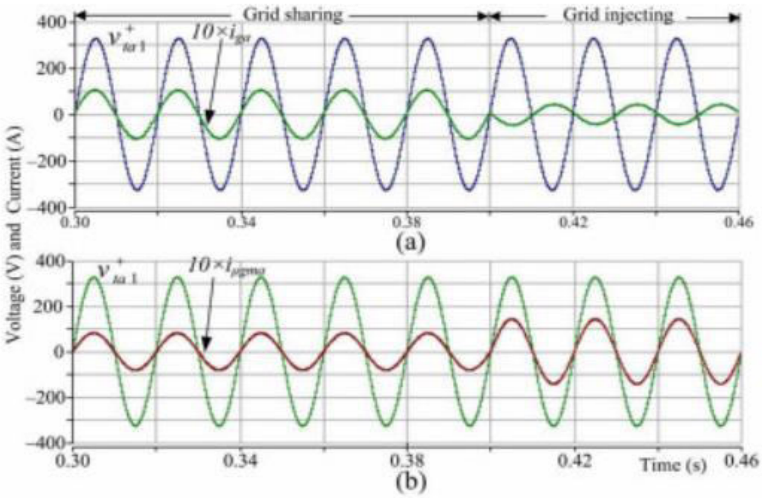

Figure 8: Grid sharing and grid injecting modes of operation: (a) PCC voltage and grid current (phase-a) and (b) PCC voltage and MVSI current

5. Conclusions:

The design and control of a Grid-Connected Dual Voltage Source Inverter (Dual VSI) system aimed at improving overall power quality in modern distribution systems. The proposed architecture utilizes two coordinated inverters—AVSI for active power injection and MVSI for harmonic, reactive power, and unbalance compensation. A decoupled control strategy based on synchronous reference frame (SRF) theory, hysteresis current control, and PI-based DC voltage regulation was employed to manage the independent objectives of each inverter. Simulation results demonstrated the effectiveness of the system in maintaining a stable DC-link voltage, achieving a unity power factor, and significantly reducing total harmonic distortion (THD) in source currents, even under nonlinear and unbalanced load conditions

- Effective harmonic mitigation with source current THD maintained below 5%, complying with IEEE 519 standards.
- Reliable active power delivery with fast dynamic response.
- Improved voltage regulation and load balancing at the Point of Common Coupling (PCC).
- Modular and scalable architecture, suitable for integration with renewable energy sources.

Overall, the dual VSI configuration proves to be a viable and robust solution for enhancing power quality in grid-connected renewable energy systems. Future work may focus on implementing the proposed control strategy on real-time digital platforms (e.g., DSP/FPGA) and extending the system for microgrid applications with energy storage integration.

6. References

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