Power quality enhancement of grid-connected PV system

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ABSTRACT

Solar photovoltaic (PV) power, for its multiple benefits, has adhered to prominent consideration in the electrical energy generation region. The double-stage triple-phase grid-connected solar PV (SPV) system is utilized to enhance the power quality by employing a lymphoblastoid cell lines LCL filter. In this method, a DC-DC converter and DC-AC converter make a feasible juncture of the PV systems to the electrical interface. For converting boosted DC into AC, A 3-phase DC-AC converter is used, which is supplied into the grid. A 3-phase voltage converter is employed in place of an inverter for interfacing amid the voltage generated by the PV system and the grid possessing an AC transmission line. An maximum power point tracking (MPPT) application is used in this proposal to amplify the effectiveness of the PV array in face of any unsteady climatic circumstances. Hence, the highest energy could be secured out of the solar PV array and interfaced with the grid. Enhancing power quality by employing an LCL filter is quantified by FFT analysis in MATLAB. The advised proposal has attained a very low total harmonic distortion (THD), proving its efficacy. Also, the outcomes ascertain the applications of the proposed system and extend future advances of renewable energy with a great power quality improvement.

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1. INTRODUCTION

Renewable sources of energy are more favored in energy production because of the high demand for green electrical energy including the decline of orthodox power sources such as natural gas, oil, coal, or nuclear. The solar PV source is the most notable source for energy production because of its pollution less, waste less, economic, and manageable fabrication. Currently, solar PV energy generation transits from the low to the high-power grid system without any challenge [1]. The burgeoning load requirement and the integration of multiple energy sources take place through the course of transmission lines to control the accumulation, and continuity, diminish the supply power bank demands, and replacement of any traditional sources with non-conventional, green, renewable sources [2], [3]. Lamentably, elevation in unbalanced loads is the cause for more predicaments in harmonics power quality in a disseminated system as opposed to the central grid.

Unbalancing is caused because of uneven distribution of either single-phase load voltage or uneven generation level or distribution level voltage. At any given junction in a grid, an unbalanced load will impact different load parameters in the corresponding node [4]. A control method is essential in grid unification. To meet the unbalanced demand load, both the active and the reactive components are to be adjusted [5]. The escalating enormity of the power deficiency pressures and environmental anxieties has rooted for the advancements in the smart grid to grow among urgent subjects researched by present scholars [6]. The association of unconventional renewable sources, like wind, PV, or fuel cells into circulation channels induces a reliable and consumable energy supply. Simultaneously, the occasional inconsistency of principal sources, the expanding employment of the power electrical machines, and the reoccurring un-balanced loads draw about furtive issues of power quality [7], [8].

LC filter can be employed for power conditioning for the minimization of ripples [9]. However, it is expensive because of its high-value inductance for average to large energy demands [10]. Hence, an LCL filter is employed. The lymphoblastoid cell lines LCL design trait has the most crucial position in an all-over system and presents an indispensable role in the stability of the system [11]. The scheme of the LCL filter must take care of expense quandaries, the greater value of capacitance, economical, and the lower value of inductance, which is massive and expensive. Further, the grid's stability is influenced by its impedance, and careful forethought is imperative while designing the LCL filter [12]. The LCL filter's resonant frequency changes as the impedance of the grid changes, which results in the stiffness of the grid. So, for the solar PV system combined with the grid to work, control strategy and synchronization are essential [13]. The control of the reference frame, which is synchronous, is carried out for the synchronization of frequency by employing a phase-locked loop (PLL) [14], [15].

This research paper represents the design of a 2-stage 3-phase grid-connected PV system and its power quality improvement using an LCL filter using MATLAB. We used the control algorithm based on synchronous reference frame theory. The input of the inverter was given a DC voltage with a bus capacitor across it. This DC voltage is obtained from a DC-DC converter, combined with a PV array. The output of the inverter is connected to the LCL filter because of its superior filtering performance. The 3-phase line to line voltage V_{abc} is being transformed to 2-phase alpha-beta voltages (V_α and V_β) using Park's transformation. Using the voltages V_α and V_β, PLL is implemented. V_α and V_β voltages are then converted to dq voltages using Clark's transformation as E_d and E_q. For controller implementation, we used the inverter side current I_{abc}.This I_{abc} is converted into the alpha-beta domain as I_α and I_β using parks transformation and then it is converted into dq domain using Clark's transformation as I_d and I_q. I_d and I_q are then subtracted from their reference currents I_{dref} and I_{qref} to find the error. The PI controller is fed this error to find the voltages U_d and U_q. U_d is added with $E_d + L\omega I_q$ to obtain V_d and U_q is added with $E_q - L\omega I_d$ to obtain V_q. V_d and V_q are multiplied by $V_{DC}/2$ to obtain E_d and E_q and it is then transformed to abc voltages (V_{abcref}) to get the reference for PWM generation. We used a sine PWM scheme with unipolar switching.

2. RESEARCH METHOD

This paper focuses on the power quality improvement of the PV grid. Figure 1 shows us the workflow diagram of the research methodology being followed in this research paper. This methodology is based on the synchronous reference frame theory.

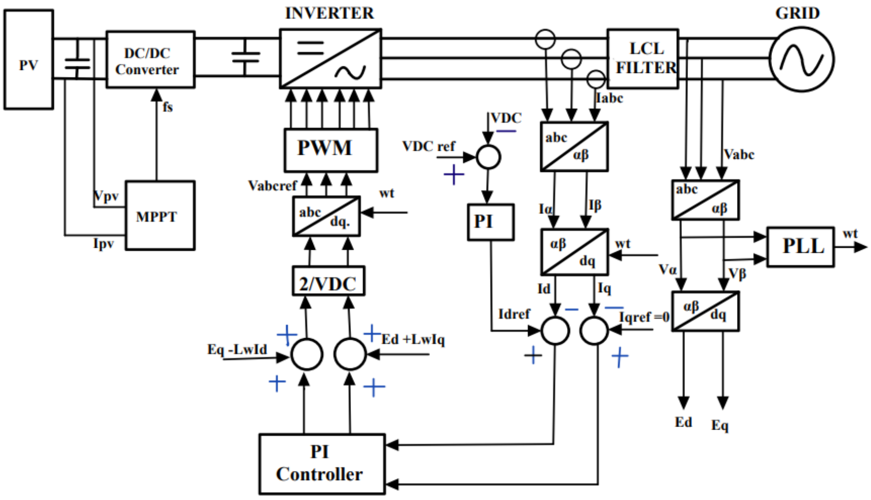


Figure 1. Proposed research methodology

2.1. Solar PV cell

The PV cell is any material that undeviatingly transforms solar radiation into electrical power using the photovoltaic effect. The circuit diagram of solar cell is depicted in Figure 2. Solar cells can be systemized into large groupings termed arrays. These arrays, constituted of thousands of singular cells, can operate as central electric power plants, transforming sunlight into electrical power for distribution to consumers [16]. A PV cell is made up of a substance that has semiconductor properties; “semi” indicates that it can transmit electric current better than an insulator but not as adequately as a conductor, like a metal [17]. The efficiency of a photovoltaic cell can be characterized by the measure of electrical power developed by the cell corresponding to the solar energy radiating over it. This efficiency of the cell designates how effective the photovoltaic cell is at transforming energy from solar radiation to electrical energy [18]. The extent of power generated from photovoltaic cells is influenced by not only the characteristics of light available but also the various execution properties of the cell [19].

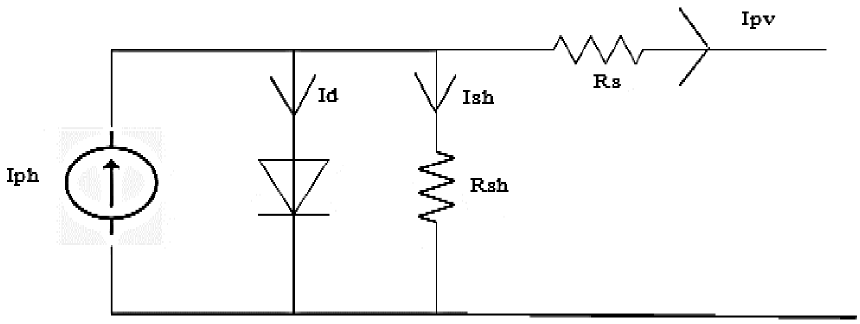


Figure 2. Circuit diagram of solar cell

2.2. Maximum power point tracking (MPPT)

The MPPT is tracked by the perturb and observe (P&O) method by frequently enhancing or lowering the magnitudes of voltage at the PV's MPPT [20]. The flow chart of P&O algorithm has been depicted in Figure 3. The execution of this technique is comparatively uncomplicated. However, it is unable to track the MPPT if the irradiance alters promptly with time [21]. Further, it is possible to prompt the system into swaying about the tip power points because of the effect of computation noise. The algorithm swings around the peak point when the steady state is obtained. The disturbance size is kept minimal to keep the power variation inadequate. The algorithm can be simply comprehended by the following flow chart. The P&O method may succeed in top-level performance, granted that a precise predictive and adaptive hill climbing strategy is appropriated [22].

2.3. Boost converter

A boost converter can be illustrated as a DC-to-DC converter and it augments the voltage of the source and feeds it to load [23]. Figure 4 depicts the circuit diagram of boost converter. To reduce the voltage fluctuations, filters constituted of capacitors (occasionally in union with inductors) are generally affixed to such a converter's load filter and source filter [24]. The inductor joined to the source causes a steady input current, and thus the boost converter is also recognized as the “constant current input source”. The regulating switch is operated using pulse width modulation (PWM) [25].

2.4. Phase-locked loop (PLL)

A phase-locked loop (PLL) can be illustrated as a control system with a voltage-driven oscillator that generates and adjusts an output signal, in phase with the input signal [26]. A variable frequency oscillator associated with a phase detector in the feedback loop is the most manageable phase-locked loop system. While a periodical signal is produced by the oscillator, the phase detector correlates its phase with the input signal, regulating the oscillator to retain those coordinated [27]. A steady-state error signal is generated whenever the PLL gets into a lock. The actual error magnitude between the input and output signals can be attenuated to minimal levels by employing an amplifier connecting the phase detector and the VCO. Nevertheless, as the VCO controls the fitting frequency, some voltage must persistently exist at the VCO's control terminal [28].

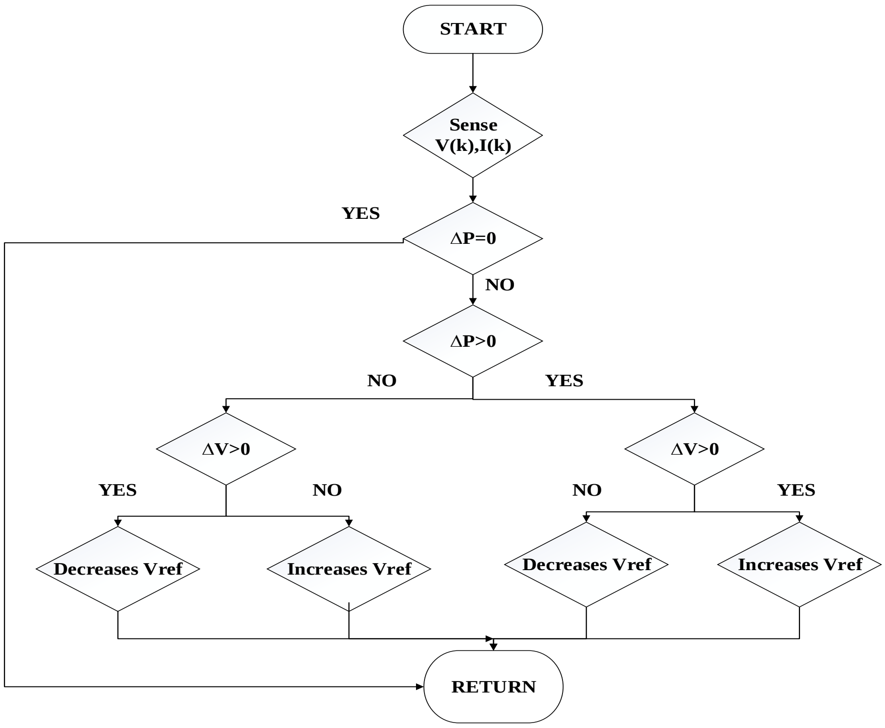


Figure 3. Perturb and observe algorithm

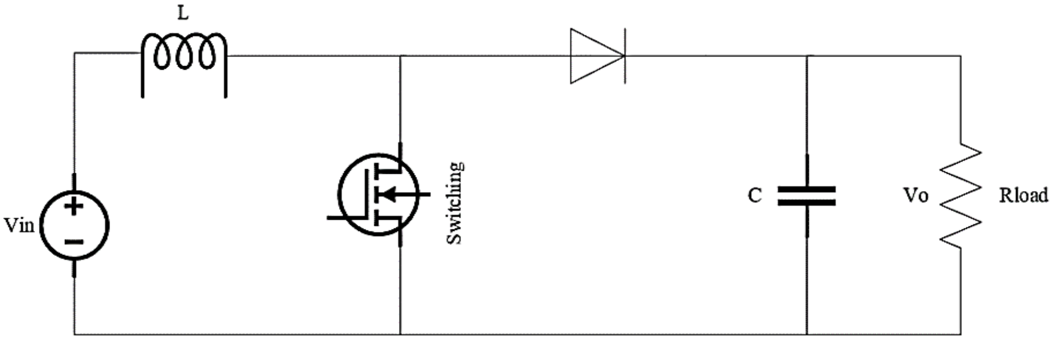


Figure 4. Circuit diagram of boost converter

2.5. ABC to alpha-beta-zero transformation

This phase implements Clarke's transformation, commonly known as the ABC to αβγ transformation. Such alteration protrudes the 3-phase measures over 2 fixed axes for a stable three-phase system. The three modes in which this transformation can occur are as follows:

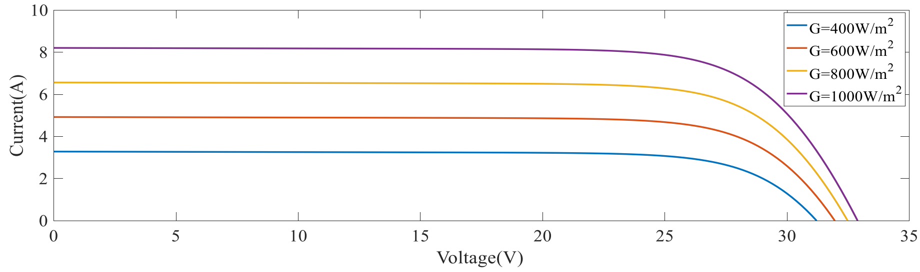
- Variant power (Clarke's original): It is the first transformation proposed by Edith Clarke. In this transformation, the γ axis is flattened so that it produces the output equal to the zero-sequence acquired from the symmetrical component's transformation. Considering the transformation matrix is not unitary, this transformation is a powered variant [29].
- Variant power (uniform): It is the evolution of the original transformation by Edith Clark to retain all axes as uniform. The output from this transformation is distinct from the zero sequence of the symmetrical component's transformation because the γ axis is not flattened. Considering the transformation matrix is not unitary, this transformation is a powered variant [30].
- Invariant power: It is also an evolution of the original transformation by Edith Clark that maintains all axis uniform and holds a unitary transformation matrix at the same time. The calculation of power after this alteration is indistinguishable from that done it. The output from this transformation is distinct from the zero sequence of the symmetrical component's transformation because the γ axis is not flattened.

3. RESULTS AND DISCUSSION

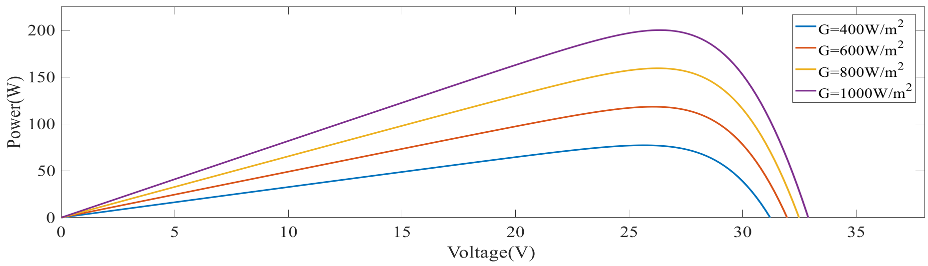
This division gives us the simulation results of the suggested model in the paper. All the simulations have been carried out in MATLAB/Simulink. This paper develops a simulation of a 2-stage 3-phase grid-connected PV system. The considered values for the simulation are reported in Table 1. Figures 5(a) and 5(b) represent the I-V characteristics and P-V characteristics of the solar cell. These characteristics are obtained at a temperature of 25 °C and irradiances of 400 W/m^2, 600 W/m^2, 800 W/m^2, and 1000 W/m^2.

Table 1. Selected values for the simulation studies

Parameter	Value
Open circuit voltage of solar panel (V_{oc})	363 V
Operating voltage range of MPPT (V_{mppt})	270 V to 300 V
Switching frequency of boost converter	5 kHz
Inductance in boost converter	1.45 mH
Capacitance in boost converter	3227 µF
Switching frequency of Inverter	10 KHz
Inductance in LCL filter	500 µH
Capacitance in LCL filter	100 µF



(a)



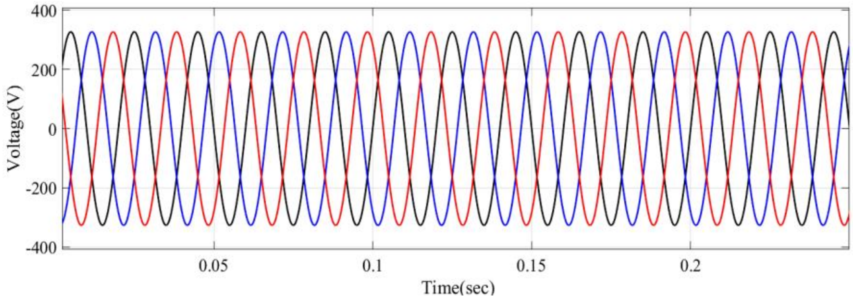
(b)

Figure 5. Characteristics of solar cell, (a) I-V characteristics and (b) P-V characteristics

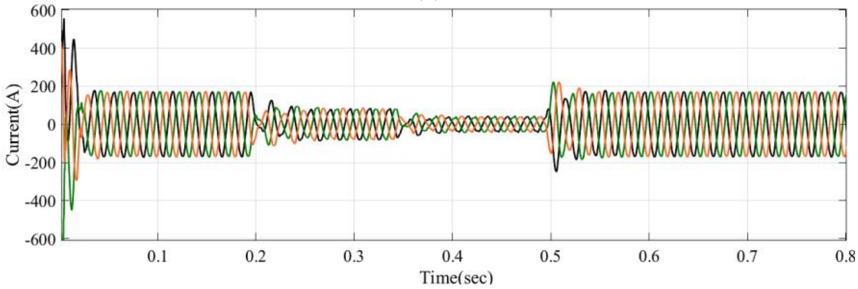
Figures 6(a) and 6(b) show us the 3-phase voltage and 3-phase current aligned in phase at the grid. The variations in the grid current are due to the change in the irradiations from 1000 to 500 W/m^2 and 250 W/m^2 and at last to 1000W/m^2 at different instances of time. We can observe that the decrease in irradiation leads to a decrease in the grid current. The decrease in grid current leads to a decrease in the active power of the grid. However, we can observe that the magnitude of the grid is maximum at irradiation of 1000 W/m^2.

Figure 7 shows us the DC output voltage from the Boost converter. The magnitude of the DC output voltage is 600V which is the same as the reference value we have considered. The perturbance in the DC voltage output is due to the sudden variations in the irradiations at different time instances. It will be a constant output voltage if the change in irradiations is changed gradually.

Figures 8(a) and 8(b) shows us the active and reactive powers of the grid at different irradiations from 1000 to 100 W/m^2 and then, back to 1000 W/m^2 at different time instances. The active power of the grid gets decreased when there is a decrease in irradiation because of a decrease in grid current. The maximum output active we obtained is 90 kW. Figure 9 shows us the THD analysis of the single-phase grid current under the LCL filter which is of the value of 1.70%. From this THD analysis, it can be ascertained that the technique proposed in this paper results in harmonics mitigation.



(a)



(b)

Figure 6. Output waveforms, (a) output voltage at the grid and (b) output current at the grid

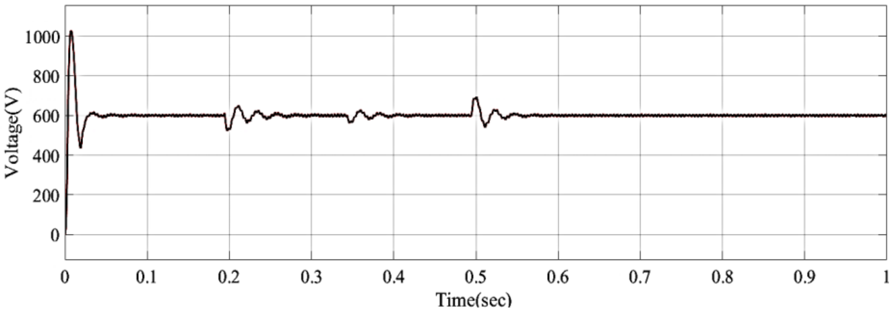
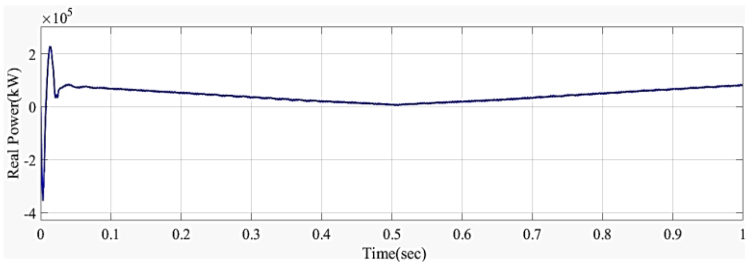
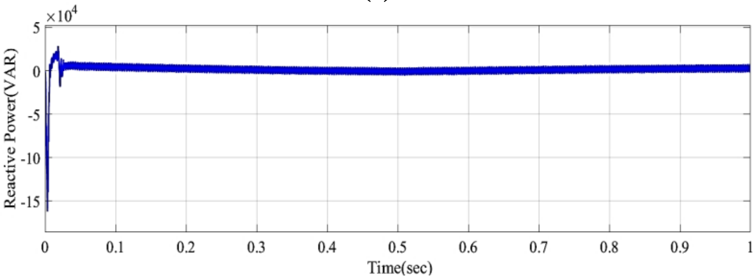


Figure 7. DC output voltage at the boost converter



(a)



(b)

Figure 8. Power of the grid, (a) active power of the grid and (b) reactive power of the grid

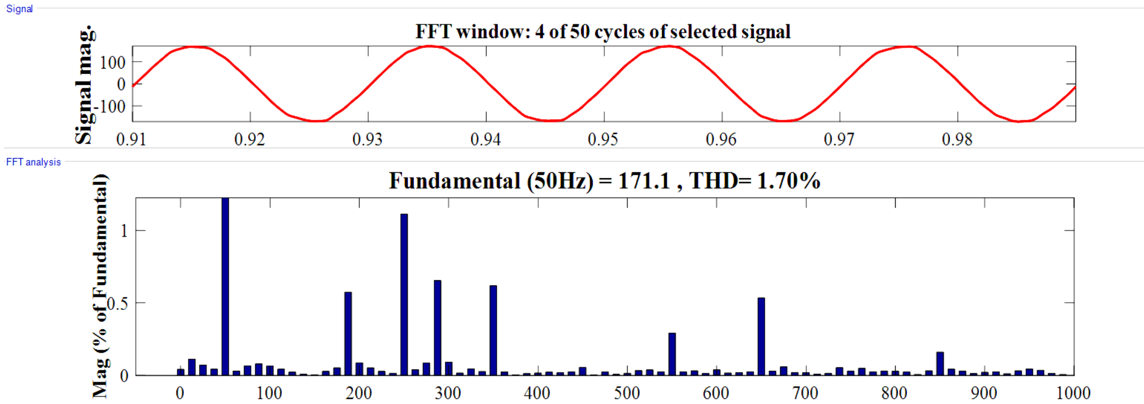


Figure 9. THD analysis of the grid current

4. CONCLUSION

By the end of this paper, a comprehensive model of a 2-stage grid-connected PV system is designed and implemented. The inverter control system of the voltage source constructively manages and constrains capacitor dc-link voltage to 600 V. The reactive power is near zero as it is integrated into the utility grid, thereby maintaining the power factor (PF) to 1. The effectively designed LCL filter mitigates the harmonics and magnifies the power quality. The total harmonic distortions of the grid current are mitigated by using an LCL filter, which we obtained is 1.70% - less than 5%. Finally, this research work is willing to contribute to better power quality in the development of renewable energy power generation and smart grids.

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