ACTIVE POWER FLOW CONTROL IN GRID-CONNECTED CONVERTERS UNDER UNBALANCED CONDITIONS BY USING FUZZY TECHNIQUE

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Abstract
The main aim of this project is active power flow control in grid-connected converters under unbalanced conditions by using the SVPWM technique. This paper proposes an advanced VSS in the converter-interfaced units, called zero-sequence compensated voltage support (ZCVS), to accurately regulate the three-phase voltages of the connection point within the pre-set safety limits. The proposed scheme not only compensates for the zero-sequence component but also considers the active power injection. Unlike the traditional methods, the proposed VSS is adapted even in resistive distribution systems. The contribution of this paper is, however, ternate. As the second contribution, the limited active power oscillation (LAPO) is proposed to be augmented to the ZCVS. This feature limits the oscillation to a specified value which provides an adjustable dc-link voltage oscillation setting while simultaneously supporting the ac host grid, even under severe unbalanced faults. Third, the maximum active power delivery (MAPD) to the ac grid is also formulated for the ZCVS. The successful results of the proposed support scheme with the Fuzzy technique and complementary strategies are verified using selected simulation test cases.

I. Introduction

The single-phase and three-phase voltage source converter is the most commonly used power electronics converter for utility level stand-alone or grid-connected distributed generation units. With the focus on reducing emission due to power production by fossil fuels, renewable energy gained immense importance over the past few decades. Renewable energy being abundantly available with no cost, it can serve as an alternative for power production. Various renewable resources present offer their own advantages and disadvantages. The most commonly used renewable power sources are the wind energy and solar energy. Extraction of power from wind energy requires high initial cost for setting up of the wind power plant i.e. the wind turbine along with its mechanical and electrical control system for optimal usage. On the other hand solar energy requires the panels to be setup over along with its electrical and mechanical systems which also involve high initial cost. However, from the perspective of maintenance solar power plants are comparatively easier to maintain from the mechanical perspective as replacement of a wind turbine would involve replacing an old wind turbine with a newer one. In this project, an advanced voltage support scheme (VSS) addressing these three issues. First, it fully compensates the zero-sequence component and accurately regulates the phase voltages within the preset safety limits under unbalanced fault conditions. The safety voltage limits are typically imposed by grid codes for uninterrupted operation of GCCs. Second, the proposed scheme is applicable to resistive grids, e.g., typical distribution systems. Third, the active power transferred by the GCC is also considered in the proposed VSS. In the existing system, little work has been carried out on the phase voltage regulation of a GCC under unbalanced conditions. However, the methods presented have three drawbacks. First, they do not consider the zero sequence voltage component whereas it exists in most unbalanced faults. Their accuracy are thus severely affected by the zero-sequence component of the PCC voltage, which will be shown later in this project. Second, these methods have been only applied in inductive grids, i.e., assuming very high X/R ratio. Third, all of the existing strategies are formulated assuming zero active power delivery. In this section, two complementary strategies are proposed to be applied to the active and reactive components of the current.

II. LITERATURE SURVEY

M. K. Hossain and M. H. Ali[1], proposes three nonlinear controllers such as fuzzy logic controller (FLC), static nonlinear controller (SNC), and adaptive-network-based fuzzy inference system (ANFIS)-based variable resistive-type fault current limiter (VR-FCL) to augment the transient stability of a large-scale hybrid power system consisting of a doubly fed induction generator (DFIG)-based wind farm, a photovoltaic (PV) plant, and a synchronous generator (SG). Appropriate resistance generation of the VR-FCL during a grid fault to provide better transient stability is the main contribution of the work. The effectiveness of the proposed control methods in improving the transient stability of the hybrid power network is verified by applying both balanced and unbalanced faults in one of the double circuit transmission lines connected to the system. Simulation results show that the proposed FLC-, SNC-, or ANFIS-based VR-FCL are effective in improving the transient stability of the studied hybrid system. Moreover, all the proposed methods exhibit almost similar performance. Therefore, any of the methods can be chosen for the transient stability enhancement of the hybrid power system.

H. Xiao, A. Luo, Z. Shuai, G. Jin, and Y. Huang[2], an improved control method for multiple bidirectional power converters is proposed to reduce the circulating current and power-sharing deviation among converters when the hybrid ac/dc micro grid operated in island mode, which can enhance the security of parallel converters. First, a unified detection method for circulating current and power-sharing deviation is described. Then, the improved control method for bidirectional converters in hybrid microgrid operated in island mode is presented to reduce circulating current and power-sharing deviation, which includes the droop controller used to achieve automatic power sharing and the improved virtual impedance controller used to further reduce circulating current and power-sharing deviation. At last, simulation and experiment results verified that the proposed control method can simultaneously achieve circulating current reduction and automatic power sharing, and does not decrease the output power capability of converter. The proposed control method is suitable for the configuration that has a specific bus between bidirectional power converters, and the ac bus connected to ac loads and the host grid.

P. Wang, C. Jin, D. Zhu, Y. Tang, P. C. Loh, and F. H. Choo[3], presents a distributed control scheme for reliable autonomous operation of a hybrid three-port ac/dc/distributed storage (ds) micro grid by means of power sharing in individual network, power exchange between ac and dc networks, and power management among three networks. The proposed distributed control scheme includes: 1) a fully decentralized control, which is achieved by local power sharing (LPS) in individual ac or dc network, global power sharing (GPS) throughout ac/dc networks, and storage power sharing (SPS) among distributed storages. Upon fully decentralized control, each power module can operate independently without communication links. This would benefit for riding through communication malfunction in multilayer supervision control system; 2) a multilevel power exchange control for scheduling LPS, GPS, and SPS has been developed to reduce unnecessary power exchange between ac/dc networks and operations of DS units with the benefit of reducing power exchange losses and prolonging storage lifetime.

K. A. Alobeidli, M. Syed, M. E. Moursi, and H. Zeineldin[4], proposes a new Coordinated Voltage Control (CVC) method with Reactive Power Management Scheme (RPMS) for a Hybrid Micro-grid (MG). The CVC scheme, based on synchronizing the response speeds of different voltage regulating devices, is coordinated with a novel Reactive Power Management Scheme (RPMS). Two cases, with and without proposed CVC, were simulated in the PSCAD/EMTDC environment and compared against each other. The case with proposed CVC shows superior performance, when tested for fault triggered islanding, intentional islanding and MG internal fault. Further, the proposed CVC with RPMS is compared to a voltage regulation method present in literature. The proposed CVC with RPMS provides better voltage regulation, maximizes the fast dynamic reactive power reserve, and improves the transient response and transient stability margin of the Hybrid Micro-Grid.

A. Camacho, M. Castilla, J. Miret, R. Guzmanm, andA. Borrell[5], describes Grid faults are one of the most severe problems for network operation. Distributed generation power plants can help to mitigate the adverse effects of these perturbations by injecting the reactive power during the sag and the postfault operation. Thus, the risk of cascade disconnection and voltage collapse can be reduced. The proposed reactive power control is intended to regulate the maximum and minimum phase voltages at the point of common coupling within the limits established in grid codes for continuous operation. In balanced three-phase voltage sags, the control increases the voltage in each phase above the lower regulated limit by injecting the positive sequence reactive power. In unbalanced voltage sags, positive and negative sequence reactive powers are combined to flexibly raise and equalize the phase voltages; the maximum phase voltage is regulated below the upper limit and the minimum phase voltage just above the lower limit. The proposed control strategy is tested by considering a distant grid fault and a large grid impedance.

III. MATHEMATICAL ANALYSIS OF PV SYSTEM

P-I Characteristic of a photovoltaic array Centralized inverter topologies are commonly employed in PV power generation systems due to their cost-effectiveness and ease of maintenance. A significant number of PV diodes are connected to in S-P arrangement. The output current of the PV panel can be expressed as [22]

$$I = N_{PP}[I_{PV} - I_O(I_P - 2)] - (\frac{V+IR_S\tau}{R_P\tau})$$

(1)

Where

$$I = exp(\frac{V+IR_S\tau}{V_T N_{SS}}) + exp(\frac{V+IR_S\tau}{(P-1)V_T N_{SS}})$$

(2)

$$\tau = \frac{N_{SS}}{N_{PP}}$$

(3)

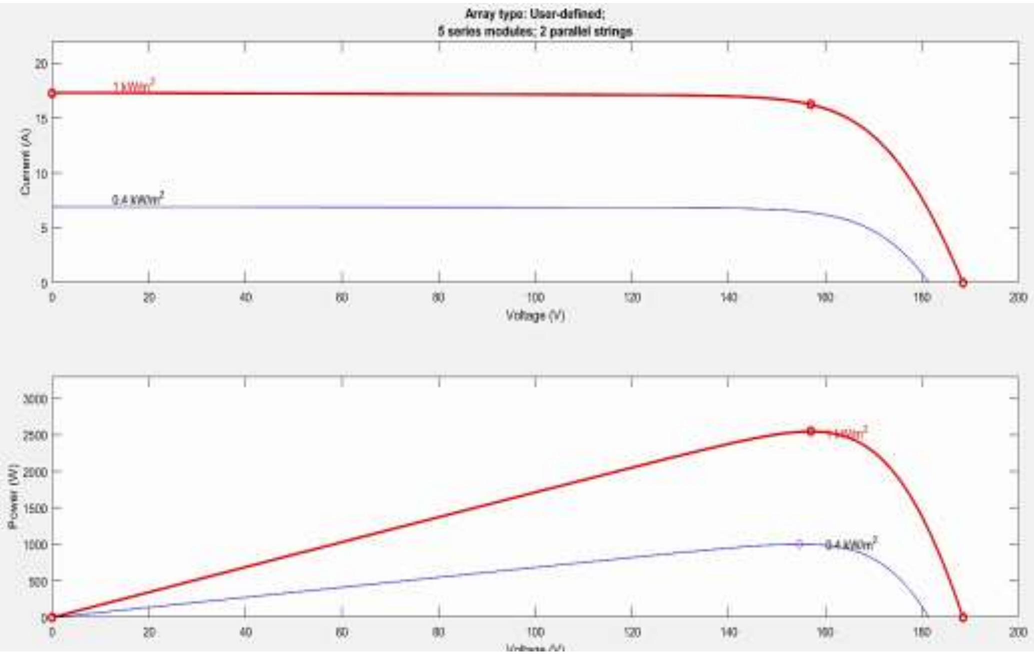

Fig.1 V-I and P-V characters of the PV system.

I and V are correspondingly, solar cell's output current and voltage Vt stands for the voltage of PV arrays, whereas IPV is the photocurrent and IO the reverse saturation current of PV arrays. A series resistance is equal to RS, while a parallel resistance equals RP Photovoltaic (PV) cell production is highly connected to solar irradiation. The PV array has high nonlinear VI characteristics when solar irradiance fluctuates. As it does not have a constant voltage nor a constant current, it cannot supply a constant amount of electricity to a given load Most of the operating voltage range has a steady output current, but towards the open circuit voltage the current declines rapidly. It can be seen from the figure that the output characteristics of the photovoltaic array vary greatly under the influence of solar irradiance. When the solar irradiance increases, the output power increases.

IV. Proposed P&O algorithm

Method of Perturb and Observe It is a popular method. This approach employs minimum sensors. In this method, the operating voltage is sampled, and the operating voltage is modified in a specified direction using an algorithm, and therefore the $\frac{d_P}{d_v}$. Pd v is sampled. If $\frac{d_P}{d_v}$. pd v is positive, the algorithm increases the voltage value towards MPP until $\frac{d_P}{d_v}$. pd v is negative. This process is repeated until the algorithm reaches MPP. This approach is unsuitable when there is a considerable change in sun irradiation. The voltage fluctuates about the maximum power point (MPP) and never reaches a precise value.

For MPPT, this technique uses the instantaneous conductance $\frac{d_P}{d_v}$. and the P and O $\frac{d_P}{d_v}$. The location of the PV module's operating point in the P–V curve can be determined based on the relationship between the two values, as expressed in (4)–(6), i.e., (4) indicates the PV module operates at the MPP, whereas (5) and (6) indicate the PV module operates on the left and right side of the MPP in the P–V curve, respectively.

Perturb and Observe method It is widely used

$$\frac{d_p}{d_v} = -\frac{P}{V}$$
(4)

$$\frac{d_p}{d_v} > -\frac{P}{V}$$
(5)

$$\frac{d_p}{d_v} < -\frac{P}{V}$$
(6)

The equations above are derived from the idea that the slope of the P–V curve at MPP is equal to zero, i.e.

$$\frac{d_p}{d_v} = 0$$
(7)

By rewriting (7), the following equation is obtained:

$$I + V\frac{d_i}{d_v} = 0$$
(8)

If (5) is satisfied, the duty cycle of the converter needs to be decreased, and vice versa if (6) is satisfied, whereas no change on the duty cycle if (8) is satisfied [23].

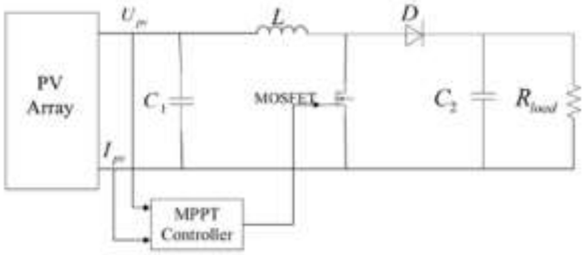

Fig. 2 PV system with the boost converter

V. PROPOSED SYSTEM MODELING

Fig. 1 illustrates the schematic of a GCC based DG unit along with its different control parameters. A grid fault or unbalanced loading can cause unbalanced voltage condition at the PCC of a GCC.

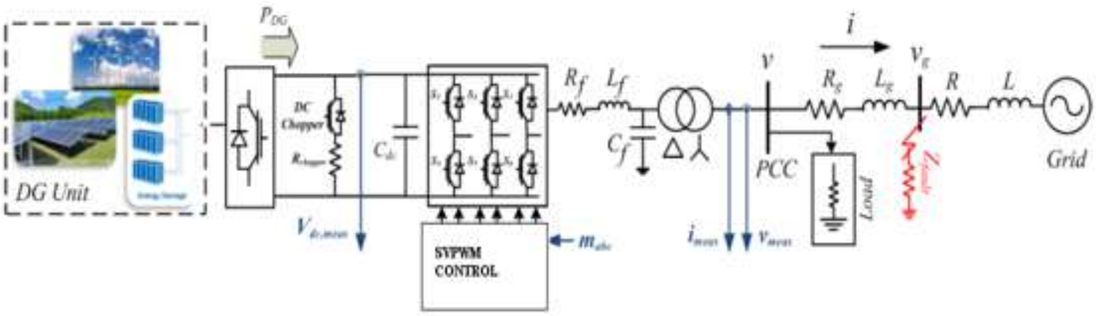

Fig.5.1 Proposed Circuit topology of the GCC with SVPWM control

These current components should be found in a way that they can provide the required voltage support with any grid condition. The basic requirement in the voltage support is to avoid the over-voltage and under-voltage at the PCC whenever possible. If the rated power of the GCC and the connecting line impedance are not small, the three-phase voltages can be regulated at the preset safety limits, i.e., V_{min}^{set} and V_{max}^{set}. In the proposed scheme was only applied to the STATCOM application where the reference current only consists of the reactive components. However, the effect of the active power in regulating the voltage should not be ignored at the distribution level since: the resistance of the lines in the distribution system is not negligible; and DGs inherently generate and inject the active power to the system. The value of V_{min}^{set}– V_{max}^{set} are set to 0.9–1.1 p.u. and 0.8–1.2 p.u., respectively, in the simulation and experimental tests in this project. To meet these limits a combination of positive/negative and active/reactive currents (i.e., I_p^+, I_p^-, I_q^+, and I_q^-) should be injected into an inductive or resistive grid to support the grid voltage. These four reference values should be properly found such that the maximum phase voltage does not overpass V_{max}^{set}, and the minimum phase voltage is kept at (or above) V_{min}^{set}. The ac-side VSS can be extracted as a function of the grid voltage and the injected positive/negative currents. In this case, they can be utilized to fulfill complementary objectives discussed in the following section (i.e., MAPD strategy). Fig.3 shows the control diagram of the proposed scheme.

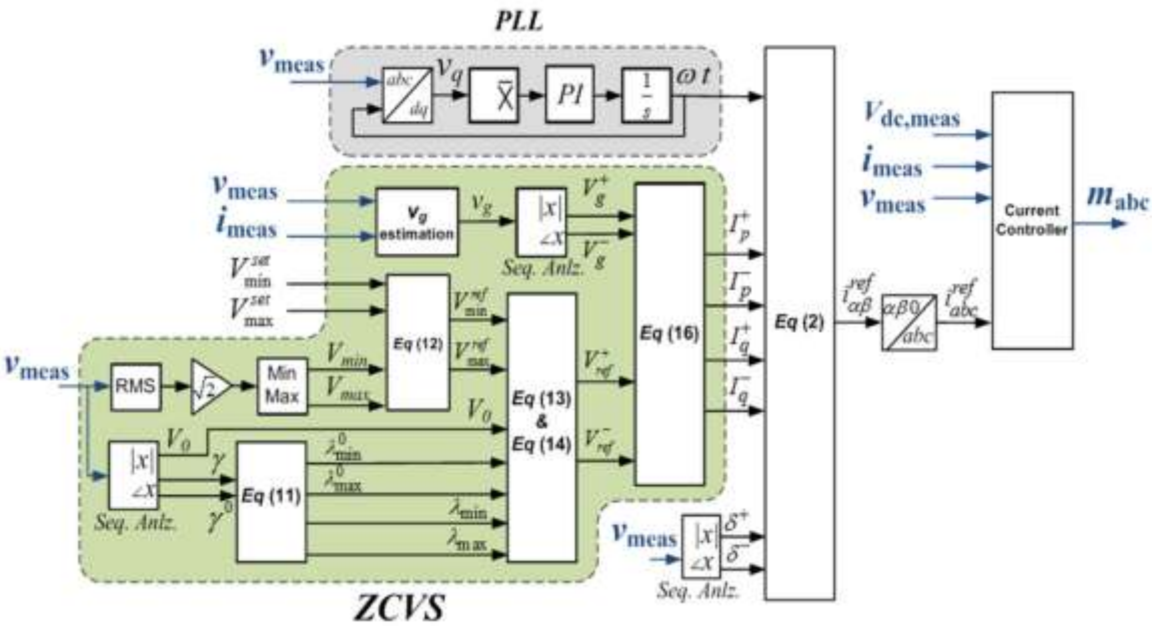

Fig.5.2 Proposed ZCVS method for VSS

VI.PROPOSED COMPLEMENTARY STRATEGIES

In the previous section, the positive and negative sequences of the reactive current component were obtained for regulating the phase voltages in an inductive grid. In this section, two complementary strategies are proposed to be applied to the active and reactive components of the current. The first strategy, i.e., LAPO, aims to limit the oscillations on the active power, which is critical to improve the dc-bus voltage stabilization. Furthermore, the second strategy, i.e., MAPD, intends to deliver the maximum active power with respect to the rating current while simultaneously supporting the voltage with ZCVS. These strategies can also be obtained for the resistive grids and grids with any X/R value if the active and reactive components are replaced or is satisfied.

A. ZCVS WITH LAPO STRATEGY

In severe unbalanced conditions, the required negative reactive component of the current obtained by ZCVS may become high. Negative sequence current and voltage components give rise to large oscillations in the active power. Therefore, the LAPO strategy is proposed to obtain a limit for the negative reactive current component, which does not cause exceeding the preset maximum allowable active power oscillation $\tilde{P}_{max}^{set}$.

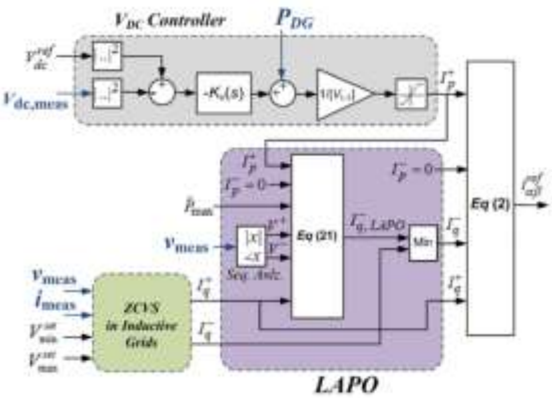

Fig. 5.1 Proposed control diagram to limit the active power oscillations.

This analytical expression limits the active power oscillations and enhances the dc-bus voltage stabilization. Fig. 3 shows the control diagram of the ZCVS scheme with LAPO strategy. LAPO may slightly affect the operation of the ZCVS. However, the GCC operator can flexibly compromise between the full ZCVS and the LAPO capability, by using these analytical expressions.

B. ZCVS WITH MAPD STRATEGY

Applying the MAPD technique ensures delivering the maximum allowable active power to the grid and simultaneously respecting the current limitations while riding through abnormal conditions, and simultaneously regulating the phase voltages. Therefore, this section finds the equation of $I_{p,MAPD}^{+}$ to achieve the aforementioned goals. $I_{p,MAPD}^{+}$ is the term determining the maximum allowable value for I_p^+ to provide the maximum allowable active power injection such that none of the phase currents passes I_{max}^{set}.

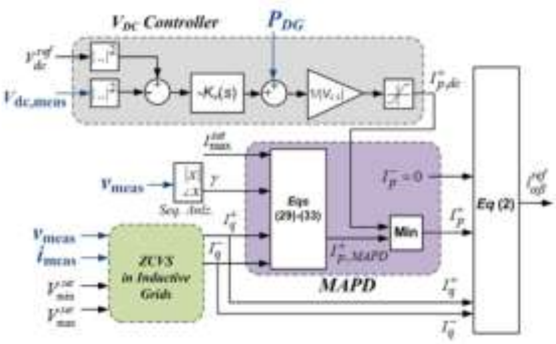

Fig.5.2 Proposed control diagram to maximize the active power delivery.

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VI. SIMULATION RESULTS

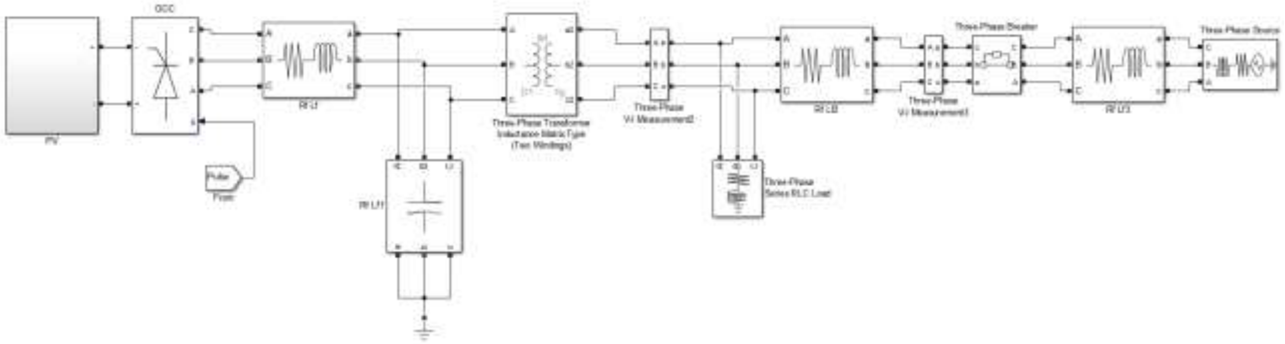


Fig.6.1 Simulation Diagram of the proposed system.

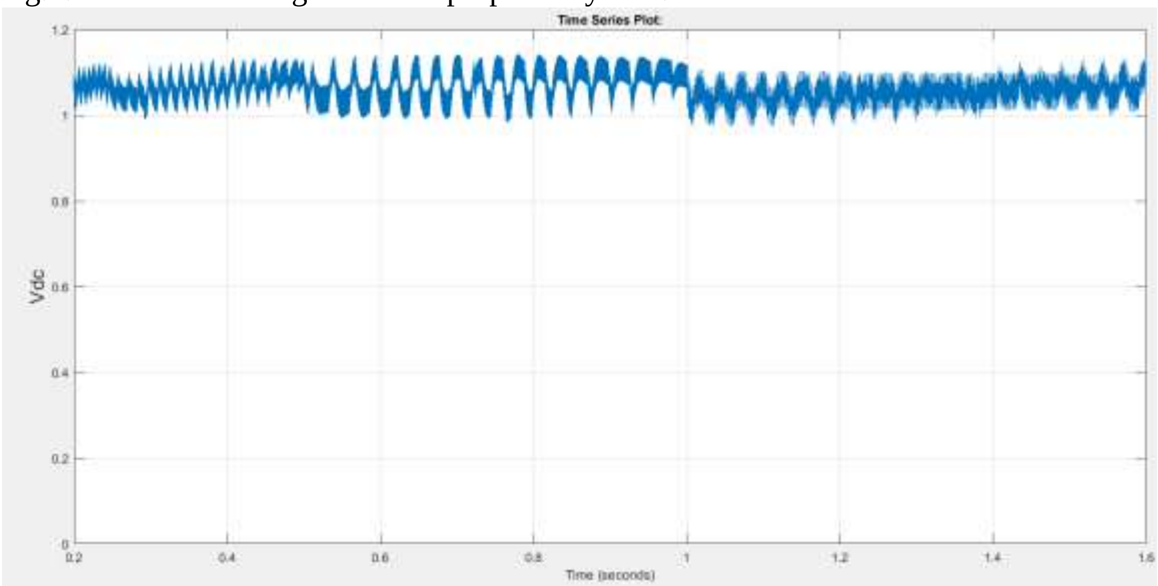
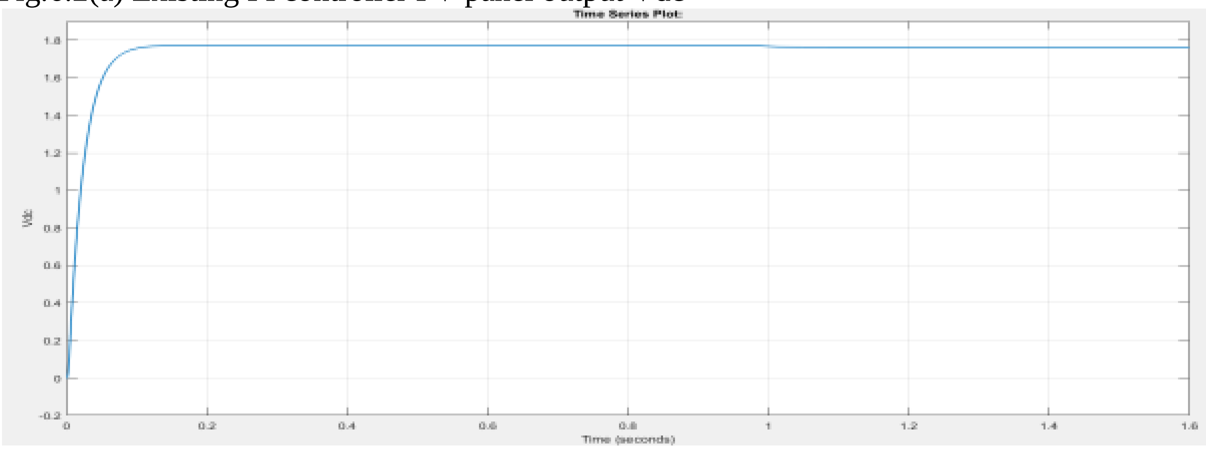


Fig.6.2(a) Existing PI controller PV panel output Vdc



(b)

Fig .6.2(b) Proposed Fuzzy (FLC) controller PV panel output Vdc

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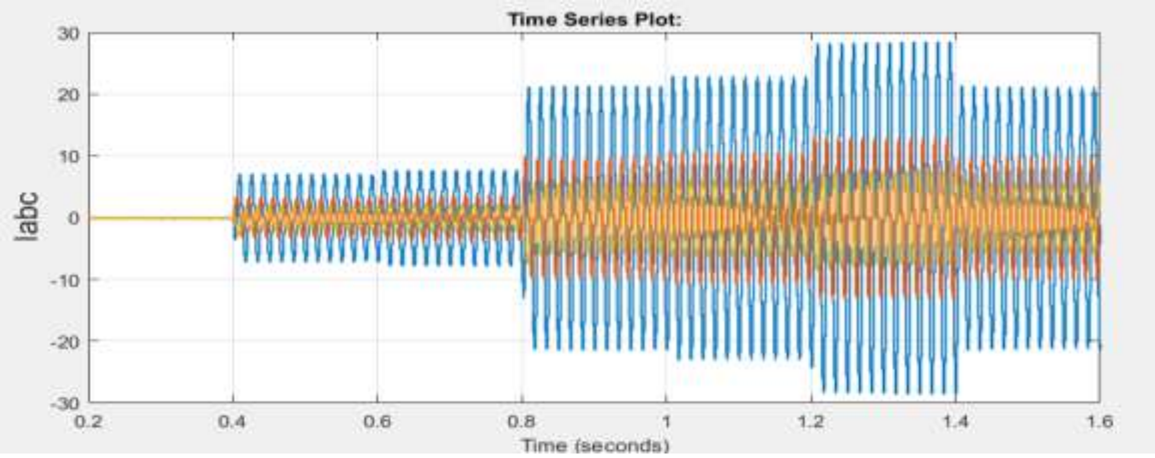

Fig. 6.3(a) Existing PI controller Grid Current I_{abc}

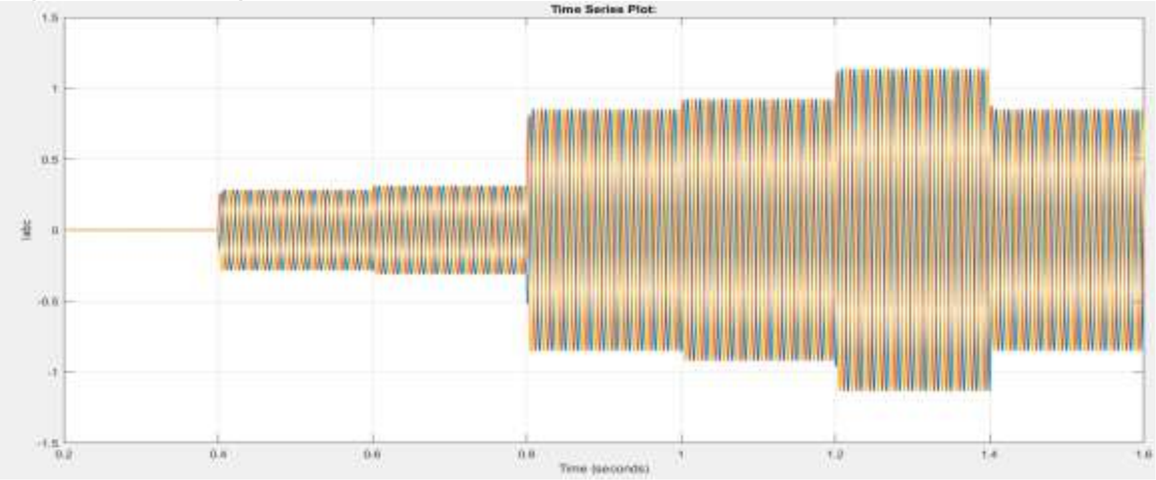

Fig. 6.3 (b) Proposed Fuzzy (FLC) controller Grid Current I_{abc}.

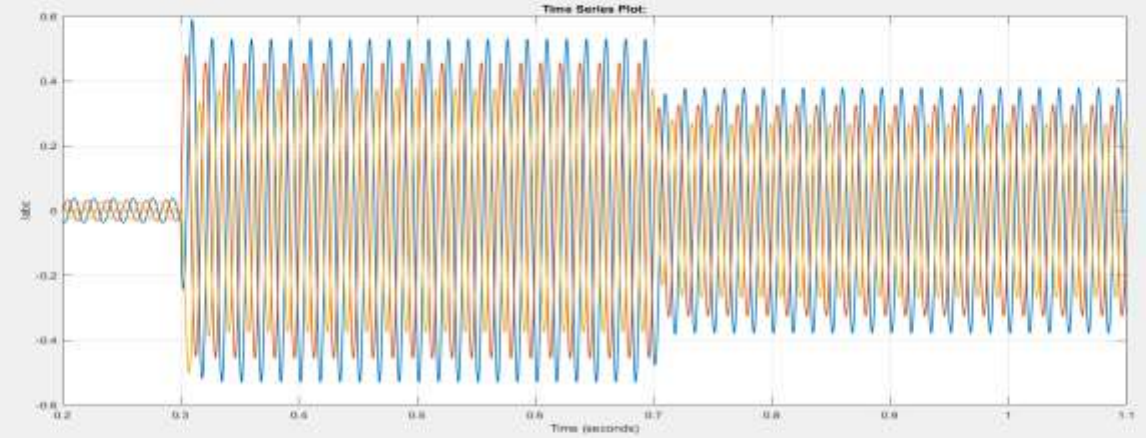

Fig 6.4(a) Existing PI controller Load Current I_{abc}

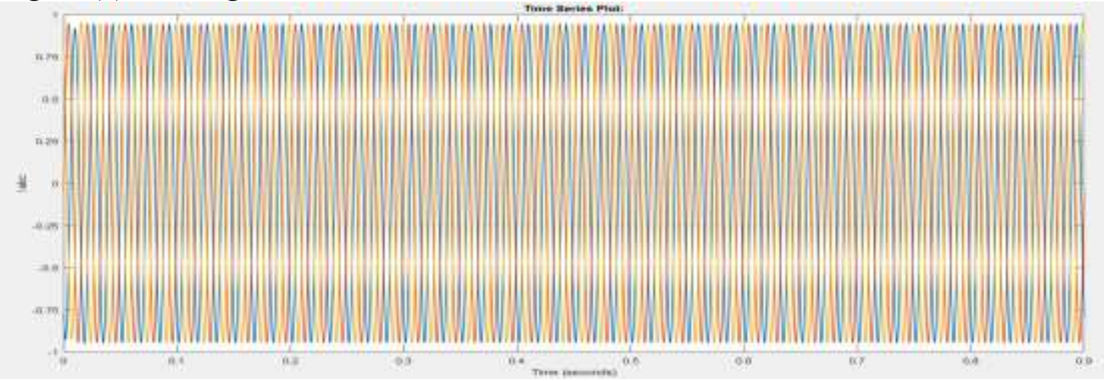

Fig.6.4 (b) Proposed Fuzzy (FLC) controller Load Current I_{abc}.

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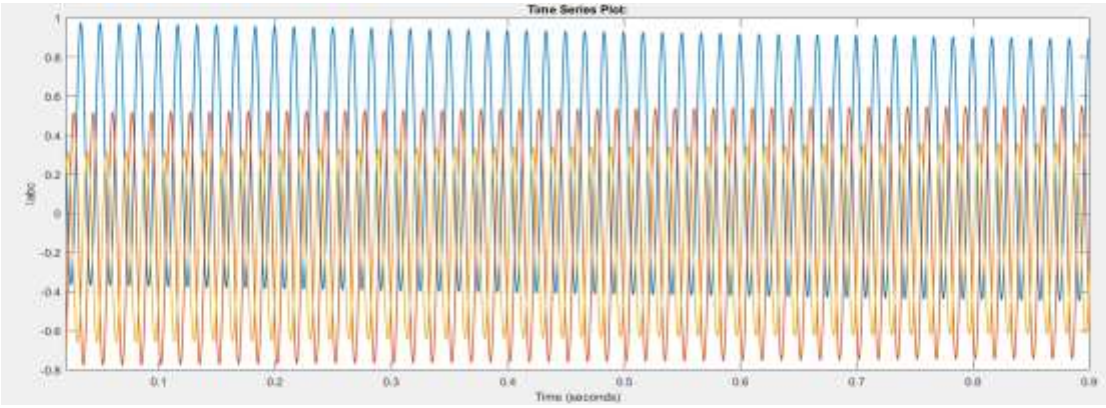

Fig.6.5 (a) Unbalanced Current at the Grid side

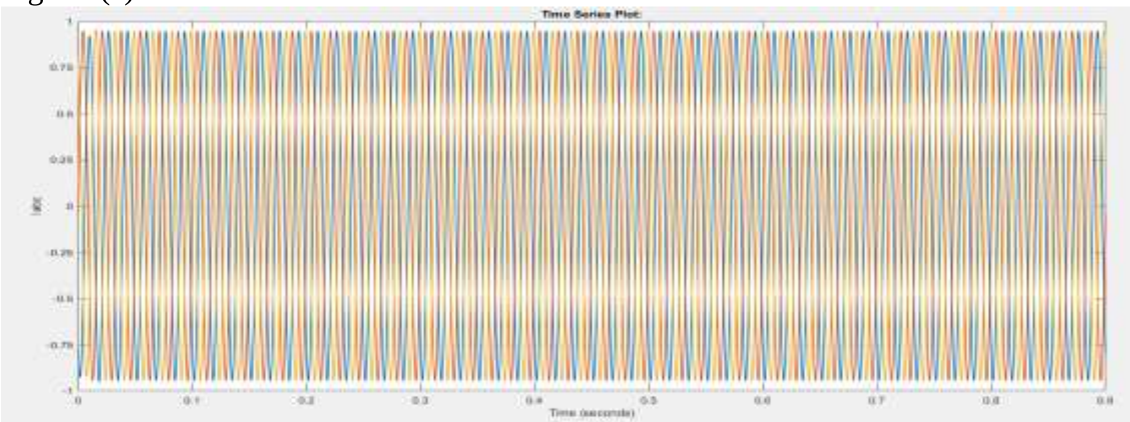

Fig.6.5 (b) Balanced Current at the Grid side with FLC

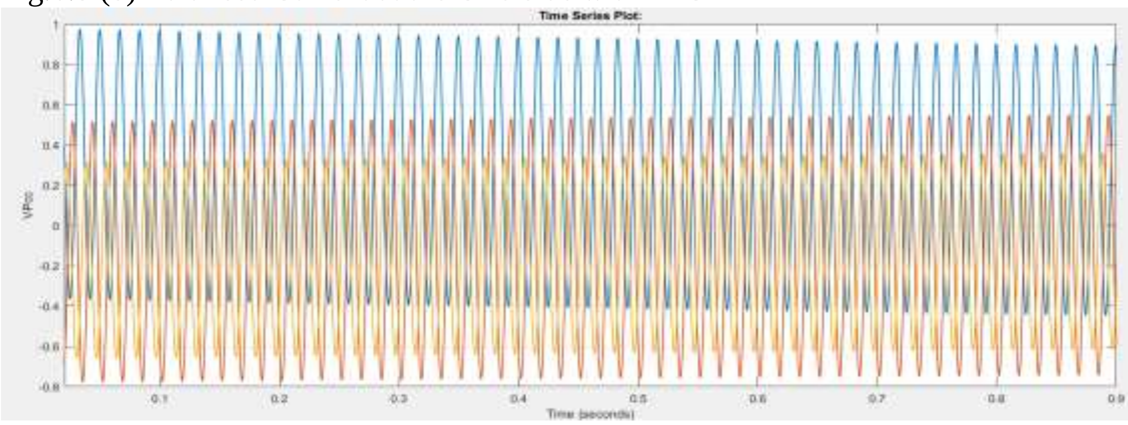

Fig. 6.6(a) existing Pcc phase voltage

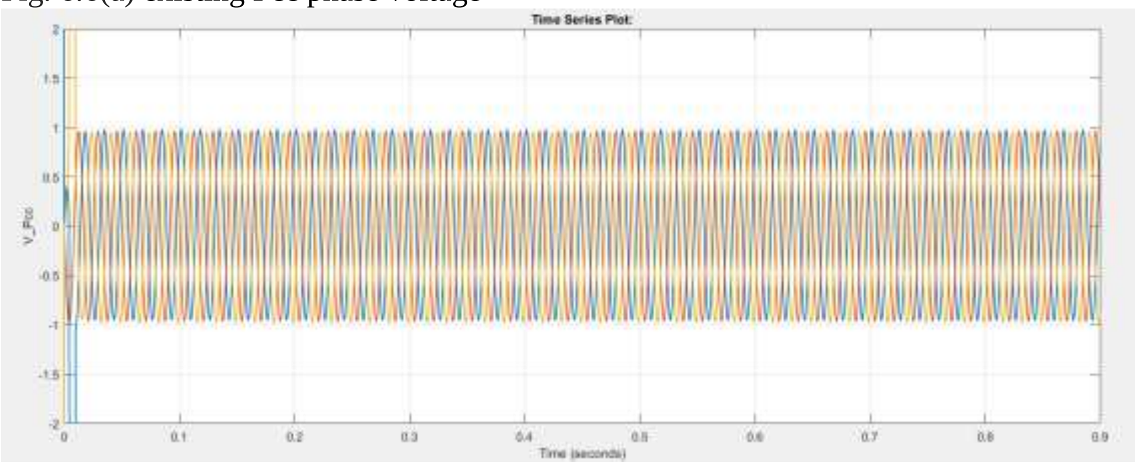

Fig. 6.6(b) proposed Pcc phase voltage

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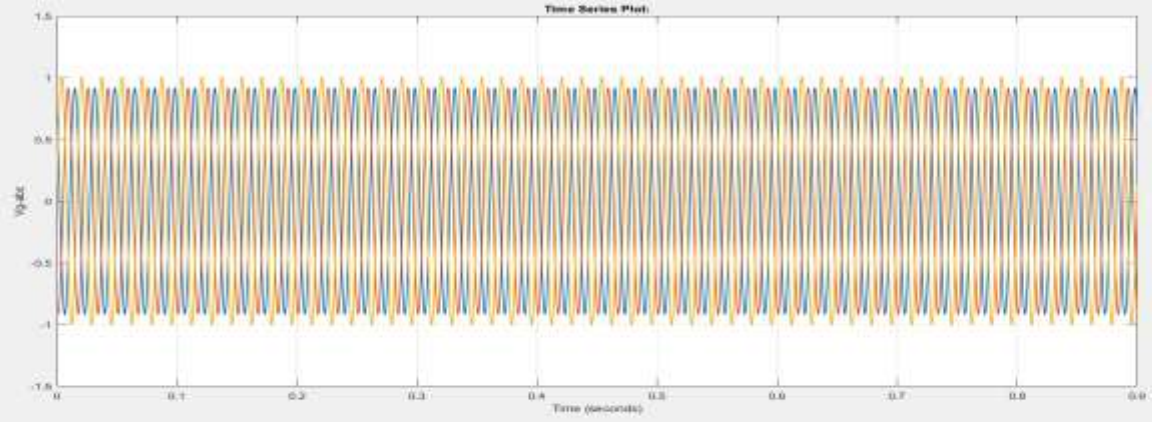

Fig. 6.7(a) Unbalanced Voltage at the Grid side

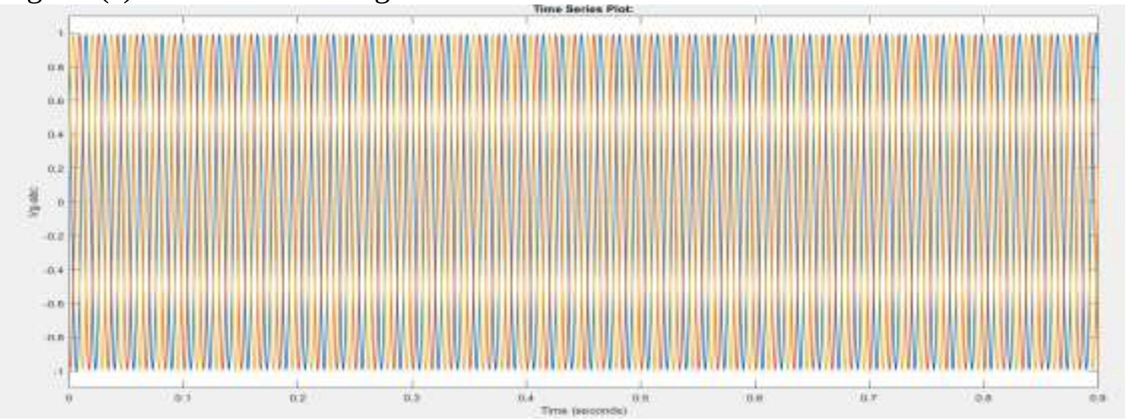

Fig. 6.7 (b) Balanced Voltage at the Grid side with FLC

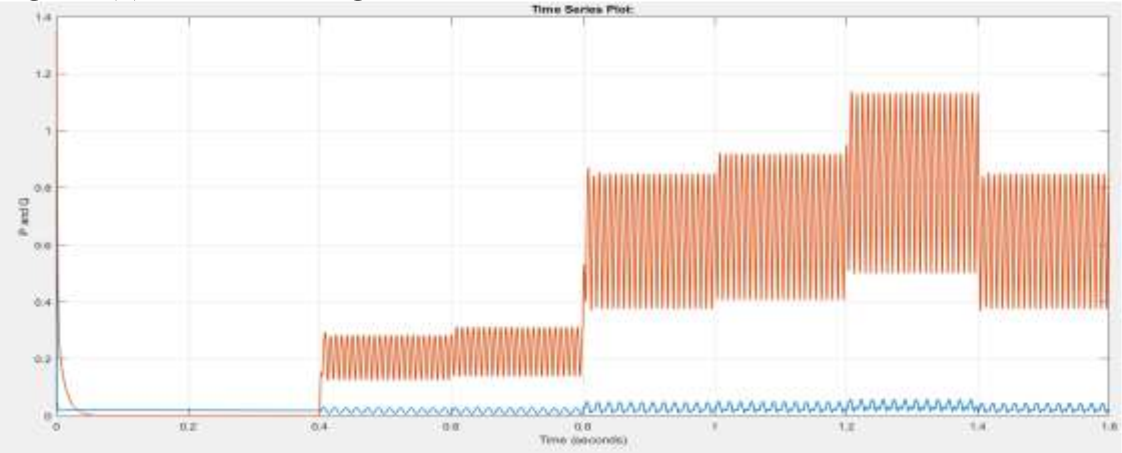

Fig. 6.8(a) existing active and reactive power

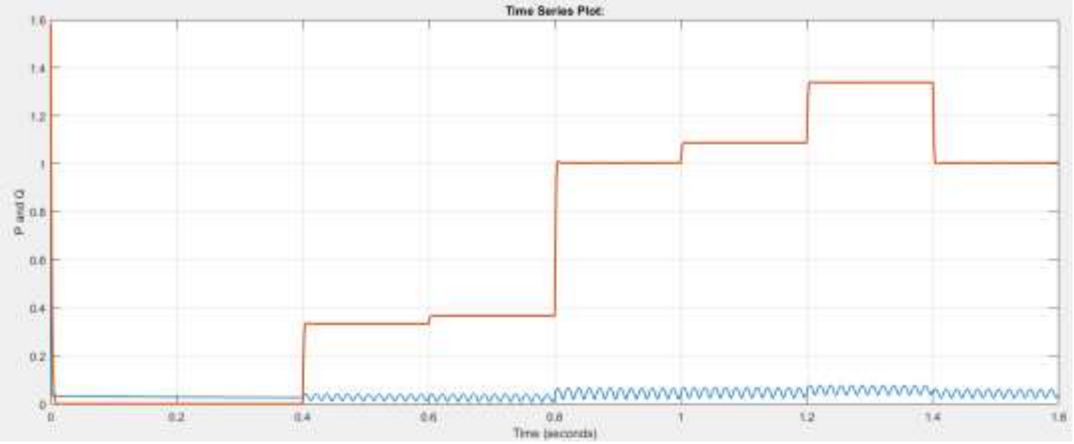

Fig. 6.8(b) proposed active and reactive power

Traditional VSS Versus Proposed ZCVS Method This section presents the simulation results of the traditional voltage support scheme (TVSS) and the proposed ZCVS method. It shows six different unbalanced faulty conditions. Between t = 0.3 s and t = 0.5 s, a single-phase fault happens on phase A (i.e., the magnitude of phase A is increased to 0.8 p.u.). From t = 0.3 s, each phase voltage experiences different sags to show and compare the performances of the traditional and proposed methods. TVSS and ZCVS for different fault conditions. The phase voltages within the preset voltage limits. Over-voltages up to 1.18 p.u. (on phase B between t = 0.3 s and t = 0.5 s) However, the proposed ZCVS method demonstrates successful results. As Fig., the phase-voltages of the PCC are precisely regulated between the V set min and V set max. Also, it is notable from that the dc voltage ripples are considerably lower when the ZCVS is applied.

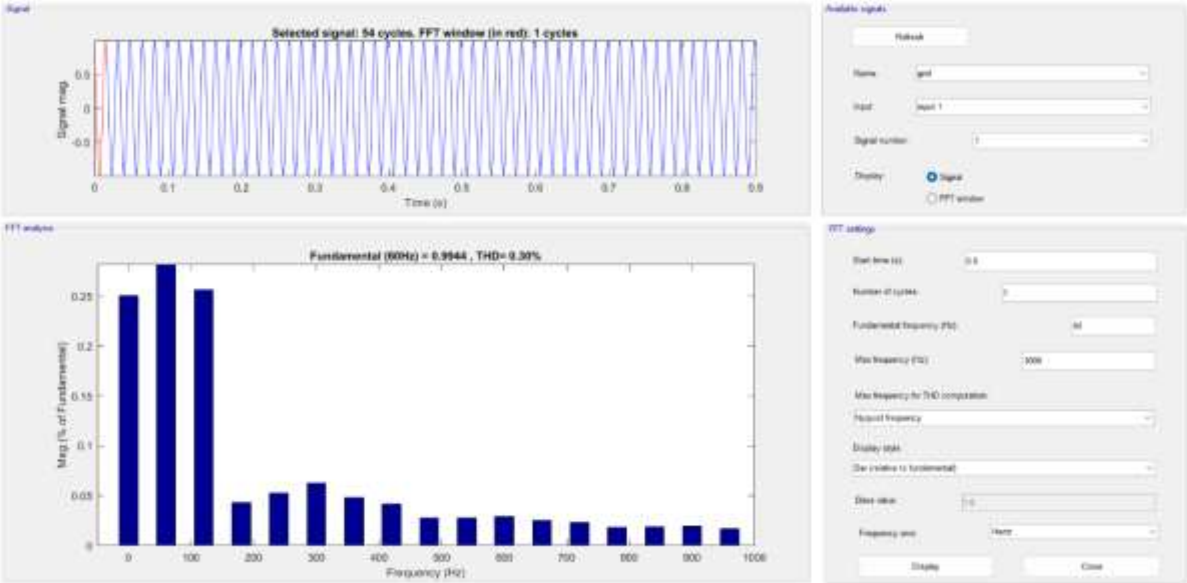

Fig. 6.9 THD of Grid Voltage Proposed controller FLC is 0.30%

In addition, the simulation results of fuzzy logic control are shown in Fig. both control methods have the ability to track the reference current THD. However, the performances of fuzzy logic control are better than that of PI control. The fuzzy logic control provides smaller overshoot, faster settling time, and smaller steady-state error.

CONCLUSION

This project proposes an advanced VSS to precisely regulate the phase voltages of a three-phase GCC within the present safety limits. Existing methods mainly suffer from three problems: first, their performance becomes inaccurate in most cases because of ignoring the zero-sequence voltage component; second, they can be only applied in inductive grids; and, third, zero active power delivery is suggested. The proposed ZCVS method addresses these three problems. Moreover, two complementary objectives, related to active power delivery, are also augmented in the proposed scheme. This feature provides an adjustable and limited oscillation on active power and improved dc voltage while supporting the ac-side voltage. In the PV system FLC is used for the MPPT method. At the Boost converter ZCVS is controlled. The proposed VSS and two complementary strategies bring significant advantages to emerging distributed generation units. In this paper, the ZCVS of the DC system was controlled, THD was below 5% of the IEEE standards and the unbalanced volages and currents are balanced

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