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Power Quality Improvement using Solar Fed Multilevel Inverter Based STATCOM

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ABSTRACT- The major goal about suggested technique is to use a PSO-based proportional-integral (PI) controller towards enhance power quality performance about three-phase grid-connected inverter system. An approach like aforementioned tries to stabilize output current & voltage, lower harmonics, & lessen DC link input voltage fluctuation. Through reducing error about voltage regulator & current controller schemes in inverter system, particle swarm optimization (PSO) technique was used towards adjust PI controller settings. When compared to conventional approach, simulation results show certain optimal parameters PI controller created among PSO produces better performance index results. According towards various research, reactive power supply can only modestly reduce voltage sags while totally mitigating harmonics using specialized power devices. Effective & dependable use about PV solar farm inverters as STATCOMs is required towards guarantee certain generating units stay connected towards grid during voltage sags & towards enhance system performance during abnormal circumstances.

General Terms: Power Quality, FACTS, Optimization techniques.
Keywords: Particle Swarm Optimization (PSO), Synchronous Reference Frame (SFR), Multilevel Inverters.

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1. INTRODUCTION

Power quality issues are occurring due to the increased utilization of non-linear loads and greater penetration of renewable energy sources, current harmonics, reactive power demands and voltage variations (voltage sag and swell), in distribution and transmission systems. Among the various power quality issues, harmonics and voltage sag are the most common and severe issues in power systems [1-4]. Rising utilization about power electronic-based electrical machine controls are one of main causes of harmonics. The main causes of voltage sag are the escalation of load current caused by the starting of large motors, transformer energization, switch ON and OFF operation of circuit breakers, faults within the customer's facility, equipment failure, abnormal weather conditions (lightning strikes on power systems) and the highly intermittent nature of renewable sources connected to distribution systems [4,5]. Voltage droop is characterized as drop in RMS (Root Mean Square) voltage (AC voltage) from 90% towards 10% about nominal voltage at power frequencies during 0.5 cycles towards 1 min [7,9] according towards IEEE Std. 1159. Voltage sags are classified based on magnitude and sag duration. More than 80% about issues among power quality in distribution & transmission systems [13]. The renewable energy sources play an important role in electric power generation with growing environmental concerns. The inter connection of renewable energy sources are incorporated using power electronic converters, with the aim of improving power quality at the Point of Common Coupling (PCC). A novel idea where a STATCOM is used innovatively as (i) a load reactive power compensator (ii) an interface unit between the grid and renewable energy source, and (iii) Voltage regulator. The performance of the algorithm is compared with the Synchronous Reference Frame (SFR) algorithm to achieve the above objectives. The MLI topologies with reduced number of components count can be categorized under two classes namely the symmetrical MLI topology or asymmetrical MLI topology. Topologies have same value of dc sources referred as symmetrical multilevel inverters whereas with unequal dc sources grouped as asymmetrical multilevel inverters [10].

In this paper a new MLI topology is proposed that is capable to produce nine level output voltage with reduce component counts. The idea is to arrange available switches and dc sources in a fashion such that the maximum combination of addition and subtraction of the input dc sources can achieve. To verify the design, the circuit is developed via MATLAB Simulation tool.

Hence, the PSO is used in the current study for the optimal design of PI controller parameters. Its aim is to obtain the best optimum values of K_p and K_i in real-time operation, The proposed controller scheme is implemented using a synchronous reference frame with two PI controllers. In addition, the PSO is used to obtain the optimum values of the PI control parameters and reduce error to enhance the voltage and frequency stability with shorter time and less complexity.

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Rest of the paper is organized as follows:
System chosen and its description is explained in *section 2*. Proposed control method with STATCOM is explained in *section 3*. *Section 4* derives particle swarm optimization. *Section 5* presents simulation results to check effectiveness of proposed control system.

2. CIRCUIT DESCRIPTION CONSIDERING PROPOSED SYSTEM

The traditional configurations about power systems be changing because about more noteworthy entrance about environmentally friendly power sources (sun based), bringing about dependability issues. As about now, most serious power quality issues in circulation frameworks be current harmonics, reactive power issues & islanding about renewables brought about through extreme voltage varieties (voltage droop & swell). Current sounds & voltage droop firmly influence exhibition about inexhaustible based power frameworks. In light about a few examinations, custom power gadgets can moderate sounds totally & marginally relieve voltage sags among responsive power supplies. Towards guarantee creating units remain system associated during voltage lists & towards further develop framework activity during unusual circumstances, effective & dependable use about PV sunlight-based power inverter as STATCOMs are required.

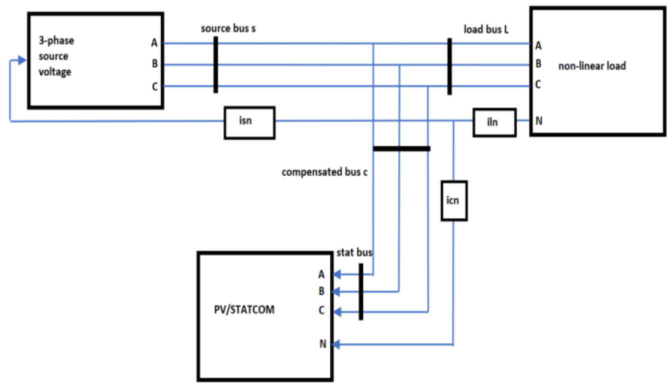

Figure 1. Outline about Proposed System

This part mostly examines arrangement about test model & powerful execution about PV-STATCOM considering moderation about voltage sag in a network coordinated framework. Nine level asymmetrical multi-level inverter -based PV-STATCOM was connected in shunt for the injection of the required active and reactive power to provide support for grid voltage recovery, in addition to harmonics compensation [11]. The photovoltaic (PV) system for the mitigation of harmonics and voltage sag at the Point of Common Coupling (PCC) in the grid-integrated PV system.

3. CONTROL STRATEGY CONSIDERING STATCOM

To improve on research into power system circuits, proposed controller converts three-phase load currents into alpha-beta components certain be in a fixed reference outline incorporating Clarke's change. Then, using Park's alteration, alpha-beta parts be totally converted into dq0 parts, which be in a pivoting reference outline. In a similar manner, PV grid voltages plus STATCOM currents are also converted to alpha-beta stationary frame in order to accurately compute reference currents. Aforementioned is done by completely converting d-q to alpha-beta plus then applying alpha-beta to a three-stage R-Y-B using opposite Clarke's change. Sinusoidal pulse width modulation (SPWM) block, the required pulses are generated for the three-phase inverter using relational operator blocks, so that the required amount of reactive current is supplied.

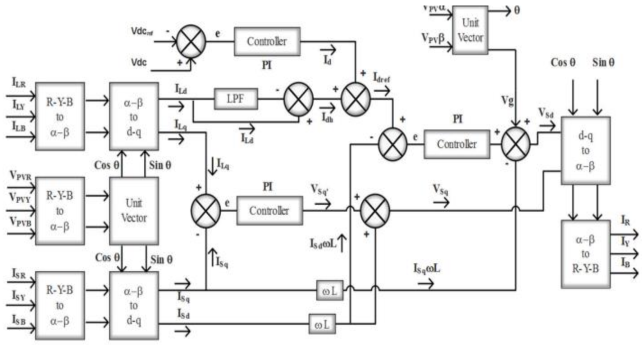

Figure 2. Control strategy considering STATCOM

3.1. Grid Voltages & Currents

It is vital towards break down network voltages & currents considering mitigation about harmonics & voltage sag. Among assistance about Clarke transformation, 3-phase voltage & currents were changed towards αβ0 (RYB otherwise abc → αβ otherwise dq). The grid voltages & flows were given as follows

$$V_{pv}R = V_m \sin(wt) \quad \rightarrow (1)$$

$$V_{pv}R = V_m \sin\left(wt - \frac{2\pi}{3}\right) \quad \rightarrow (2)$$

$$V_{pv}R = V_m \sin\left(wt - \frac{4\pi}{3}\right) \quad \rightarrow (3)$$

The instantaneous load currents were:

$$I_L R = \sum I_L R_n \sin\{n(wt - \theta R_n)\} \quad \rightarrow (4)$$

$$I_L Y = \sum I_L Y_n \sin\{n\left(wt - \frac{4\pi}{3}\right) - \theta Y_n\} \quad \rightarrow (5)$$

$$I_L B = \sum I_L B_n \sin\{n\left(wt - \frac{4\pi}{3}\right) - \theta B_n\} \quad \rightarrow (6)$$

The stationary frame representations of the grid voltages and currents were expressed as per a Clarke transformation (abc → αβ0), as follows

$$I_{sd} + jI_{sq} = I_{s\alpha}\cos\theta + jI_{s\beta}\sin\theta - jI_{s\alpha}\sin\theta + jI_{s\beta}\cos\theta \quad \rightarrow (7)$$

$$I_{sd} + jI_{sq} = I_{s\alpha} + jI_{s\beta}(\cos\theta - j\sin\theta) \quad \rightarrow (8)$$

$$I_{s\alpha} + jI_{s\beta} = (I_{sd} + jI_{sq})e^{j\theta} \quad \rightarrow (9)$$

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Similarly, considering voltages

$$V_{s\alpha} + jV_{s\beta} = (V_{sd} + jV_{sq})e^{j\theta} \quad \rightarrow (10)$$

$$V_{G\alpha} + jV_{G\beta} = (V_{Gd} + jV_{Gq})e^{j\theta} \quad \rightarrow (11)$$

4. Nine level asymmetrical MLI-Based PV-STATCOM

PV-STATCOM has typically been used to manage reactive power and harmonics at the PCC in distribution networks for the mitigation of power quality issues. The photovoltaic (PV) solar system collects energy from sunlight and generates a direct current [16]. *Fig. 3* depicts schematic circuit topology of the proposed nine levels asymmetrical multilevel inverter. Proposed topology consists of two asymmetrical dc sources, defined as V1 and V2 and ten switches. IGBTs are used as switches. Asymmetrical dc sources are independent of each other and are in ratio of V1:V2 = 1:3. In order to prevent the short circuit of the sources, simultaneous conduction of the switches (S1, S2), (S3, S4), (S4, S5, S6), (Sa1, Sa3), (Sa2, Sa4) must be avoided. This can be done by proper switching of the switches. *Fig. 4* shows the switching pulses for one complete cycle. All the switches operate at low frequency. The conduction period is short for all switches except for the bridge switches. Hence, it envisages that the power losses in the circuit are reduced significantly.

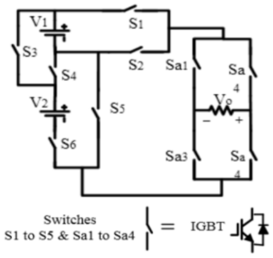

Figure 3. Asymmetrical 9-level inverter topology

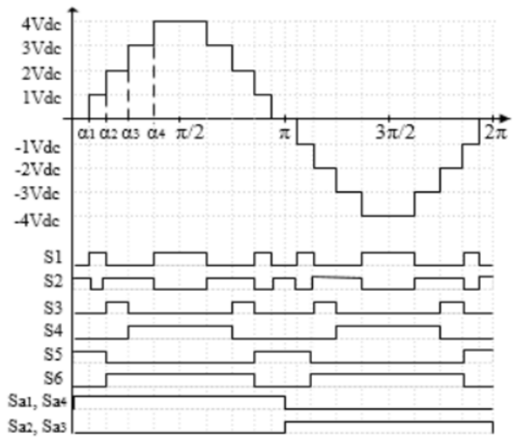

Figure 4. Switching pattern about 9-level inverter

It is understood certain a higher level about significance regarding outcome voltage will produce a cleaner sinusoidal waveform. Hence, the design of the filter can be less burden. For MLI, the number of levels is related to the number of power switches used [17-20]. If the number of levels is increased, the number of power switches will also be increased. For example, a cascaded six-level (N=6) MLI requires 2(N-1) = 10 number of switches. Therefore, if the required number of levels is N = 9, then the number of power switches is 2 (N – 1) = 16. Reduced number of switch count considering only 8 switches for 9 level inverter.

4.1 Modes about Operation

Various methods about action be depicted in a half-positive pattern in *fig. 5* in relation to suggested topology. Thick lines indicate current flow direction considering various modes. Nine different operating modes will be used to operate circuit considering one full cycle, including four considering positive half cycle, four considering negative half cycle, plus one considering zero level. Accordingly, each mode is responsible considering generating a single voltage level as a result. Switching conditions, magnitude about output voltage per unit, plus course certain is taken when operating in each mode be all structured.

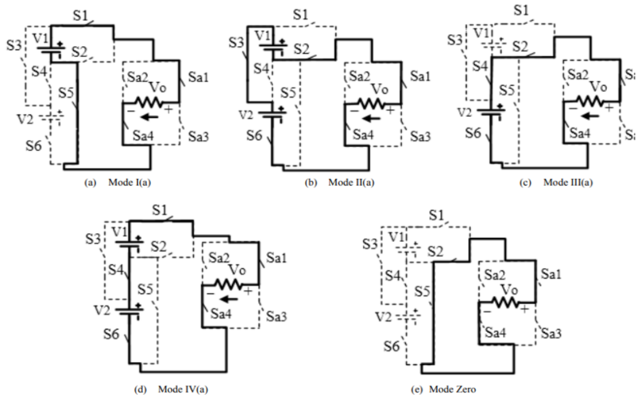

Figure 5. Different Switching state of the proposed nine level inverter topology during positive half cycle.

In *figure 5*. Modes I(a) through IV(a), which be positive cycle modes, yield results certain be positive. Negative cycle modes I(b) through IV(d) result in negative result levels. Table makes it obvious certain switches S1 through S6 be exchanged in same order considering both halves about cycle. Although switches (Sa1, Sa4) plus (Sa2, Sa3) only operate during positive plus negative halves about a cycle, respectively.

Table 1. Modes about operation, current path, source combination, output voltage

Modes		Current Path	Source Comb.	Output Volt.
Positive Level	I	S_5-V_1-S_1-Sa_1-Sa_4	V_1	1V
	II	S_6-V_2-S_3-V1-S_2-Sa_1-Sa_4	V_2-V_1	2V
	III	S_6-V_2-S_4-S_2-Sa_1-Sa_4	V_2	3V
	IV	S_6-V_2-S_4-V_1-S_1-Sa_1-Sa_4	V_2+V_1	4V
Zero Level		S_5-S_2-Sa_1-V_0-Sa_4	0	0
		S_5-S_2-Sa_2-V_0-Sa_3	0	0
Negative Level	I	S_5-V_1-S_1-Sa_2-Sa_3	V_1	-1V
	II	S_6-V_2-S_3-V_1-S_2-Sa_2-Sa_3	V_2-V_1	-2V
	III	S_6-V_2-S_4-S_2-Sa_2-Sa_3	V_2	-3V
	IV	S_6-V_2-S_4-V_1-S_1-Sa_2-Sa_3	V_2+V_1	-4V

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4.2. Particle Swarm Optimization (PSO) Tuning Pi Controller

PSO was resolved thanks to Edward plus Kennedy (1995). Perspective underlying estimating was sparked by social approaches about acting in support about animals, such as fish mentoring otherwise bird jogging. PSO is similar to predictable GA in certain it starts within a haphazard human structure. PSO lacks advancement directors like crossover & change, which is not least thing like GA. Particles be organisational sections (same as GA chromosome). They don't have double encoding plus have various properties. Every particle travels over surface at a speed.

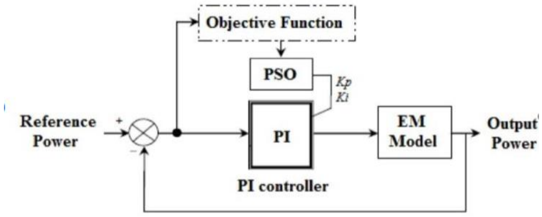

Figure 6: Block diagram PSO tuning among PI controller

Tuning about boundaries about PI regulator is done through utilizing Particle Swarm Optimization (PSO). Fundamental target about aforementioned paper is towards execute transformative calculation, similar towards particle swarm streamlining as well as towards comprehend inside & out about particle swarm enhancement. Lastly transient reaction about framework is taken & contrasted & customary strategy like Ziegler Nichols technique. In aforementioned paper, ideal PI regulator boundary tuning is endeavored utilizing PSO calculation presented through Kennedy & Eberhart [19]. Primary benefit about PSO calculation is certain it is an auto-tuning strategy; it doesn't need a point through point numerical depiction about interaction & tracks down most ideal k_p, k_i, based on Objective Function (OF) to get direct calculation.

5. SIMULATION RESULT

Case 1: nonlinear load & sag swell condition considering PSO among pi controller.

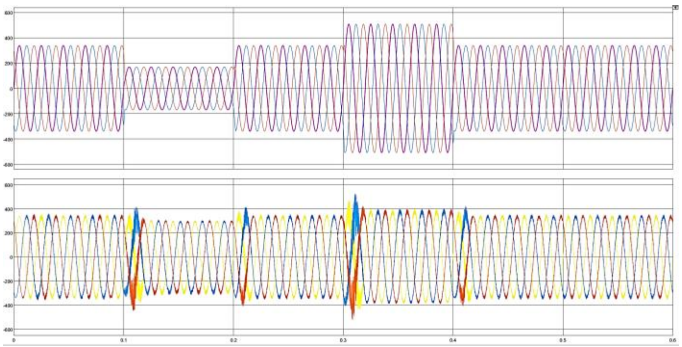

Figure 7: Source voltage about three phases VSabc, load voltage about three phases VLabc

At point when a nonlinear burden draws twisted (non-sinusoidal) current from inventory, aforementioned misshaped current goes through all about impedance between load & power source. The related harmonic current flows going through system impedance cause voltage drops considering every harmonic frequency. The vector sum of all the individual voltage drops results in total voltage distortion, the magnitude of which depends on the system impedance, available system fault current levels and the levels of harmonic currents at each harmonic frequency.

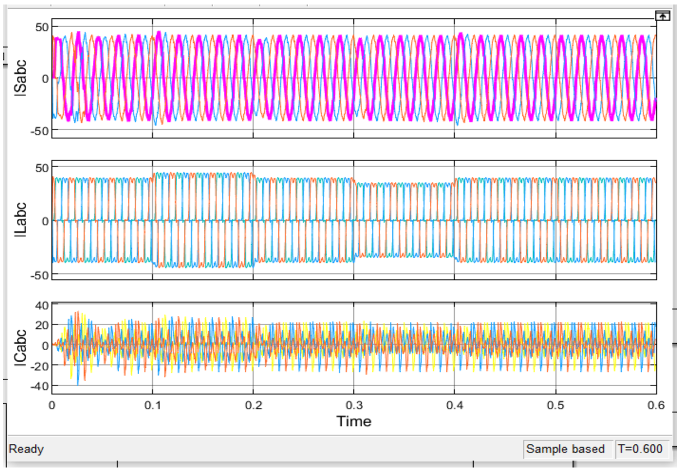

Figure 8: Source current ISabc, load current ILabc, compensated current ICabc

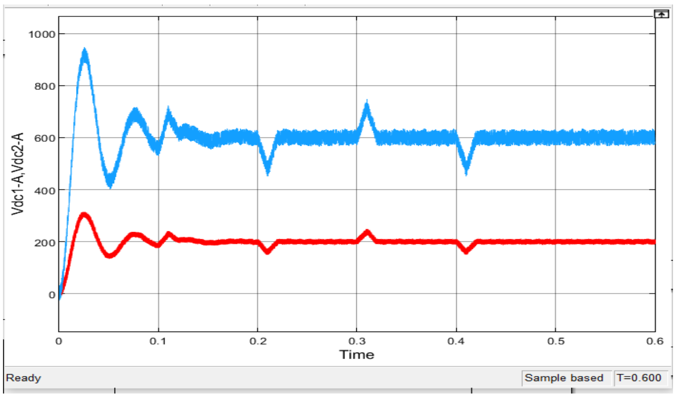

Figure 9(a) Dc -link voltage Vdc1a, Vdc2

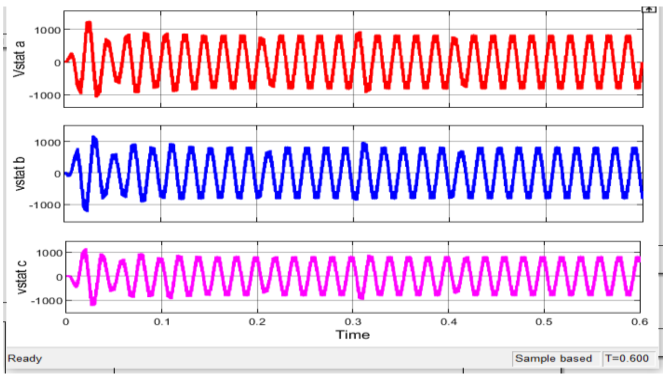

Figure 9 (b) STATCOM voltage Vstatabc

From above figures voltage sag is seen in 0.2to 0.3 sec & voltage grow is seen from 0.4 towards 0.5 sec

Case2: Extra load is added considering R=10ohm, l=50 mh , in aforementioned load increments condition voltage droop is happening between 0 towards 0.3 sec about load current, source current, compensating current responses.

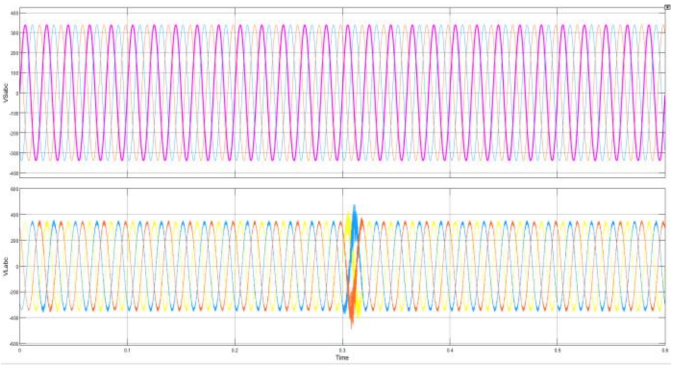

Figure 10(a) Source voltage about three phases VSabc, load voltage about three phases VLabc

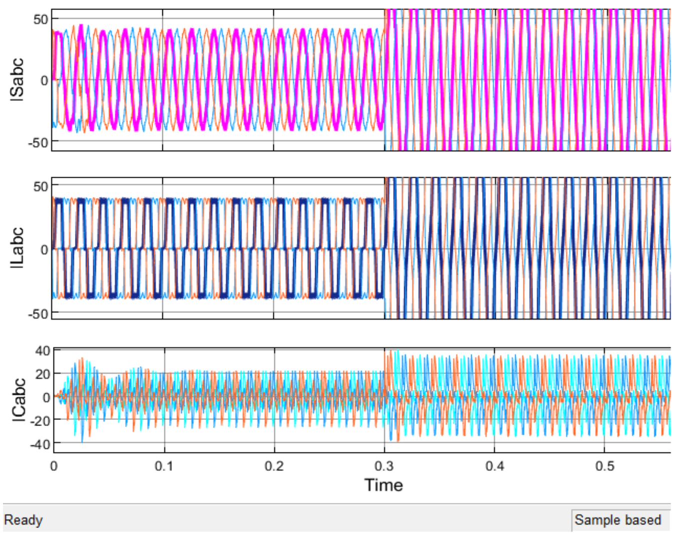

Figure 10 (b) Source current ISabc, load current ILabc, compensated current ICabc

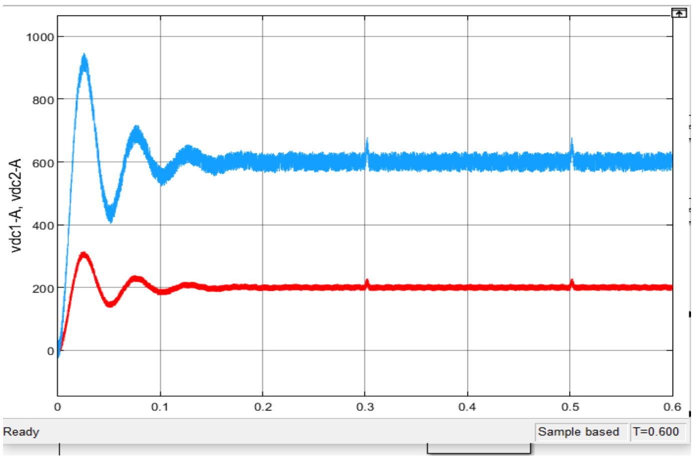

Figure 11(a). Dc -link voltage Vdc1A, Vdc2A

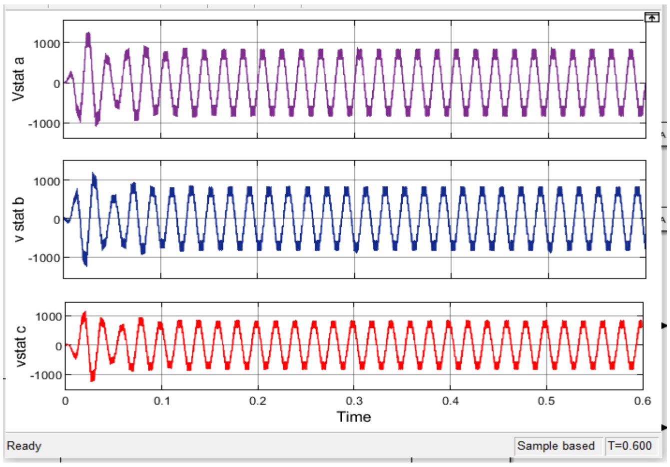

Figure 11 (b) STATCOM voltage VStatabc

Case 3: The unbalance load causes a voltage unbalance at the PCC. *Figure 12* illustrates the PCC voltage when the proposed control system is employed for compensating the unbalanced voltage. This figure shows that the proposed control strategy effectively compensates for the unbalanced voltage

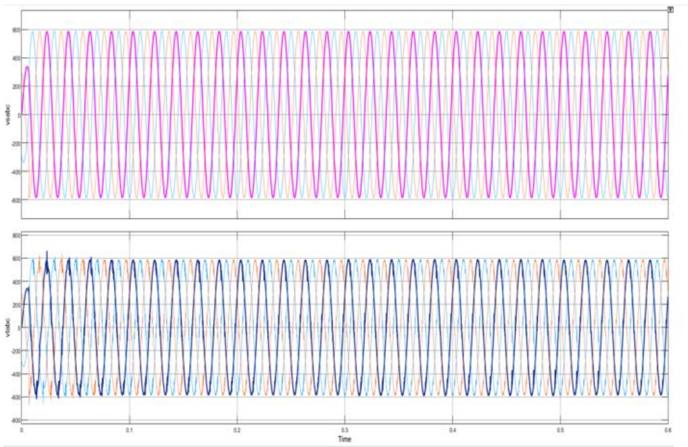

Figure 12: Source voltage about three phases Vsabc, load voltage about three phases Vlabc

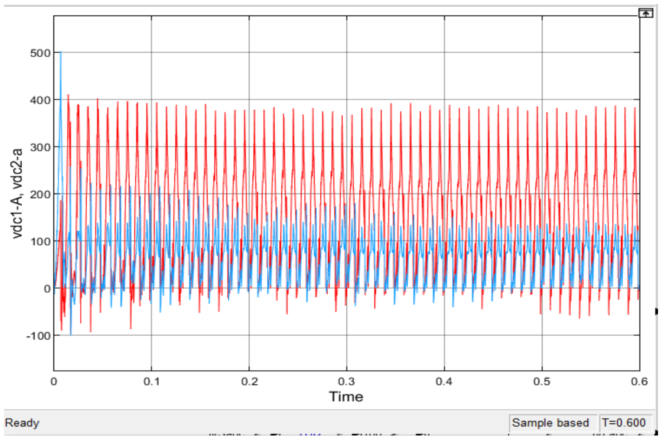

Figure 13: Dc -link voltage Vdc1a, vdc2a

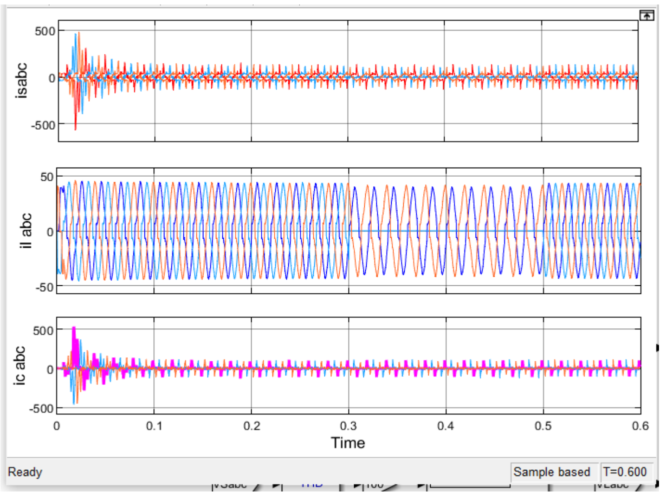

Figure 14. Source current Isabc, load current Ilabc, compensated current Icabc

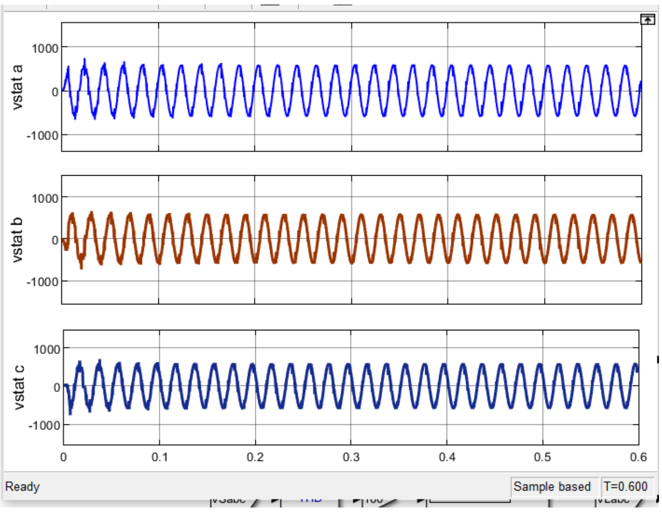

Figure 15: STATCOM voltage Vstatabc

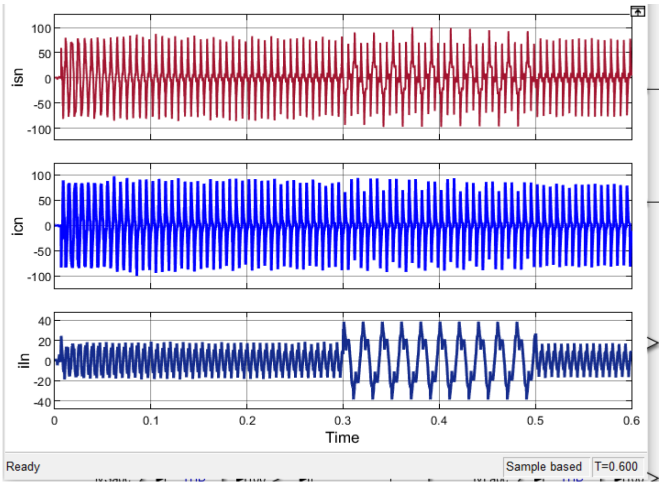

Figure 16. Source bus current Isn, injected current Icn, load bus current Iln

Table2: Comparison about THD considering PSO among PI& PI controllers

Cases	PI	PSO with PI
Nonlinear load	Isabc---6.05%	Isabc--3.08%
	ILabc-31.06%	ILabc-31.06%
	VSabc-1.92%	VSabc-1.92%
	VLabc-4.34%	VLabc-2.16%
Load increase	Isabc--4.43%	Isabc--2.21%
	ILabc--14.6%	ILabc--14.6%
	VSabc-1.92%	VSabc-1.92%
	VLabc-4.34%	VLabc-2.16%
Load unbalance	Isabc--8.32%	Isabc-6.05%
	ILabc-31.07%	ILabc--11.6%
	VSabc-8.11%	VSabc-1.92%
	VLabc-4.34%	VLabc-2.69%

6. CONCLUSION

The irregularity of output generation through PV systems in view about sun illumination prompts unsteady power supply towards loads particularly where utility is inaccessible. Thus, improper control and optimal design of controller leads to pure of power quality and stability performance of the inverter system. PSO method is executed towards acquire ideal upsides about PI regulator parameters by minimizing the error of voltage regulator and current controllers. The procedure is minimizing the error as much as possible and find the best parameters of the PI controller. The effects of load currents to the source currents as well as grid voltages are also discussed. The impacts about burden flows towards source flows as well as network voltages be likewise talked about. In aforementioned paper we have examined & broke down activity & execution about STATCOM at different load conditions, considering example, load increments, unbalanced & non-linear loads. On foundations about gadget counts, proposed topology is contrasted & regular as well as other asymmetrical nine-level inverter topologies presented in literature. This work further can be extended with other optimization techniques to minimize power quality problems.

Conflicts of Interest: The authors have no conflicts of interest

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