A Comprehensive Evaluation of FFR-CG Controller Based DSTATCOM For Power-Quality Enhancement

K. Ravi Sankar, V. Kamaraju, R. Srinivasa Rao

Abstract*: *At present, the extensive recognition on active compensators is pre-requisite for enhancing the PQ features in a three-phase 3-wire power distribution system. It is an exigent user related issue which is commenced by evading the mal-function of massive non-linear power-electronic controlled loads. This impacts on serious power pollution at position of common coupling and disrupts the voltage/current quality in a distribution system. A multi-objective DSTATCOM is the key choice for enhancing PQ features in a distribution system by utilizing attractive control strategies. The classical control strategies are more adversed with extreme switching losses due to the presence of high-order harmonic frequencies in a reference current sequence. This paper explores the novel fundamental frequency based current reference generation scheme for feasible functioning of DSTATCOM with greater efficiency and minimized switching losses. The critical performance of DSTATCOM with novel FFR-CG controller is validated by using Matlab/Simulink platform and simulation results are conferred.

Index Terms*: *Conventional Control Strategies, Distributed Static Compensator, Fundamental Reference Current Generation Control Scheme, Power Quality Enhancement, Total Harmonic Distortions

I. INTRODUCTION

Now-a-days, the electric energy demand has been raised to unusual levels owing to immense population growth and greater domestic/industrial corridors. These corridors utilize the massive power-electronic converters for attaining adjustable situations and impact the power pollution which is strived very hard to maintain Power-Quality (PQ) features [1]. The power distribution system is highly affected from the voltage/current quality due to presence of harmonized switching frequencies coming from the non-linear characterized loads. The other PQ issue includes current harmonics, power-factor correction, reactive-power exchanging, un-balanced loads, etc. In general, these issues in distribution system are not only new but also the perception of issues has been recently increased by load-side consumers. The traditional PQ enhancement schemes like passive compensators, static capacitors, etc., are generally used in olden days, which are interfaced to common-coupling point for counteracting the PQ issues. Various disadvantages are clearly illustrated in [2], like consisted compensation, low response, bulky size and attain superior resonance issues from source side because of line impedances. Among the traditional schemes, the modern active compensators are highly preferred for enhancement of above-specified PQ issues, attains reliable power flow to the other loads interfaced at PCC [3]. The modern active compensator plays a significant role in power distribution system which involves power-electronic converters to eradicate the PQ issues and flexible power flow to loads [4]. Various modern active compensators are used to accommodate the PQ features such as clearly highlighted in [5]. Among, the DSTATCOM is integrated as shunt-interfaced device at near to PCC to compensate all current-related PQ issues such as harmonic current distortions, power-factor improvement, reactive-power exchanging, unbalanced-loading, neutral currents, etc [6]. The DSTATCOM administers the respective harmonic current sequences as in-phase compensation principle for generation of switching states with the help of reference current generation through attractive control strategy. It transforms the harmonized, unbalanced, reactive common-coupling area into equivalent balanced-linear resistive system is explored in [7]. Several researchers strive about the design and performance of DSTATCOM, *M. Barghi et al.* [8], explores the comprehensive review of various DSTATCOM configurations for mitigation of PQ issues in three-phase distribution systems. *M. Valappil et al.* [9], proposes a novel three-phase VSI based static compensator to mitigate effects from non-linear loads and unbalanced loading condition in a three-phase 4-wire distribution system with a recognized controller to maintain DC-link voltage as constant. The state of art, design and performance characteristics of various DSTATCOM configurations for PQ enhancement is studied in [10]. The main objective of control strategy is unique functioning and optimum performance of DSTATCOM through generation of reference current components to generate optimal switching pattern to acquire the certain compensation task [7], [8]. The generalized several control strategies are recently reviewed by various literatures such as, Synchronous Reference Frame (SRF) theory, Instantaneous Active-Reactive (IPQ) Power theory, Id-Iq theory, etc. *N. Geddada et al.* [11], explores the new sinusoidal pulse-width modulation based DTSTACOM for non-linear un-balanced load compensation by utilizing the SRF control theory under steady state and dynamic conditions. *S. S. Pawar et al.*, presents the modeling and simulation analysis of DSTATCOM topology for mitigating the current harmonics, un-balanced loading,

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reactive power compensation, power-factor correction, voltage sag-swell mitigation, etc., by utilizing IPQ theory [12]. The classical control strategies furnishes the reference current sequence, it consists of extreme harmonized frequencies which results the greater dv/dt switch stress, high switching losses, minimizes the over-all DSTATCOM efficiency.

This paper proposes the evolution of unique control strategy for generation of optimal switching pattern to DSTATCOM without the violation of PQ compensation characteristics and overcome the issues coming from classical control strategies. A novel Fundamental Frequency Based Reference Current Generation (FFR-CG) controller is designed to extract the reference current sequences at fundamental switching frequency with low dv/dt switch stress, low switching loss and maximize the overall compensator efficiency. The performance evaluation of proposed FFR-CG controller is verified on DSTATCOM under balanced non-linear load conditions with classical control strategies by using Computer-Simulation platform, results are conversed with attractive comparisons.

II. PROPOSED CONFIGURATION

The DSTATCOM is integrated near to the PCC in a three-phase distribution system to compensate all current-related issues like eradication of current harmonics, reactive-power exchanging, load-balancing, neutral current elimination and power factor correction, etc.

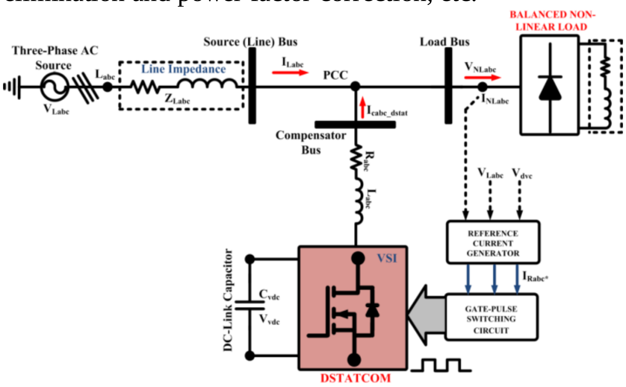

Fig.1 The Block Diagram of Proposed DSTATCOM Topology

The DSTATCOM is interfaced into three-phase distribution system to drive the balanced non-linear load and comprising of various elements such as, DC-link capacitor as C_{vdc}, three-phase voltage-source inverter (VSI) is designed by MOSFET switches, line-interfacing filter R_{Labc} circuit, sensing elements, reference current generator, gate-pulse switching circuitry, etc. The block diagram of proposed DSTATCOM topology is integrated at PCC of three-phase 3-wire distribution system is illustrated in Fig.1., various elements are V_{Labc}, I_{Labc}, V_{NLabc}, I_{NLabc}, and I_{Cabc}, are line voltage, line current, non-linear load voltage and current as well as Z_{Labc} is constituted as line impedance of three-phase network, respectively. In general, the VSI of DSTATCOM is powered by DC-link source as DC-link capacitor C_{vdc}, the voltage across this capacitor V_{vdc} is sustained for maintaining PCC voltage V_{pcc} as constant. The appearance of DSTATCOM is typically adopted from active-filtering technique working based on in-phase current injection methodology at PCC level of distribution system. A front-ended line-interfacing second-order filters are pre-requisite for griddling the harmonic components to acquire the active-compensation principle with superior control functions. The significant control strategy provides the optimal switching states to DSTATCOM by sensing the accurate values of load and source parameters by using signal analyzers.

III. CONVENTIONAL CONTROL SCHEMES

In general, the proposed DSTATCOM topology pre-requisite of well-recognized control strategy to administer the optimal compensation structure to acquire attractive appearance in three-phase 3-wire distribution system. The attractive control strategies play a vital role in power-electronic controlled compensation devices to control the distribution system dynamics through gate-pulse generation scheme. Various classical control strategies are clearly explained as follows,

A. Synchronous Reference Frame (SRF) Theory

The VSI of proposed DSTATCOM topology is integrated to PCC as shunt device. It acts as current-controlled objective which is established for injecting demanded current component at PCC level. Such that line current is sustained as sinusoidal nature and which is maintained in-phase sequence to the line voltage treated as unity-power factor. The control scheme of DSTATCOM is designed based on operating principle of active-filtering technique for eradication of odd-harmonics at PCC, reactive power exchanging, reduce the sudden interruptions, power-factor regulation, mitigate all current-related PQ issues to attain the stable operation of loads interfaced at PCC. The SRF theory is developed in [13] based on Clarke's/Park's conversion process which is perfect manner to control the line parameters in rotating-reference frame over the standard frames as *abc-dq* process.

The initiation of dq control strategy is designed based on utilization of immediate reactive and active current components with non-sinusoidal and/or sinusoidal input wave-shapes. The dual conversion technique furnishes the absolute correlation between the standard and rotating reference frames, but the direct/quadrature current sequences are often acquired from established weighting parameters. The main intension of Park's conversion process is generally used to establish the complex computed functions by transforming three (*abc*) quantities into two (*dq*) quantities, in that d-direct axis and q-quadrature axis which is positioned by angle "θ" produced by Phase-Locked Loop (PLL). The sensed non-linear load currents (i_{NLabc}) at load-bus is converted into *dq* quantities as (i_{NLdq}), these are attained by arbitration process of ($\alpha\beta$) coordinates as ($i_{NL\alpha\beta}$), the equations are illustrated in Eqn. (1) and (Eqn. (2).

$$\begin{bmatrix} i_{NL\alpha} \\ i_{NL\beta} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} i_{NLa} \\ i_{NLb} \\ i_{NLc} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_{NLd} \\ i_{NLq} \end{bmatrix} = \begin{bmatrix} cos\omega t & sin\omega t \\ -sin\omega t & cos\omega t \end{bmatrix}\begin{bmatrix} i_{NL\alpha} \\ i_{NL\beta} \end{bmatrix} \quad (2)$$

The dual conversion of non-linear load currents on *dq* frame is illutsrated in Eqn. (3)

$$\begin{bmatrix} i_{NLd} \\ i_{NLq} \end{bmatrix} = \begin{bmatrix} \overline{i_{NLd}} + \widetilde{i_{NLd}} \\ \overline{i_{NLq}} + \widetilde{i_{NLq}} \end{bmatrix} \quad (3)$$

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Where, $\overline{i_{NLd}}$, $\overline{i_{NLq}}$ are DC-components of non-linear load current in dq reference frame, $\widetilde{i_{NLd}}$, $\widetilde{i_{NLq}}$ are AC-components of non-linear load current in dq reference frame. From the above-mentioned Eqn. (3) is in dq reference frame, the second-order Low-Pass Filter (SO-LPF) is highly recognized for extracting the harmonic elements of $\widetilde{i_{NLd}}$, $\widetilde{i_{NLq}}$ from desired non-linear load currents. The SO-LPF cut-off frequency range is defined based on partly of line fundamental frequency. This SO-LPF minimizes the higher-order switching frequencies and permits the other frequencies into control functions as generation of reference-currents. The voltage across DC-link capacitor of DSTATCOM is regulated by accommodating the Proportional-Integral (PI) regulator, which is highly preferred for sustaining DC-link voltage is retained as constant. The desired reference DC-link voltage (V_{vdcr}^{*}) and actual DC-link voltage (V_{vdc}) is directly differentiated for estimation of error sequences, these are administered by PI regulator and furnish the active current component as (Δ_{iNLd}). The estimated error-quantities and PI regulator responses at n[th] instants are illustrated in Eqn. (4) & Eqn. (5).

$$V_{vdcer} = V_{vdcr}^{*} - V_{vdc} \tag{4}$$

$$\Delta_{iNLd} = \Delta_{iNLdn} - K_p * \left(V_{vdcer\,(n)} - V_{vdcer\,(n-1)}\right) + K_i * \left(V_{vdcer\,(n)}\right) \tag{5}$$

The active current component (Δ_{iNLd}) and the fundamental filtered current ($\widetilde{i_{NLd}}$) are assimilated to furnish the reference current component in dq-frame. The attained reference currents are in dq-frame can be re-converted into abc quantities as (i_{Rabc}^{*}) is illustrated in Eqn. (6) & Eqn. (7).

$$\begin{bmatrix} i_{NL\alpha} \\ i_{NL\beta} \end{bmatrix} = \begin{bmatrix} cos\omega t & -sin\omega t \\ sin\omega t & cos\omega t \end{bmatrix} \begin{bmatrix} i_{NLd} \\ i_{NLq} \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} i_{Ra}^{*} \\ i_{Rb}^{*} \\ i_{Rc}^{*} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{NL\alpha} \\ i_{NL\beta} \end{bmatrix} \tag{7}$$

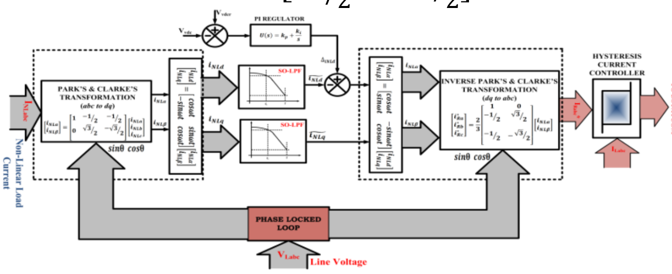

Fig.2 Schematic Diagram of SRF Control Strategy for DSTATCOM Topology

The schematic diagram of SRF Control Strategy for DSTATCOM topology is depicted in Fig.2. The reference current (i_{Rabc}^{*}) coming from SRF control strategy is used to generate the optimal switching states to DSTATCOM by using Hysteresis Current Controller (HCC).

B. Instantaneous Active-Reactive (IPQ) Power Theory

The Instantaneous Active-Reactive Power (IPQ) theory is developed in [14], it is superlative control strategy for production of reference current sequences with dominance of active-reactive powers. The working principle of IPQ theory is based on conversion process of three-phase abc into $\alpha\beta$ quantities in a orthogonal coordinated frame by using Clarke's conversion scheme. The input functions of IPQ theory are sensed from sensors as load currents (i_{NLabc}) and line voltage as (V_{Labc}) are fed to conversion process. This process furnishes the voltage-current components are in orthogonal coordinates ($V_{L\alpha\beta}, I_{NL\alpha\beta}$) as instantaneous active-reactive components. These components are V_{La}, I_{NLa} is posed on a-axis, b-axis, respectively and the respective amplitudes are varied with positive-negative time sequences. By using Clarke's conversion process, the three-phase quantities are represented in rotating reference frame as illustrated in Eqn. (8) & Eqn. (9)

$$\begin{bmatrix} v_{L\alpha} \\ v_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} v_{La} \\ v_{Lb} \\ v_{Lc} \end{bmatrix} \tag{8}$$

$$\begin{bmatrix} i_{NL\alpha} \\ i_{NL\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} i_{NLa} \\ i_{NLb} \\ i_{NLc} \end{bmatrix} \tag{9}$$

The active-reactive powers in (αβ) orthogonal rotating reference over the formal instantaneous powers for three-phase quantities can be defined as,

$$p = v_{L\alpha} i_{NL\alpha} + v_{L\beta} i_{NL\beta} \tag{10}$$

$$q = -v_{L\beta} i_{NL\alpha} + v_{L\alpha} i_{NL\beta} \tag{11}$$

The instantaneous active-reactive power is represented in matrix form is shown as,

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_{\alpha L} & v_{L\beta} \\ -v_{L\beta} & v_{L\alpha} \end{bmatrix} \begin{bmatrix} i_{NL\alpha} \\ i_{NL\beta} \end{bmatrix} \tag{12}$$

The (αβ) current sequences are extracted as,

$$\begin{bmatrix} i_{NL\alpha} \\ i_{NL\beta} \end{bmatrix} = \frac{1}{\Delta_k} \begin{bmatrix} v_{L\alpha} & v_{L\beta} \\ -v_{L\beta} & v_{L\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \tag{13}$$

Where,

$$\Delta_k = v_{L\alpha}^2 + v_{L\beta}^2 \tag{14}$$

The instantaneous active (p), reactive power (q) can be constituted in a AC oscillatory and DC-average components defined as,

$$p = \bar{p} + \tilde{p}$$

$$q = \bar{q} + \tilde{q} \tag{15}$$

Where, $\bar{p}, \bar{q}$ – DC-average values, $\tilde{p}, \tilde{q}$ – AC oscillatory values, the reference currents $i_{c\alpha\beta}^{*}$ coming from IPQ control strategy can be illustrated in Eqn. (16),

$$\begin{bmatrix} i_{c\alpha}^{*} \\ i_{c\beta}^{*} \end{bmatrix} = \frac{1}{\Delta_k} \begin{bmatrix} v_{L\alpha} & -v_{L\beta} \\ v_{L\beta} & v_{L\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \tag{16}$$

The active current component was produced by extraction of non-linear load currents and source currents in αβ by using second-order High-Pass Filter (SO-HPF). This SO-HPF minimizes the lower-order switching frequencies and permits the higher-order frequencies are pertained in reference-currents generation. The voltage across DC-link capacitor of DSTATCOM is regulated by accommodating the Proportional-Integral (PI) regulator furnish the active current component as (Δ_{iNLd}), the mathematical formations as shown in Eqn. 4 and Eqn. 5. The active current component (Δ_{iNLd}) and the fundamental filtered current ($i_{c\alpha\beta}^{*}$) are assimilated to furnish the reference current component in αβ -frame. The attained reference currents are in αβ-frame can be re-converted into abc quantities as (i_{Rabc}^{*}) is illustrated in Eqn. (17)

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$$\begin{bmatrix} i_{Ra}^{*} \\ i_{Rb}^{*} \\ i_{Rc}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{0}^{*} \\ i_{c\alpha}^{*} \\ i_{c\beta}^{*} \end{bmatrix} \qquad (17)$$

The schematic diagram of IPQ Control Strategy for DSTATCOM topology is depicted in Fig.3. The reference current (i_{Rabc}^{*}) coming from IPQ control strategy is used to generate the optimal switching states to DSTATCOM by using Hysteresis Current Controller (HCC).

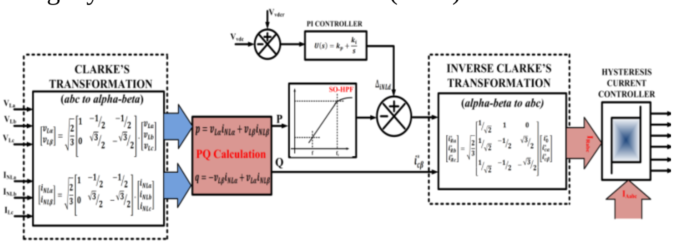


Fig.3 Schematic Diagram of IPQ Control Strategy for DSTATCOM Topology

IV. PROPOSED FUNDAMENTAL FREQUENCY BASED REFERENCE CURRENT GENERATION (FFR-CG) CONTROL STRATEGY

The proposed FFR-CG control strategy is same as classical SRF theory; a dual conversion process is designed based on correlation between the stationary reference and rotating switching components. The phase sequences of non-linear load currents (i_{NLabc}) is converted into stationary frame as ($I_{NL\alpha\beta}$) by using Clarke's conversion technique. These coordinates are again converted into rotating reference frame as (i_{NLdq}) by utilizing angle "θ", as conversion angle which is pretended as $\frac{d\theta}{dt}$ due to non-constant of un-balanced and harmonic components. This dual conversion process is established to attain the decoupled action between the active-reactive sequences converting the three-phase quantities *abc* into two-phase *dq* quantities. The representation of direct axis as d-axis and quadrature as q-axis is positioned based on angle "θ" which is generated by Phase-Locked Loop (PLL). The sensed non-linear load currents (i_{NLabc}) at load-bus is converted into *dq* quantities as (i_{NLdq}), these are attained by arbitration process of ($\alpha\beta$) coordinates as ($i_{NL\alpha\beta}$), the equations are illustrated in Eqn. (18), Eqn. (19) and Eqn. (20).

$$\begin{bmatrix} i_{NLd} \\ i_{NLq} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin(\theta) & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} i_{NLa} \\ i_{NLb} \\ i_{NLc} \end{bmatrix} \qquad (18)$$

$$\begin{bmatrix} i_{NL\alpha} \\ i_{NL\beta} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{NLa} \\ i_{NLb} \\ i_{NLc} \end{bmatrix} \qquad (19)$$

$$\begin{bmatrix} i_{NLd} \\ i_{NLq} \end{bmatrix} = \begin{bmatrix} cos\omega t & sin\omega t \\ -sin\omega t & cos\omega t \end{bmatrix} \begin{bmatrix} i_{NL\alpha} \\ i_{NL\beta} \end{bmatrix} \qquad (20)$$

The dual conversion of non-linear load currents on *dq* frame is illutsrated in Eqn. (21),

$$\begin{bmatrix} i_{NLd} \\ i_{NLq} \end{bmatrix} = \begin{bmatrix} \overline{i_{LNd}} + \widetilde{i_{NLd}} \\ \overline{i_{NLq}} + \widetilde{i_{NLq}} \end{bmatrix} \qquad (21)$$

From the above-mentioned Eqn. (23) is in *dq* reference frame, the second-order Low-Pass Filter (SO-LPF) is highly recognized for extracting the harmonic elements of $\widetilde{i_{NLd}}$, $\widetilde{i_{NLq}}$ from desired non-linear load currents. The SO-LPF cut-off frequency range is defined based on partly of line fundamental frequency. This SO-LPF minimizes the higher-order switching frequencies and permits the other frequencies into control functions as generation of reference-currents. Since, the main source doesn't supply reactive power to the non-linear load, thus the d-quantities ($\overline{i_{NLq}}\ \widetilde{i_{NLq}}$) are set as zero (0), the respective form is defined in Eqn. (22),

$$\begin{bmatrix} i_{NLd} \\ i_{NLq} \end{bmatrix} = \begin{bmatrix} \overline{i_{NLd}} + \widetilde{i_{NLd}} \\ 0 \end{bmatrix} \qquad (22)$$

The active current component (Δ_{iNLd}) is generated by DC-link controller with the help of PI regulator, the mathematical formations as shown in Eqn. 4 and Eqn. 5. The fundamental filtered current ($\widetilde{i_{NLd}}$) are assimilated to furnish the reference current component in *dq*-frame. The attained reference currents are in *dq*-frame can be re-converted into *abc* quantities as (i_{Rabc}^{*}) is illustrated in Eqn. (23) & Eqn. (24).

$$\begin{bmatrix} i_{NL\alpha} \\ i_{NL\beta} \end{bmatrix} = \begin{bmatrix} cos\omega t & -sin\omega t \\ sin\omega t & cos\omega t \end{bmatrix} \begin{bmatrix} i_{NLd} \\ i_{NLq} \end{bmatrix} \qquad (23)$$

$$\begin{bmatrix} i_{Ra}^{*} \\ i_{Rb}^{*} \\ i_{Rc}^{*} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{NL\alpha} \\ i_{NL\beta} \end{bmatrix} \qquad (24)$$

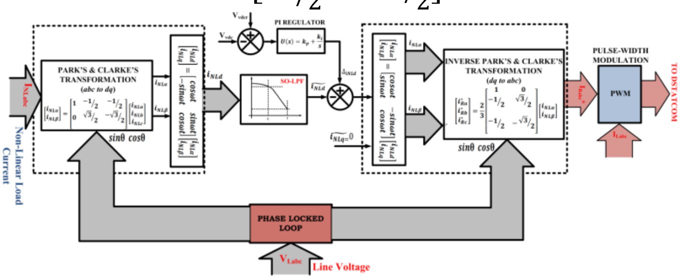


Fig.4 Schematic Diagram of Proposed FFR-CG Control Strategy for DSTATCOM Topology

The schematic diagram of proposed FFR-CG control strategy for DSTATCOM topology is depicted in Fig.4. The reference current (i_{Rabc}^{*}) coming from FFR-CG control strategy is used to generate the optimal switching states to DSTATCOM by using Hysteresis Current Controller (HCC). The HCC is pre-requisite to generate optimum switching pattern by using pre-defined HCC band limits. These limits treated as boundaries of DSTATCOM injected current which is controlled by upper/lower HCC limits to produce the switching states to respective switches in VSI of DSTATCOM depended by actual and reference current sequences. The switches in VSI's are controlled by reference current, switch is conducted when the actual current is greater than reference current, and other-wise switch is un-conducted. Moreover, the actual current component is swinging continuously in between the HCC bands followed by acquired reference current furnished by FFR-CG control strategy. The Over-all schematic diagram of proposed DSTATCOM with FFR-CG controller is depicted in Fig.5

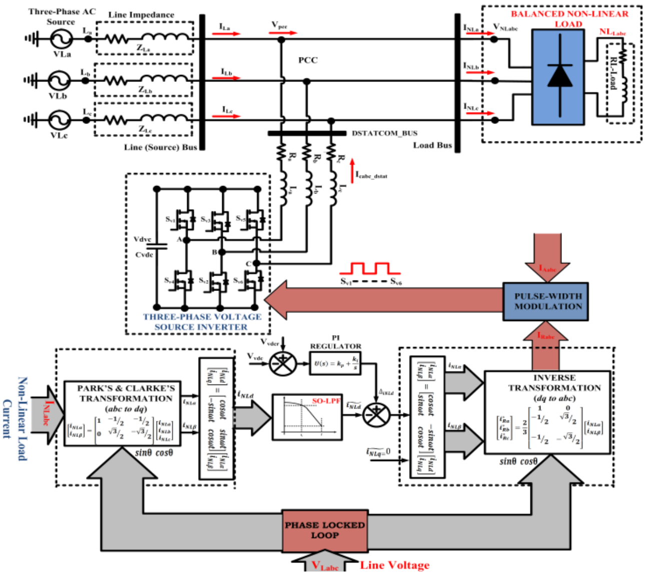


Fig.5 Over-all Schematic Diagram of DSTATCOM with Proposed FFR-CG Controller

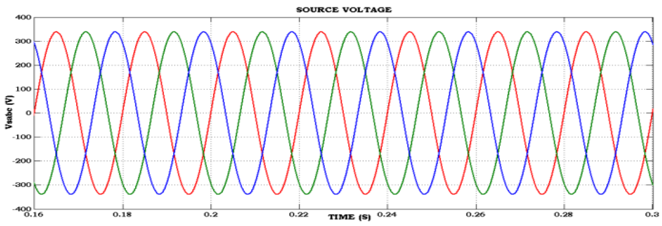
V. MATLAB/SIMULINK RESULTS

The Matlab/Simulink analysis is carried-out based on performance of DSTATCOM in both classical and proposed control strategies for PQ enhancement in a three-phase 3-wire distribution system by using computer-simulation tool. Simulation results are carried, the system specifications of proposed FFR-CG based DSTATCOM is illustrated in Table.1.

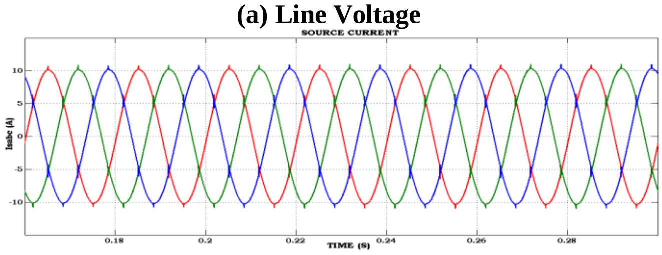
Table 1. System Specifications of FFR-CG based DSTATCOM

S.No	Parameters	Values
1	Source Voltage	415V, 50 Hz
2	Source Impedance	0.1+j0.9Ω
3	Load Impedance	30+j30Ω
4	DC-Link Capacitor	4000μF
5	VSI Filter Units	R-0.1; L-5mH
6	PI Controller Gains	Kp-0.8; Ki-0.5

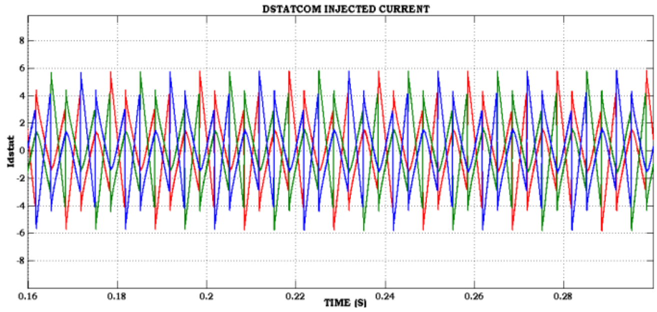
A. Evaluation of DSTATCOM by using Classical SRF Theory for PQ Enhancement



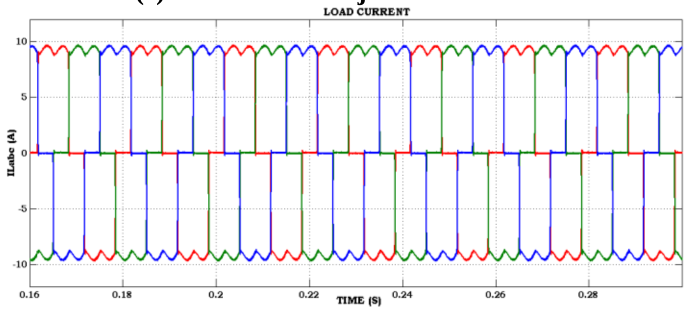
(a) Line Voltage



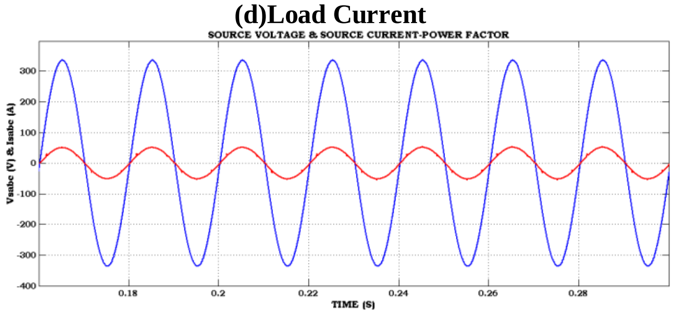
(b) Line Current



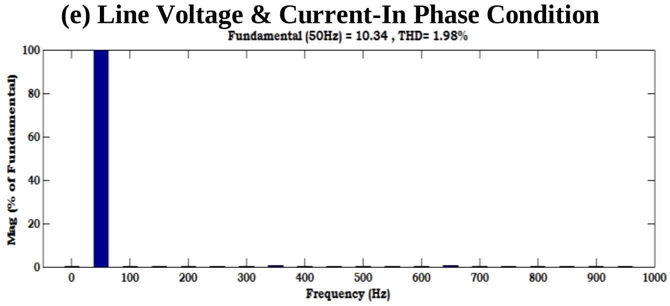
(c) DSTATCOM Injected Current



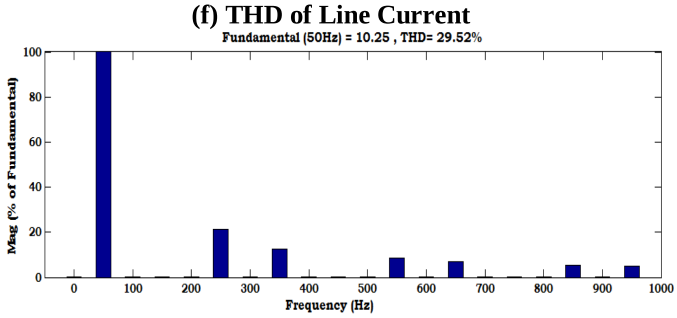
(d)Load Current



(e) Line Voltage & Current-In Phase Condition



(f) THD of Line Current



(g) THD of Load Current

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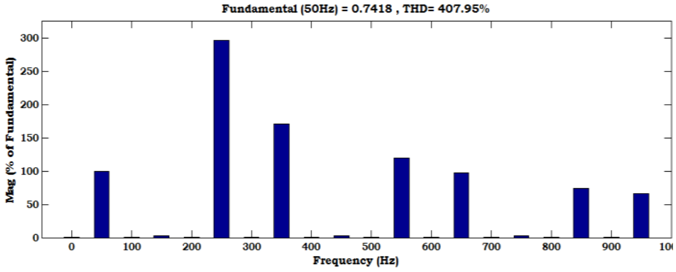
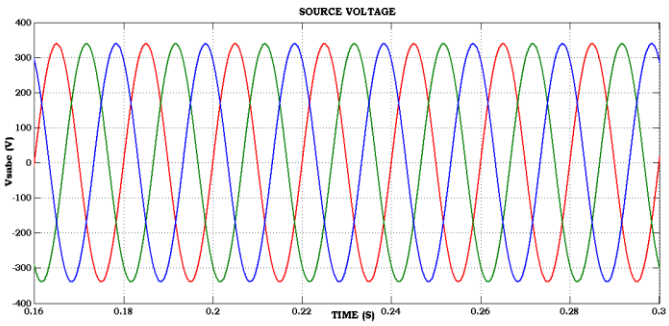


(h) THD of Compensation Current

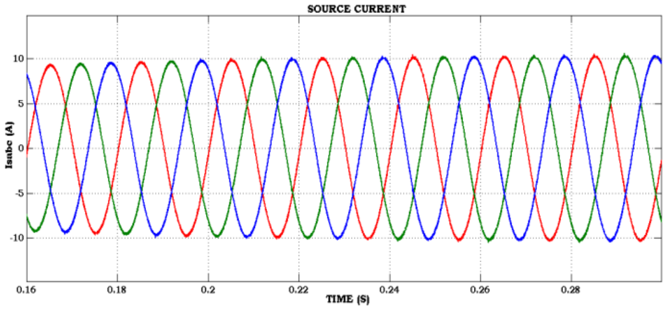
Fig.6 Simulation Results of Classical SRF Control Strategy Based DSTATCOM for PQ Enhancement

The simulation results of classical SRF control strategy based DSTATCOM topology under PQ enhancement scheme is depicted in Fig.6. In that, (a) Line Voltage, (b) Line Current, (c) DSTATCOM Injected Current, (d) Load Current, (e) Line Voltage & Current-In Phase Condition, (f) THD of Source Current, (g) THD of Load Current, (h) THD of Compensation Current, respectively. The three-phase 3-wire distribution system is comprised of balanced non-linear load driven by a three-phase line voltage 415V (rms), 50Hz frequency from utility. The non-linear load is integrated near to PCC, the line current component is slightly harmonized due to massive loads and also affects the other loads interfaced at PCC. The DSTATCOM eradicates the harmonics coming from non-linear load and acquires the sinusoidal and fundamental components attained based on in-phase compensation process which mitigates the various obstacles at PCC level. The line currents are sustained nearly as sinusoidal wave-shapes, which is in-phase to line voltage to define the unity-power factor at PCC (for clear representation of power factor the line current is multiplied by 5-times) other loads also acquires same compensation features. While using the classical SRF-theory fed DSTATCOM topology, the THD of load current is 29.52%, the THD of line current is 1.98%, THD of compensator current is 407.95%. The THD of line current is well within an IEEE-519/1992 standard limitation and attains good compensation features. Due to extreme harmonized switching frequencies in reference current, THD of compensation current attains very high THD value and acquires more dv/dt switch stress, high switching loss, reduced efficiency, in-comply with IEEE standard limitations.

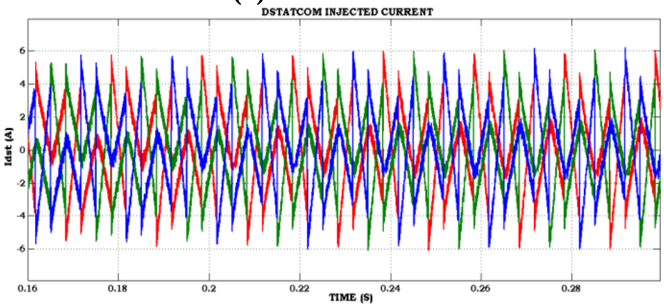
B. Evaluation of DSTATCOM by using Classical IPQ Theory for PQ Enhancement



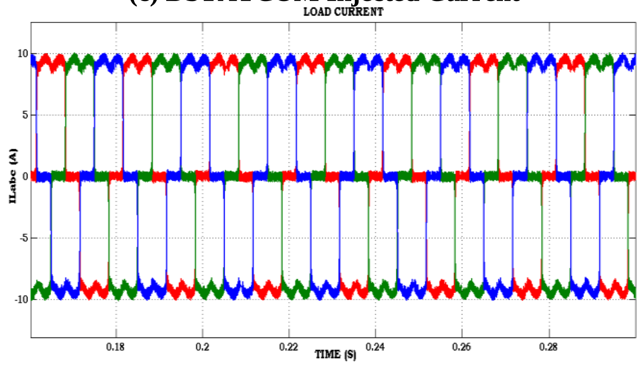
(a) Line Voltage



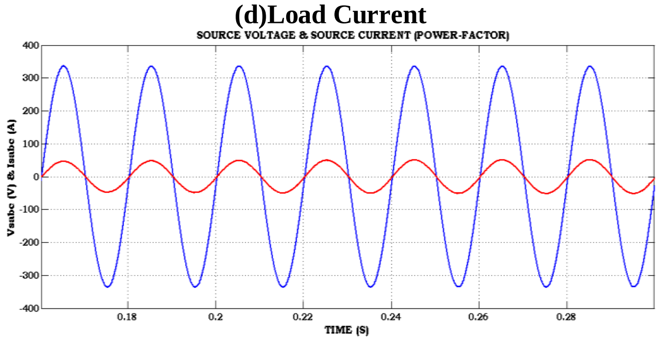
(b) Line Current



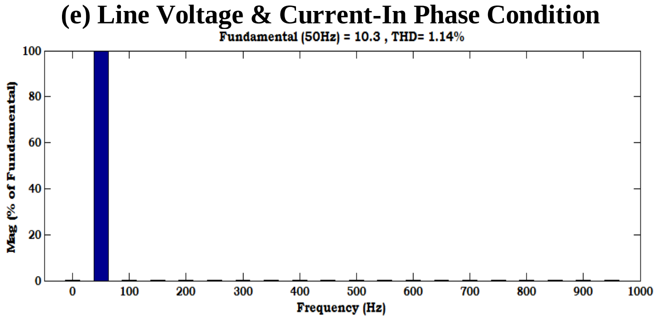
(c) DSTATCOM Injected Current



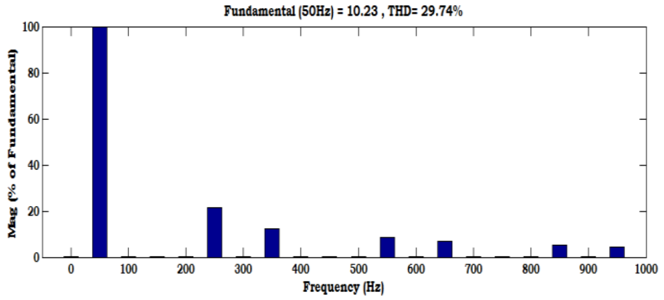
(d)Load Current



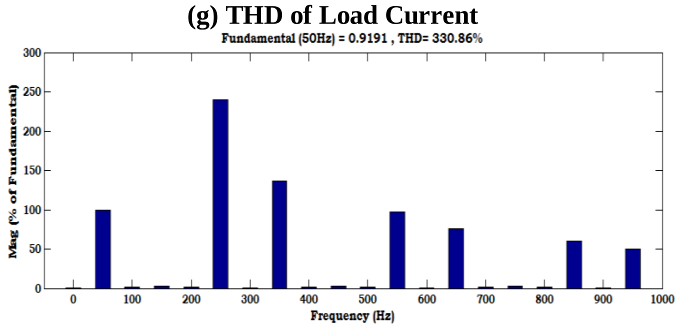
(e) Line Voltage & Current-In Phase Condition



(f) THD of Line Current



(g) THD of Load Current

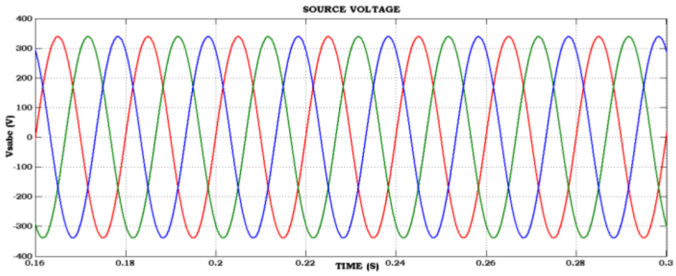


(h) THD of Compensation Current

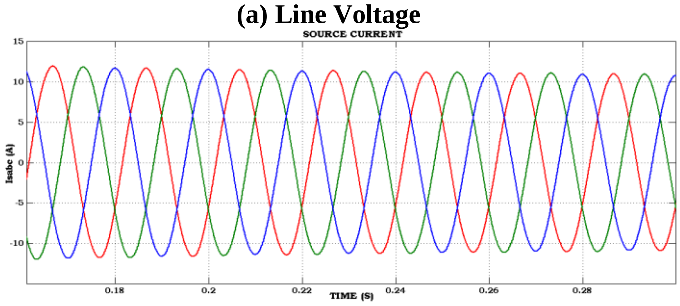
Fig.7 Simulation Results of Classical IPQ Control Strategy Based DSTATCOM for PQ Enhancement

The simulation results of classical IPQ control strategy based DSTATCOM topology under PQ enhancement scheme is depicted in Fig.7. In that, (a) Line Voltage, (b) Line Current, (c) DSTATCOM Injected Current, (d) Load Current, (e) Line Voltage & Current-In Phase Condition, (f) THD of Source Current, (g) THD of Load Current, (h) THD of Compensation Current, respectively. The classical IPQ control strategy is used for generation of reference current components with dominance of instantaneous active-reactive power equivalents in orthogonal coordinates. The line voltage is maintained as sinusoidal and constant with a 415V (rms), 50 Hz frequency, powering the non-linear balanced load. The line current is maintained near-by sinusoidal due to active compensation process, which is in-phase to line voltage to define the unity-power factor at PCC (for clear representation of power factor the line current is multiplied by 5-times) is initiated at PCC of three-phase 3-wire distribution system by using classical IPQ fed DSTATCOM. While using the classical IPQ-theory fed DSTATCOM topology, the THD of load current is 29.74%, the THD of line current is 1.14%, THD of compensator current is 330.86%. The THD of line current is well within an IEEE-519/1992 standard limitation and attains good compensation features over the classical SRF control theory. Due to moderate harmonized switching frequencies in reference current, THD of compensation current attains moderate THD value over SRF theory and acquires moderate dv/dt switch stress, switching loss, minimized efficiency, in-comply with IEEE standard limitations. The IPQ controller based DSTATCOM attains moderate compensation features over the SRF control theory, but IPQ control strategy also un-perfect due to harmonized switching frequencies in reference current. For reducing above-mentioned issues, a novel current control strategy is proposed for getting good compensation features over the classical control functions.

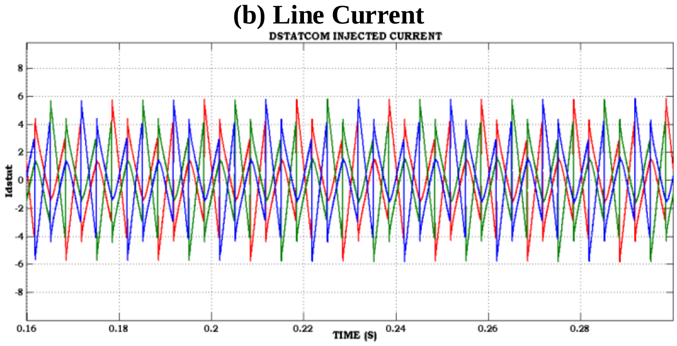
C. Evaluation of DSTATCOM by using Proposed FFR-CG Theory for PQ Enhancement



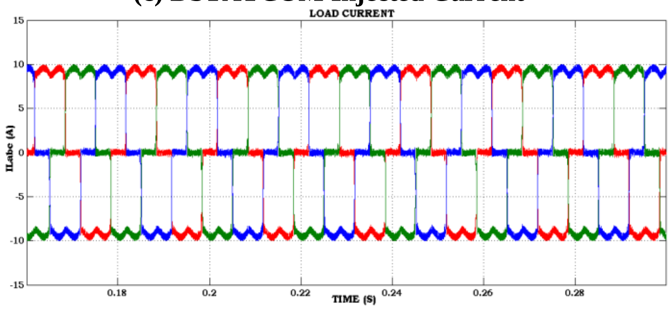
(a) Line Voltage



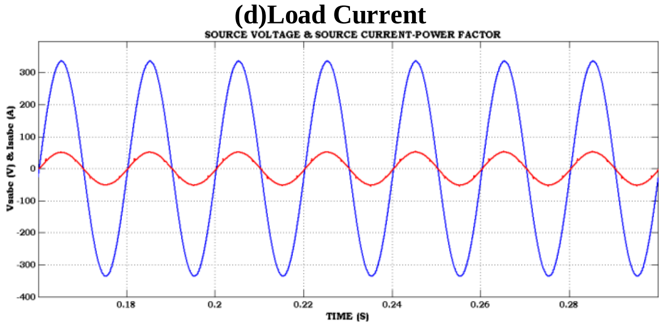
(b) Line Current



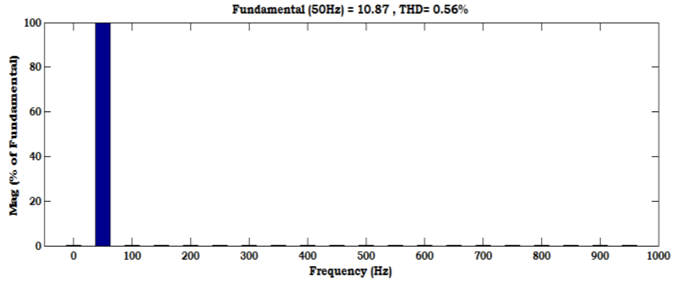
(c) DSTATCOM Injected Current



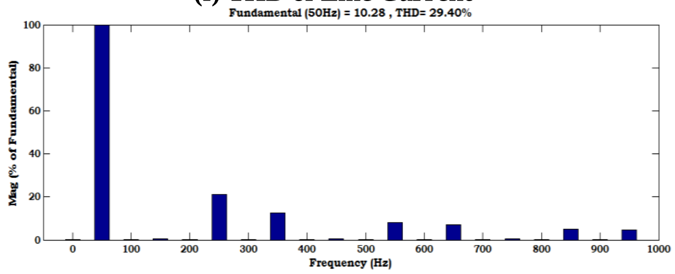
(d)Load Current



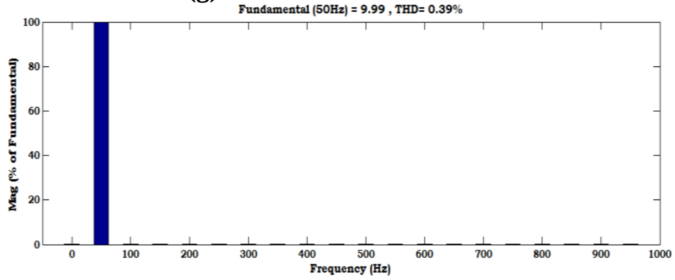
(e) Line Voltage & Current-In Phase Condition



(f) THD of Line Current



(g) THD of Load Current



(h) THD of Compensation Current

Fig.8 Simulation Results of Proposed FFR-CG Control Strategy Based DSTATCOM for PQ Enhancement

The simulation results of proposed FFR-CG control strategy based DSTATCOM topology under PQ enhancement scheme is depicted in Fig.8. In that, (a) Line Voltage, (b) Line Current, (c) DSTATCOM Injected Current, (d) Load Current, (e) Line Voltage & Current-In Phase Condition, (f) THD of Source Current, (g) THD of Load Current, (h) THD of Compensation Current, respectively. The proposed FFR-CG control strategy is used for generation of reference current components under fundamental switching frequency, the FFR-CG is adopted from classical SRF control theory but slight alterations are done. The line voltage is maintained as sinusoidal and constant with a 415V (rms), 50 Hz frequency, powering the non-linear balanced load. The line current is maintained near-by sinusoidal due to active compensation process, which is in-phase to line voltage to define the unity-power factor at PCC (for clear representation of power factor the line current is multiplied by 5-times) is initiated at PCC of three-phase 3-wire distribution system by using proposed FFR-CG fed DSTATCOM. While using the proposed FFR-CG control theory fed DSTATCOM topology, the THD of load current is 29.40%, the THD of line current is 0.56%, THD of compensator current is 0.39%. The THD of line current is well within an IEEE-519/1992 standard limitation and attains good compensation features over the classical SRF/IPQ control strategies. Due to low harmonized switching frequencies in reference current, THD of compensation current attains very-low harmonics and the THD value is very low over the classical SRF/IPQ controllers and acquires low dv/dt switch stress, low switching loss, good efficiency, comply with IEEE standard limitations.

Table 2. THD Comparisons under Classical SRF/IPQ Control Strategies over Proposed FFR-CG based DSTATCOM for PQ Enhancement

Parameter (THD %)	Classical SRF Control Theory	Classical IPQ Control Theory	Proposed FFR-CG Control Theory
Line Current	1.98%	1.14%	0.56%
Load Current	29.52%	29.74%	29.40%
Compensation Current	407.95%	330.86%	0.39%

The THD comparisons under classical SRF/IPQ control strategies over proposed FFR-CG based DSTATCOM for PQ enhancement in a three-phase 3-wire distribution system is illustrated in Table.2. The proposed FFR-CG control strategy provides the best compensation characteristics over the classical SRF/IPQ controllers. Mainly, the THD of line current attains very accurate value and the THD of compensator injected/reference current has very reduced value over the classical SRF/IPQ theories, both the values are complying with IEEE-standard limits. The graphical view of THD comparisons is shown in Fig.9, the proposed FFR-CG has good compensation characteristics and it is best suited for any compensator to control the dynamics in power distribution system.

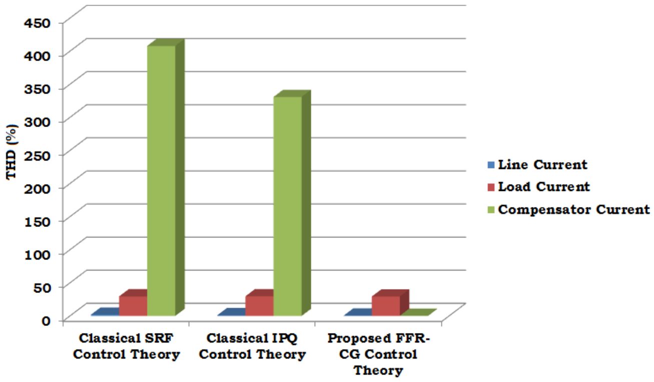


Fig.9. Graphical View for Comparisons of THD vs Various Control Strategies under Different Parameters

VI. CONCLUSION

The comprehensive review on control strategies of shunt-connected DSTATCOM topology offers several advantages addressing the mitigation of all-current related PQ issues. The proposed FFR-CG control strategy is used for generation of optimal switching pattern to VSI of DSTATCOM in a three-phase 3-wire distribution system over the classical SRF/IPQ controllers. The switching states acquired from fundamental reference current generator provides the favourable merits such as low switch dv/dt stress, low switching losses, greater efficiency, low THD in reference currents, etc. The critical evaluation of classical SRF/IPF and proposed FFR-CG control strategies fed DSTATCOM topology is validated in a three-phase 3-wire distribution system by using Matlab/Simulink tool, simulation results are conferred with appropriate comparative analysis.

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The harmonic spectrums of line and compensator reference current components are complying with IEEE-519/1992 standard limits. The further recommendations are carried on review on FFR-CG control on several multilevel inverter topologies based DSTATCOM for controlling the attractive parameters by using advanced PWM modulation techniques.

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