International Journal of Scientific Research in Computer Science, Engineering and Information Technology
© 2017 IJSRCSEIT | Volume 2 | Issue 4 | ISSN : 2456-3307

# Wide Compensation Range and Low DC Link Voltage with A Hybrid STATCOM

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## ABSTRACT

The Production and usage of electricity are changing by considering the impact of electricity systems on environment. This is mainly due to the topological difference between the distribution and transmission system in which control of voltage and reactive power is the major issue in power system operation. Large reactive currents in transmission lines is one of the major problem which increases loses and reduces stability. This paper proposes a hybrid static synchronous compensator (crossover STATCOM) in a three-phase control transmission system that has a wide remuneration range and low DC-connect voltage. As a result of these noticeable attributes, the system expenses can be significantly lessened.. From that point forward, a control methodology for hybrid STATCOM is proposed to permit operation under various voltage and current conditions. At last, reproduction and test comes about are given to confirm the wide pay range and low DC-interface voltage attributes and the great dynamic execution of the proposed mixture STATCOM.

**Keywords :** Hybrid-STATCOM, Low DC Link Voltage ,C-STATCOM, Wide compensation range.

## I. INTRODUCTION

The expansive reactive current in transmission systems is a standout amongst the most widely recognized power issues that expands transmission losses and brings down the soundness of an influence system[1]-[12]. Use of reactive power compensators is one of the answers for this issue. Static VAR compensators (SVCs) are customarily used to progressively remunerate reactive streams as the loads differ now and again. Be that as it may, SVCs experience the ill effects of numerous issues, for example, reverberation issues, consonant current infusion, and moderate reaction[2],[3]. To defeat these impediments, static synchronous compensators (STATCOMs) and dynamic powerfilters (APFs) were created for reactive current remuneration with quicker reaction, less symphonious current infusion, and better[4],[9].execution . Be that as it may, the STATCOMs or APFs ordinarily require multilevel structures in a medium-or high-voltage level transmission system to diminish the high-voltage worry over each power switch and DC-link capacitor, which drives up the underlying and operational expenses of the system and furthermore builds the control unpredictability[11]. Afterward, series sort capacitive-coupled STATCOMs (C-STATCOMs) were proposed to decrease the system DC-interface working voltage necessity, and different arrangement sort hybrid structures that comprise of various inactive power channels (PPFs) in arrangement with STATCOMs or APF structures (PPF-STATCOMs) have been connected to control circulation systems and footing power systems . In any case, C-STATCOMs and different arrangement sort PPF-STATCOMs contain moderately limit reactive power remuneration ranges. At the point when the required repaying reactive power is outside their pay extends, their system exhibitions can altogether weaken. To enhance the working exhibitions of the conventional STATCOMs, C-STATCOMs, and other PPF-STATCOMs, a wide range of control procedures have been proposed, for example, the prompt p-q hypothesis[10],[11], the momentary d-q hypothesis[5],[6], the quick id-iq technique, negative-and zero-arrangement control, the back spread (BP) control strategy[9], nonlinear control, Lyapunov-work based control, immediate symmetrical segment hypothesis , and half and half voltage and current control To lessen the present rating of the STATCOMs or APFs, a half and half mix structure of PPF in parallel with STATCOM (PPF//STATCOM)[20]and[21].

Nonetheless, this cross breed compensator is devoted for inductive stacking operation. When it is connected for capacitive stacking remuneration, it effectively loses its little dynamic inverter rating qualities. To grow the pay range and keep low current rating normal for the APF, Dixon et al. proposed another half and half mix structure of SVC in parallel with APF (SVC//APF) in three-phase dispersion systems. In this half and half structure, the APF is controlled to take out the music and make up for the little measures of load reactive and lopsided power left by the SVC. In any case, ithis structure is connected in a medium-or high-voltage level transmission system, the APF still requires an exorbitant voltage venture down transformer or potentially multilevel structure. Also, these two parallel associated half and half STATCOM[15]-[17] structures may experience the ill effects of a reverberation issue.

To defeat the inadequacies of various reactive power compensators[1],[9] for transmission systems, this paper proposes a cross breed STATCOM that comprises of a thyristor-controlled LC part (TCLC) and a dynamic inverter part, as appeared in Fig. 1. The TCLC part gives a wide reactive power pay go and an extensive voltage drop between the system voltage and the inverter voltage with the goal that the dynamic inverter part can keep on operating at a low DC-interface voltage level. The little appraising of the dynamic inverter part is utilized to enhance the exhibitions of the TCLC part by retaining the consonant streams produced by the TCLC part, abstaining from mistuning of the terminating edges, and keeping the reverberation issue. The commitments of this paper are compressed as takes after.

A mixture STATCOM is proposed, with the particular attributes of a significantly more extensive remuneration extend than C-STATCOM and different arrangement sort PPF-STATCOMs and a much lower DC-interface voltage than customary STATCOM [4]-[9] and other parallel-associated half and half STATCOMs . Its V-I characteristics is investigated to give an unmistakable perspective of the upsides of hybrid STATCOM in correlation with customary STATCOM and C-STATCOM. Its parameter outline strategy is proposed in light of thought of the reactive power pay extend, aversion of the potential reverberation issue and evasion of mistuning of terminating edge.Another control system for cross breed STATCOM is proposed to arrange the TCLC part and the dynamic inverter part for reactive power pay under various voltage and current conditions, for example, lopsided current, voltage blame, and voltage plunge.

## II. METHODS AND MATERIAL

### 1. CIRCUIT CONFIGURATION OF THE HYBRID-STATCOM

Fig. 1 demonstrates the circuit design of half and half STATCOM, in which the subscript "x" remains for phase a, b, and c in the accompanying investigation. $v_{sx}$ and $v_x$are the source and load voltages; $i_{sx}$, $i_{Lx}$, and $i_{cx}$ are the source, stack, and remunerating streams, separately. Ls is the transmission line impedance. The half and half STATCOM comprises of a TCLC and a dynamic inverter part. The TCLC part is made out of a coupling inductor $L_c$, a parallel capacitor CPF, and a thyristor-controlled reactor with LPF. The TCLC part gives a wide and persistent inductive and capacitive reactive power remuneration go that is controlled by controlling the terminating points hatchet of the thyristors. The dynamic inverter part is made out of a voltage source inverter with a DC-link capacitor Cdc, and the little evaluating dynamic inverter part is utilized to enhance the execution of the TCLC part. Moreover, the coupling segments of the customary STATCOM and C-STATCOM are additionally introduced in Fig. 1. In view of the circuit arrangement in Fig. 1, the V-I attributes of conventional STATCOM, C-STATCOM, and hybrid STATCOM are analyzed and talked about.

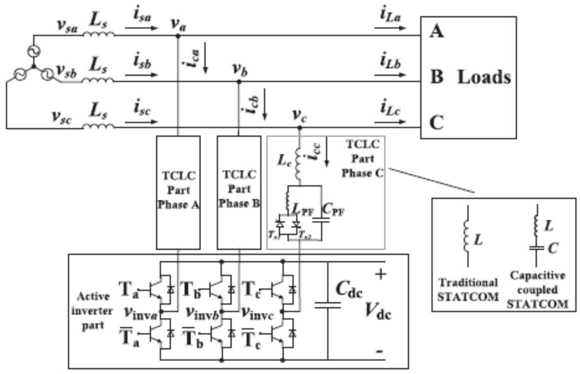


**Figure 1.** Circuit configuration of the hybrid-STATCOM

## 2. V-I CHARACTERISTICS OF THE TRADITIONAL STATCOM, C-STATCOM AND HYBRID-STATCOM

The motivation behind the cross breed STATCOM is to give an indistinguishable measure of reactive power from the loadings ($Q_{Lx}$) expended, yet with the inverse extremity ($Q_{cx}$=-$Q_{Lx}$). The hybrid STATCOM remunerating reactive power $Q_{cx}$ is the total of the reactive power QTCLC that is given by the TCLC part and the reactive power $Q_{invx}$ that is given by the dynamic inverter part. Along these lines, the relationship among QLx, QTCLC, and Qinvx can be communicated as

$$Q_{Lx}= --Q_{Cx}= -(Q_{TCLC}+Q_{invx}) \qquad (1)$$

The reactive powers can also be expressed in terms of voltages and currents as

$$Q_{Lx}=V_xI_{Lqx}= -(X_{TCLC}(\alpha_x)I^2_{cqx}+V_{invx}I_{cqx}) \qquad (2)$$

where *XTCLC(*a*x)* is the coupling impedance of the TCLC part; a*x* is the corresponding firing angle; $V_x$and $V_{invx}$are the root mean square (RMS) values of the coupling point and the inverter voltages; and $I_{Lqx}$and $I_{cqx}$are the RMS value of the load and compensating reactive currents, where *ILqx=-Icqx*. Therefore, (2) can be further simplified as

$$V_{invx}=V_x+X_{tclc}(\alpha_x)I_{Lqx} \qquad (3)$$

where the TCLC part impedance *XTCLC(*a*x)* can be expressed as

$$X_{TCLC}(\alpha_x)=\frac{X_{TCR}(\alpha_x)X_{C_{PF}}}{X_{C_{PF}}-X_{TCR}(\alpha_x)}+X_{Lc}$$
$$=\frac{\pi X_{L_{PF}}\ X_{C_{PF}}}{X_{C_{PF}}\ (2\pi-2\alpha_x+\sin 2\alpha_x)-\pi X_{L_{PF}}}+X_{Lc} \qquad (4)$$

Where $X_{L_c}$ , $X_{L_{pf}}$ , and $X_{c_{pf}}$ are the fundamental impedances of $L_C$, $L_{PF}$, and $C_{PF}$, respectively. In (4), it is shown that the TCLC part impedance is controlled by firing angle a*x*. And the minimum inductive and capacitive impedances (absolute value) of the TCLC part can be obtained by substituting the firing angles $\propto_x$=$90^0$and $\propto_x$=$180^0$, respectively. In the following discussion, the minimum value for impedances stands for its absolute value. The minimum inductive ($X_{ind(min)}$>0) and capacitive ($X_{cap(min)}$<0) TCLC part impedances can be expressed as

$$X_{Ind(min)}\,(\alpha_x=90^0)=\frac{X_{L_{PF}}X_{C_{PF}}}{X_{C_{PF}}-X_{L_{PF}}}+X_{Lc} \qquad (5)$$

$$X_{Cap(min)}(\alpha_x=180^0)= -X_{C_{PF}}+X_{Lc} \qquad (6)$$

Ideally, $X_{TCLC}\ (\propto_x)$ is controlled to be $Vx \approx X_{TcLC}(\propto_x)I_{lqx}$, so that the minimum inverter voltage ($V_{inx} \approx 0$ ) can be obtained as shown in (3). In this case, the switching loss and switching noise can be significantly reduced. A small inverter voltage $V_{inx(min)}$ is important to assimilate the symphonious current created by the TCLC part, to keep a reverberation issue, and to abstain from mistuning the terminating points. On the off chance that the stacking capacitive present or inductive current is outside the TCLC part remunerating range, the inverter voltage$V_{inx}$will be slightly increased to further enlarge the compensation range. The coupling impedances for traditional STATCOM andC-STATCOM, as shown in Fig. 1, are fixed as $X_L$and $X_C$-1/$X_L$. The relationships among the load voltage$V_x$, the inverter voltage$V_{inx}$, the load reactive current $I_{Lqx}$, and the couplingimpedance of traditional STATCOM and C-STATCOM can be expressed as

$$V_{invx}= V_x+X_L\,I_{Lqx} \qquad (7)$$

$$V_{invx}= V_x-(X_c-\frac{1}{X_L}) \qquad (8)$$

where$X_L$>>$X_C$. Based on (3)-(8), the V-I characteristics of the traditional STATCOM, C-STATCOM, and hybrid-STATCOM can be plotted as shown in Fig. 2.

For traditional STATCOM as shown in Fig. 2(a), the required $V_{invx}$, is bigger than $Vx$ when the stacking is inductive. Conversely, the required $Vinvx$ is littler than $Vx$ when the stacking is capacitive. Really, the required inverter voltage $Vinvx$ is near the coupling voltage $Vx$, because of the little benefit of coupling inductor L[5]-

[8]. For C-STATCOM as appeared in Fig. 2(b), it is demonstrated that the required $Vinvx$ is lower than $Vx$ under a little inductive stacking range. The required $Vinvx$ can be as low as zero when the coupling capacitor can completely make up for the stacking reactive current. Conversely, $Vin\quad x$ is bigger than $Vx$ when the stacking is capacitive or outside its little inductive stacking range. In this way, when the stacking reactive current is outside its planned inductive range, the required $Vinvx$ can be vast. For the proposed hybrid STATCOM as appeared in Fig. 2(c), the required $Vinvx$ can be kept up at a low (least) level ($Vinvx(min)$) for a huge inductive and capacitive reactive current range. In addition, when the stacking reactive current is outside the remuneration scope of the TCLC part, the $Vinvx$ will be marginally expanded to additionally grow the repaying range Compared with customary STATCOM and C-STATCOM, the proposed half and half STATCOM has a prevalent V-I normal for a vast pay go with a low inverter voltage. What's more, three cases spoken to by focuses A, B, and C in Fig. 2 are reproduced in Section VI. In light of Fig. 1, the parameter plan of mixture STATCOM is examined in the accompanying segment.

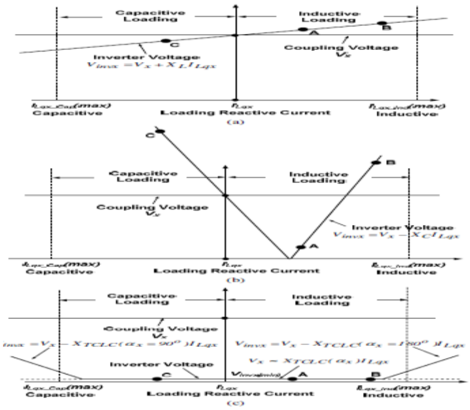


**Figure 2.** V-I characteristic of (a)traditional STATCOM, (b)C-STATCOM and (c)hybrid-STATCOM.

## 3. PARAMETER DESIGN OF HYBRID-STATCOM

The proposed TCLC part is a recently proposed SVC structure which outlined in light of the premise of the thought of the reactive power remuneration go (for L_PF and C_PF) and the aversion of the potential reverberation issue (for L_c). The dynamic inverter part (DC-link voltage V_DC) is intended to abstain from mistuning of the terminating point of TCLC part. A. Plan of C_PF and L_PF The reason for the TCLC part is to give a similar measure of remunerating reactive power Q_cxTCLC,(∝_x) as the reactive power required by the loads Q_Lx yet with the other way. Along these lines, C_PF and L_PF are planned on the premise of the most extreme capacitive and inductive reactive power. The repaying reactive power Q_cx run in term of TCLC impedance X_TCLC (∝_x) can be communicated as

$$Q_{cx,TCLC}(\alpha_x) = \frac{V_x^2}{X_{TCLC(\alpha x)}} \tag{9}$$

where $V_x$ is the RMS value of the load voltage and $X_{TCLC}(\propto_x)$is the impedance of the TCLC part, which can be obtained from (4). In (9), when the $X_{TCLC}$ ( $\propto_x$ )= $X_{Cap(maxcap)}$ ( $\propto_x = 180^0$ ) and $X_{TCLC}(\propto_x)=X_{ind(maxcap)}(\propto_x=90^0)$, the TCLC part provides the maximum capacitive and inductive compensating reactive power $Q_{Cx(mincap)}$ and $Q_{Cx(maxcap)}$, respectively.

$$Q_{cx(MaxCap)} = \frac{V_x^2}{X_{Cap(min)}(\alpha_x = 180^o)} = -\frac{V_x^2}{X_{C_{PF}} - X_{L_C}} \tag{10}$$

$$Q_{cx(MaxInd)} = \frac{V_x^2}{X_{Ind(min)}(\alpha_x = 90^o)} = \frac{V_x^2}{\frac{X_{L_{PF}} X_{C_{PF}}}{X_{C_{PF}} - X_{L_{PF}}} + X_{L_C}} - \tag{11}$$

where the minimum inductive impendence $X_{ind(min)}$ and the capacitive impendence $X_{cap(min)}$ are obtained from (5) and (6), respectively.

To compensate for the load reactive power ($Q_{Cx}$=-$Q_{Lx}$ ), $C_{PF}$and $L_{PF}$can be deduced on the basis of the loading maximum inductive reactive power $Q_{Lx(maxind)}$ (=-$Q_{Lx(maxcap)}$) and capacitive reactive power$Q_{Lx(maxcap)}$(=-$Q_{Lx(maxind)}$). Therefore, based on (10) and (11), the parallel capacitor $C_{PF}$and inductor $L_{PF}$can be designed as

$$C_{PF} = \frac{Q_{Lx(MaxInd)}}{\omega^2 Q_{Lx(MaxInd)} L_c + \omega V_x^2} \tag{12}$$

$$L_{PF} = \frac{V_x^2 + \omega L_c Q_{Lx(MaxCap)}}{-\omega Q_{Lx(MaxCap)} + \omega^3 L_c C_{PF} Q_{Lx(MaxCap)} + \omega^2 V_x^2 C_{PF}} \tag{13}$$

whereω is the fundamental angular frequency and $V_x$is the RMS load voltage.

### B. Design of $L_c$

For energizing reverberation issues, an adequate level of symphonious source voltages or streams must be available at or close to the resounding recurrence. In this way, L_c can be intended to tune the reverberation focuses to wander from the commanded symphonious requests n_d =6n±1th (n=1, 2, 3… ) of a three-phase three-wire transmission system to maintain a strategic distance from the reverberation issue. The thyristors (T_x1 and T_x2) for each period of the TCLC part can be considered as a couple of bidirectional switches that produce low-arrange symphonious streams when the switches change states. The improved single-phase identical circuit model of half and half STATCOM is appeared in Fig. 3.

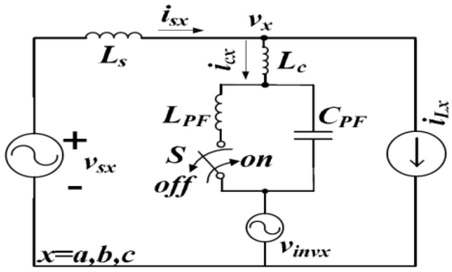


**Figure 3.** Simplified single-phase equivalent circuit model of hybrid-STATCOM.

Referring to Fig. 3, when switch S is turned off, the TCLC part can be considered as the $L_c$ in series with $C_{PF}$, which is called $L_c$ -mode. In contrast, when switch S is turned on, the TCLC can be considered as the Lcin series with the combination of $C_{PF}$ in parallel with $L_{PF}$, which is called LCL-mode. From Table IV in the Appendix A, the TCLC part harmonic impedances under $L_c$ -mode and LCL-mode at different harmonic order n can be plotted in Fig. 4 and expressed as

$$X_{LC,n}(n) = \left|\frac{1-(n\omega)^2 L_C C_{PF}}{n\omega C_{PF}}\right| \quad (14)$$

$$X_{LCL,n}(n) = \left|\frac{n\omega(L_C+L_{PF})-(n\omega)^3 L_{PF} L_C C_{PF}}{1-(n\omega)^2 L_{PF} C_{PF}}\right| \quad (15)$$

In (14) and (15), there are two series resonance points $n_1$ at $X_{LC,n}(n1)=0$ and $n_2$ at $X_{LC,n}$ (n2)=0 and a parallel resonance point $n_3$ at $X_{LCL,n}$ (n3)= $+\infty$ . $L_n$ can be designed to tune the resonancepoints n1 and n2 to diverge from the dominated harmonic orders $n_d$=6n±1th (n=1, 2, 3…) or approach the 3n thorder in a three-phase three-wire system. Based on the above discussion,the design criteria of $L_c$ can be expressed as

$$L_c = \frac{1}{(\omega n_1)^2 C_{PF}} \text{and} L_c = \frac{1}{(\omega n_2)^2 C_{PF} - 1/L_{PF}} \quad (16)$$

$$n_3 = \frac{1}{\sqrt{L_{PF} C_{PF} \omega^2}} (n_1 , n_2, and\ n_3\ awayfrom\ n_d )(17)$$

In (16), they can be satisfied simultaneously as long as $n_1$ and $n_2$ are away from the dominated harmonic orders $n_d$. The designed $C_{PF}$ and $L_{PF}$ should also satisfy (17). In this paper, $n_1$=3.6, $n_2$=3.9, and $n_3$=1.5 are chosen.

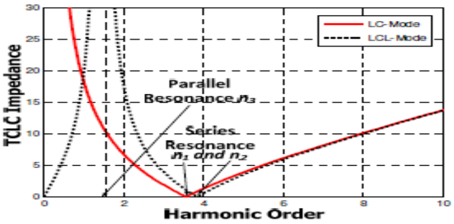


**Figure 4.** TCLC impedance under different harmonic order

### C. Design of $V_{dc}$

Distinctive with the customary V_DC plan technique for the STATCOM to repay greatest load reactive power, the V_DC of Hybrid-STATCOM is configuration to take care of the terminating point mistuning issue of TCLC (i.e., influence the reactive power pay) so the source reactive power can be completely adjusted. Improving (3), the inverter voltage V_invx can likewise be communicated as

$$V_{invx} = V_x\left[1 + \frac{V_x I_{Lqx}}{V_x^2 / X_{TCLC}(\alpha_x)}\right] = V_x\left[1 + \frac{Q_{Lx}}{Q_{cx,TCLC}\,(\alpha_x)}\right] \quad (18)$$

where $Q_{Lx}$ is the load reactive power, $Q_{cx,TCLC}(\propto_x)$ is the TCLC part compensating reactive power, and $V_x$ is the RMS value of the load voltage. Combing (18) with $V_{DC} = 6V_{invx}$ , the required DC-link voltage $V_{DC}$ for hybrid-STATCOM can be expressed as

$$V_{dc} = \sqrt{6}V_x\left|1 + \frac{Q_{Lx}}{Q_{cx,TCLC}\,(\alpha_x)}\right| \quad (19)$$

Ideally, $Q_{cx,TCLC}(\propto_x)$ is controlled to be equal to $-Q_{Lx}$ so that the required $V_{DC}$ can be zero. However, in the practical case, the $Q_{cx,TCLC}(\propto_x)$ may not be exactly equal to $-Q_{Lx}$ due to the firing angle mistuning problem. The worst case of mistuning $Q_{Lx}/Q_{cx,TCLC}(\propto_x)$ ratio can be pre-measured to estimate the required minimum $V_{DC}$value. Finally, a slightly greater $V_{DC}$value can be chosen.

Based on (12), (13), (16), and (19), the system parameters $C_{PF}$, $L_{Pf}$, $L_c$, and $V_{DC}$of hybrid-STATCOM can be designed accordingly. In the following section, the control strategy of hybrid-STATCOM is proposed and discussed.

## 4. CONTROL STRATEGY OF HYBRID-STATCOM

In this segment, a control procedure for half and half STATCOM is proposed by organizing the control of the TCLC part and the dynamic inverter part with the goal that the two sections can supplement each other's inconveniences and the general execution of crossover STATCOM can be made strides. In particular, with the proposed controller, the reaction time of hybrid STATCOM can be quicker than SVCs, and the dynamic inverter part can work at bring down dc-connect working voltage than the conventional STATCOMs. The control methodology of half and half STATCOM is isolated into two sections for talk: A. TCLC part control and B. Dynamic inverter part control. The reaction time of hybrid STATCOM is talked about to some extent C. The control piece graph of half and half STATCOM is appeared in Fig. 5.

### A. TCLC part control

Distinctive with the customary SVC control in view of the conventional meaning of reactivepower[2],[3], to enhance its reaction time, the TCLC part control depends on the prompt pq hypothesis[4]. The TCLC part is mostly used to repay the reactive current with the controllable TCLC part impedance X_TCLC. reffering to (3), to acquire the base inverter voltage V_invx≈0, X_TCLC can be ascertained with Ohm's law as far as the RMS estimations of the load voltage (V_x) and the loadreactive current (I_Lqx). Be that as it may, to compute the X_TCLC progressively, the outflow of X_TCLC can be revised as far as quick esteems as

$$X_{TCLC} = \frac{V_x}{I_{Lqx}} = \frac{\overrightarrow{\|v\|}^{2}}{\sqrt{3}.\ \overrightarrow{q}_{Lx}} \qquad (20)$$

where$||\bar{I}||$is the norm o f the three-phase instantaneous load voltage and $q_{Lx}$is the DC component of the phase reactive power. The real-time expression of v and $q_{Lx}$can be obtained by (21) and (22) with low-pass filters.

$$\|v\| = \sqrt{v_a^2 + v_b^2 + v_c^2} \quad (21)$$

$$\begin{bmatrix} q_{La} \\ q_{Lb} \\ q_{Lc} \end{bmatrix} = \begin{bmatrix} v_b . i_{Lc} - v_c . i_{Lb} \\ v_c . i_{La} - v_a . i_{Lc} \\ v_a . i_{Lb} - v_b . i_{La} \end{bmatrix} \quad (22)$$

In (21) and (22), v_x and q_Lx are the momentary load voltage and the load reactive power, individually. As appeared in Fig. 5, a limiter is connected to restrict the computed X_TCLC in (9) inside the scope of X_TCLC >X_(ind(min)) and X_TCLC <X_(cap(min)) (X_cap<0). With the ascertained X_TCLC, the terminating edge ∝_x can be dictated by comprehending (4). Since (4) is confused, a look-into table (LUT) is introduced inside the controller. The trigger signs to control the TCLC part would then be able to be created by contrasting the terminating point _x and _x, which is the phase edge of the load voltage vx. _x can be gotten by utilizing a phase bolt circle (PLL). Note that the terminating edge of each phase can vary if the lopsided burdens are associated (see (4) and (20)). With the proposed control calculation, the reactive energy of each phase can be repaid and the dynamic power can be fundamentally adjusted, with the goal that DC-connect voltage can be kept up at a low level even under unequal load remuneration.

### B. Active inverter part control

In the proposed control procedure, the momentary dynamic and reactive current i_d-i_qtechnique[7] is actualized for the dynamic inverter part to enhance the general execution of crossover STATCOM under various voltage and current conditions, for example, adjusted/lopsided, voltage plunge, and voltage blame. In particular, the dynamic inverter part is utilized to enhance the TCLC part characteristics by restricting the remunerating current i_cx to its reference esteem i_cx* with the goal that the mistuning issue, the reverberation issue, and the symphonious infusion issue can be maintained a strategic distance from. The i_cx* is computed by applying the i_d-i_v technique [7] in light of the fact that it is legitimate for various voltage and current conditions. The figured i_cx* contains reactive power, unequal power, and current symphonious segments. By controlling the repaying current i_cx to track its reference i_cx*, the dynamic inverter part can make up for the load symphonious streams and enhance the reactive power remuneration capacity and dynamic execution of the TCLC part under various voltage conditions. The i_cx* can be computed as

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} . \begin{bmatrix} \cos\theta_a & -\sin\theta_a \\ \sin\theta_a & \cos\theta_a \end{bmatrix} \cdot \begin{bmatrix} \tilde{i_d} \\ i_q \end{bmatrix} (23)$$

where$i_d$and $i_q$are the instantaneous active and reactive current, which include DC components $\bar{i}_d$and $\bar{i}_q$, and AC components and $\tilde{i}_d$ . $\tilde{i}_d$ is obtained by passing $i_d$through ahigh-pass filter. $i_d$and$i_q$are obtained by

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\theta_a & \sin\theta_a \\ -\sin\theta_a & \cos\theta_a \end{bmatrix} \cdot \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}. \quad (24)$$

In (24), the currents ( $i_a$ and $i_b$ ) in a-b plane are transformed from a-b-c frames by

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} (25)$$

where$i_{Lx}$is the load current signal.

### C. Response time of hybrid-STATCOM

The TCLC part has two consecutive associated thyristors in each phase that are activated on the other hand in each half cycle, with the goal that the control time of the TCLC part is one cycle (0.02 s).

In any case, the proposed hybrid STATCOM structure associates the TCLC part in arrangement with a quick worked dynamic inverter part, which can altogether enhance its general reaction time. With the proposed controller, the dynamic inverter part can constrain the remunerating current i_Cx to its reference esteem i_Cx* through heartbeat width regulation (PWM) control, and the PWM control recurrence is set to be 12.5 kHz. Amid the transient express, the reaction time of crossover STATCOM can be independently examined in the accompanying two cases. an) If the load reactive power is progressively changing inside the inductive range (or inside the capacitive range), the reaction time of hybrid STATCOM can be as quick as customary STATCOM. b) conversely, when the load reactive power all of a sudden changes from capacitive to inductive or the other way around, the half and half STATCOM may take roughly one cycle to settle down. Be that as it may, in commonsense application, case b) portrayed above at times happens. Thusly, in light of the above dialog, the proposed cross breed STATCOM can be considered as a quick reaction reactive power compensator in which the dynamic arrays of half and half STATCOM are demonstrated by the reenactment result (Fig. 6) and the exploratory outcomes (Fig. 7, Fig. 8, Fig. 10, and Fig. 12).

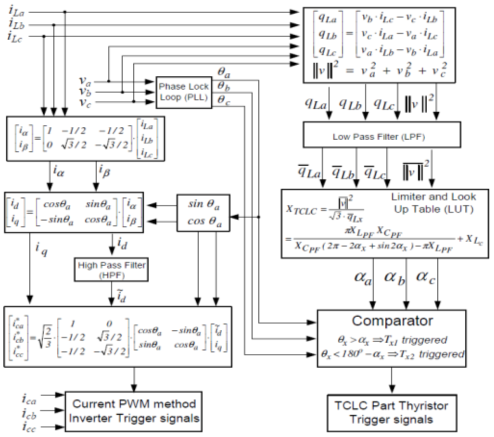


**Figure 5.** The control block diagram of hybrid-STATCOM.

The following section reports the simulation and experimental results to verify the above V-I characteristics analysis and the control strategy of the hybrid-STATCOM in comparison with traditional STATCOM and C-STATCOM.

## III. RESULTS AND DISCUSSION

### SIMULATION RESULTS

The objective of the simulation results is to verify that the proposed hybrid –STATCOM has the characteristics of a wide compensation range and low dc-link voltage under different voltage and current conditions such as unbalanced current,voltage dip and voltage fault.

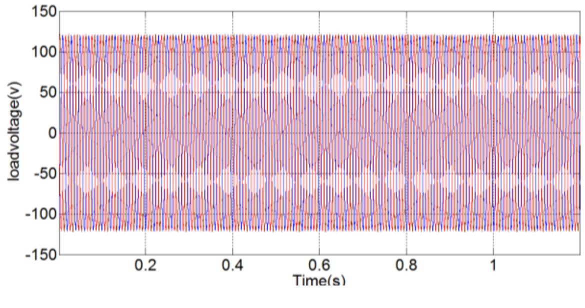


**Figure 6.** Dynamic compensation waveform of Load voltage by not applying hybrid STATCOM under unbalanced loads.

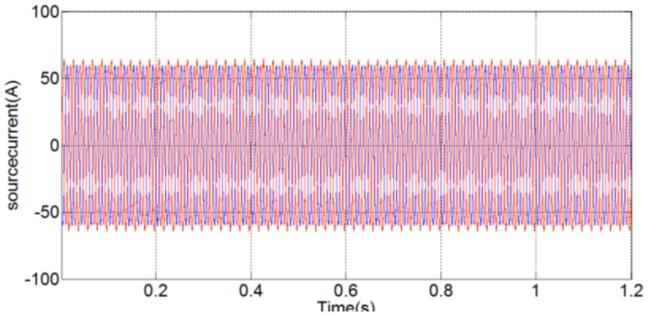


**Figure 7.** Dynamic compensation waveform of source current by not applying hybrid STATCOM under unbalanced loads.

Thedynamic compensation waveforms of load voltage and source current by not applying hybrid STATCOM under unbalanced loads are illustrated in fig.6 and 7.

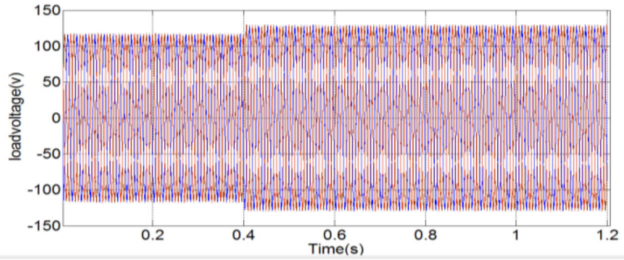


**Figure 8.** Dynamic compensation waveform of Load voltage by applying hybrid STATCOM under unbalanced loads.

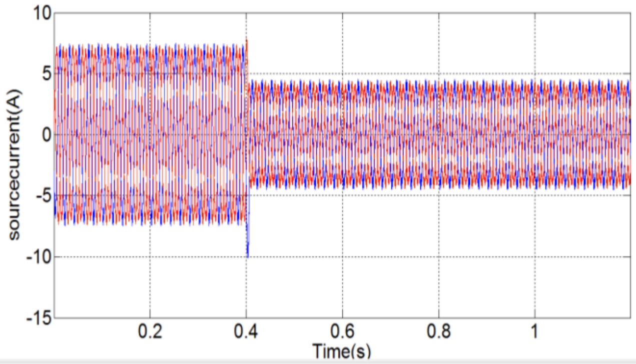


**Figure 9.** Dynamic compensation waveform of Source current by applying hybrid STATCOM under unbalanced loads.

The dynamic compensation waveforms of load voltage and source current by applying hybrid STATCOM under unbalanced loads are described in fig.8 and 9in which unbalanced source currents compensates from 4.80 to3.83Aproves good dynamic performance and balance the source current even under unbalanced loads with low dc voltage of 50v.

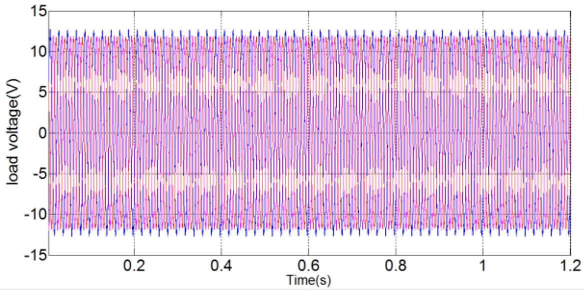


**Figure 10.** Dynamic compensation waveform of Load voltage by not applying hybrid STATCOM under voltage fault condition.

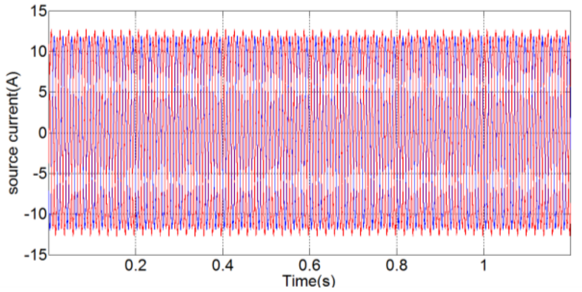


**Figure 11.** Dynamic compensation waveform of source current by not applying hybrid STATCOM under voltage fault condition

The dynamic compensation waveforms of load voltage and source current by not applying hybrid STATCOM under voltage fault conditions are shown in fig 10 &11.

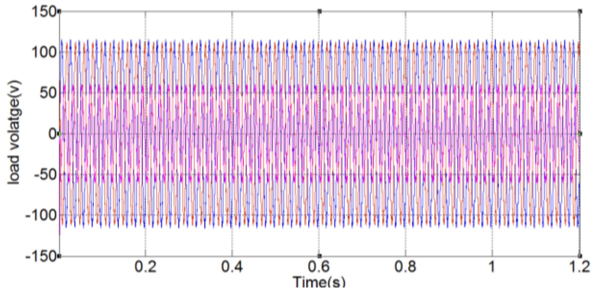


**Figure 12.** Dynamic compensation waveform of load voltage by applying hybrid STATCOM under voltage fault condition.

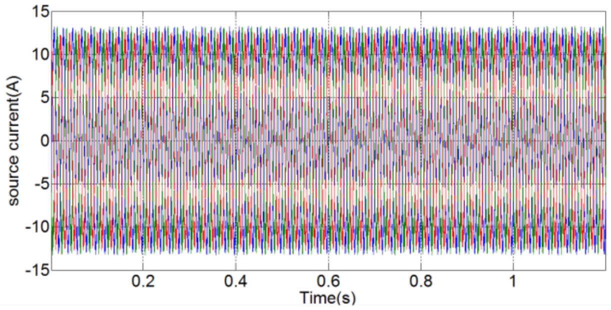


**Figure 13.** Dynamic compensation waveform of source current by applying hybrid STATCOM under voltage fault condition

Dynamic compensation waveforms of load voltage and source current by applying hybrid STATCOM under voltage fault conditions in which source current compensates from 5.74 to 2.94A are described in fig.12 & 13 and proves good dynamic performance even under asymmetric grid fault.

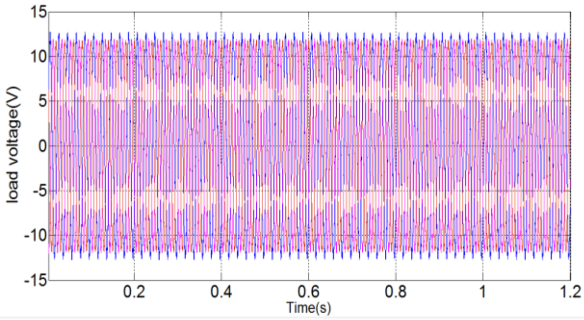


**Figure 14.** Dynamic compensation waveform of load voltage by applying hybrid STATCOM during voltage dip condition.

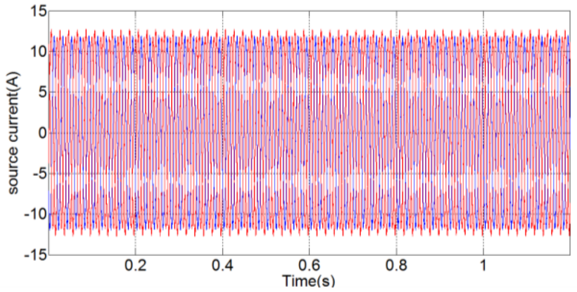


**Figure 15.** Dynamic compensation waveform of source current by applying hybrid STATCOM during voltage dip condition.

The load voltage and source current of the dynamic compensation waveforms by applying hybrid STATCOM during a sudden voltage dip are shown in fig14 & 15.

**Dynamic Response of hybrid STATCOM using PI Controller:**

The dynamic performance of hybrid-STATCOM for different conditions are shown in figs.16,17,18 and 19.The proposed hydrid STATCOM can avoid the use of multi level structures in medium level transmission system when compared to other systems,the reliability of the system is greatly increased and the control complexity of the system is reduced.

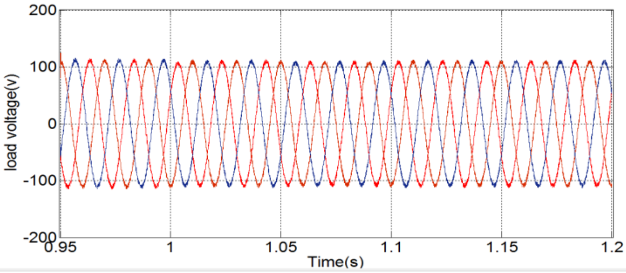


**Figure 16.** Dynamic compensation waveforms of load voltage by applying hybrid STATCOM under different loading cases.

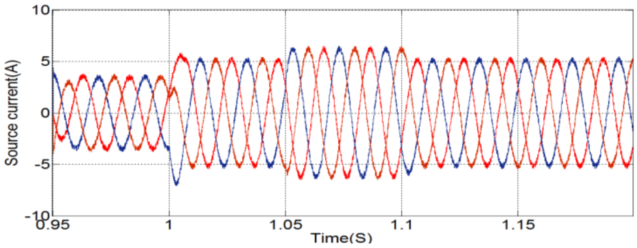


**Figure 17.** Dynamic compensation waveforms of source current by applying hybrid STATCOM under different loading cases.

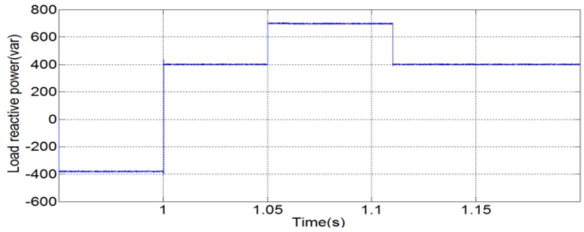


**Figure 18.** Dynamic compensation waveforms of load reactive power by applying hybrid STATCOM under different loading cases.

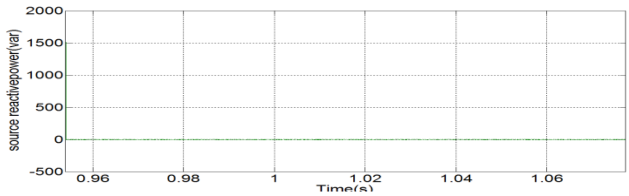


**Figure 19.** Dynamic compensation waveforms of source reactive power by applying hybrid STATCOM under different loading cases.

Due to low dc link voltage of the hybrid STATCOM,the source current $THD_{isx}$is reduced. Comparison between with and without hybrid STATCOM at all loading conditions are listed in

tableI.

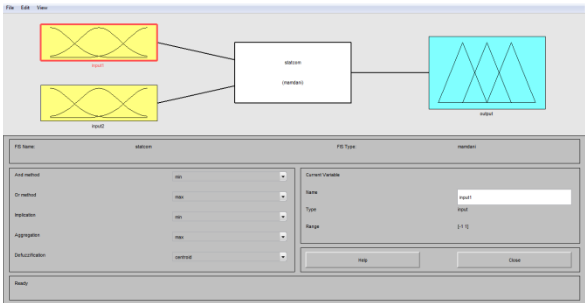
### TABLE I

COMPENSATION RESULTS OF $THDi_{sx}$ BY HYBRID STATCOM (VDC= 50V) UNDER DIFFERENT SYSTEM AND LOADING CONDITIONS BY USING FFT ANALYSIS

| Different situations | Without Hybrid STATCOM | | | With Hybrid STATCOM | | |
|---|---|---|---|---|---|---|
| | A | B | C | A | B | C |
| Capacitive load | 5.36 | 5.39 | 5.36 | 3.10 | 3.06 | 3.05 |
| Inductive load | 3.41 | 3.48 | 3.47 | 1.00 | 1.00 | 1.00 |
| Unbalanced loads | 5.91 | 8.54 | 8.10 | 2.03 | 1.39 | 1.20 |
| Voltage faults | 4.70 | 9.33 | 6.43 | 2.29 | 2.50 | 1.60 |

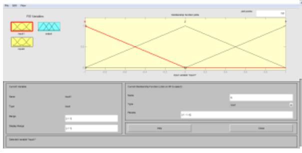
**Dynamic Response of hybrid STATCOM using Fuzzy Logic Controller:**

Usage of conventional control "PI", its reaction is not all that great for non-linear systems. The change is striking when controls with Fuzzy logic are utilized, acquiring a superior dynamic reaction from the system. The PI controller requires exact direct numerical models, which are hard to get and may not give tasteful execution under parameter varieties, load unsettling influences, and so forth. The benefits of fuzzy logic controllers over ordinary PI controllers are that they needn't bother with a precise scientific model, Can work with uncertain information sources and can deal with non-linearities and are more powerful than traditional PI controllers.For application of the fuzzy logic controller mainly requires the membership functions,decision table and rulebase values which were shown in figs.20,21,22.

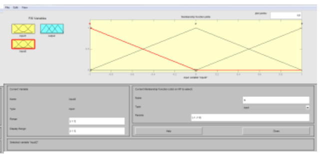


FIS Name: statcom
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: input1
Type: input
Range: [-1 1]

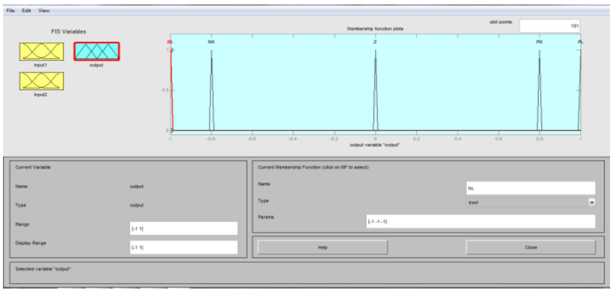
**Figure 20.** FIS editor STATCOM for the dynamic compensation waveform by applying hybrid STATCOM under different loading conditions.



**Input 1**



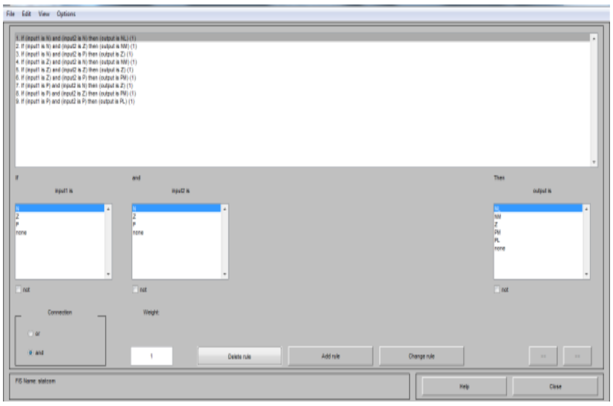
**Input 2**



Current Variable
Name: output
Type: output
Range: [-1 1]
Display Range: [-1 1]
Current Membership Function (click on MF to select)
Name: NL
Type: trimf
Params: [-1 -1 -1]
Selected variable "output"

**Output**

**Figure 21.** Membership function for thedynamic compensation waveform by applying hybrid STATCOM under different loading conditions



1. If (input1 is N) and (input2 is N) then (output is NL) (1)
2. If (input1 is N) and (input2 is Z) then (output is NM) (1)
3. If (input1 is N) and (input2 is P) then (output is Z) (1)
4. If (input1 is Z) and (input2 is N) then (output is NM) (1)
5. If (input1 is Z) and (input2 is Z) then (output is Z) (1)
6. If (input1 is Z) and (input2 is P) then (output is PM) (1)
7. If (input1 is P) and (input2 is N) then (output is Z) (1)
8. If (input1 is P) and (input2 is Z) then (output is PM) (1)
9. If (input1 is P) and (input2 is P) then (output is PL) (1)

FIS Name: statcom

**Figure 22.** Decision table and rulebase of dynamic compensation waveform by applying hybrid STATCOM under different loading conditions

In this paper for the extension ,we consider fuzzy logic controller whose FIS editor is named as STATCOM.In the membership function we have two input currents and output voltage ranging from [-1,1].The parameters for the input current are [-1,-1,0] and for output voltage is [-1,-1,-1].

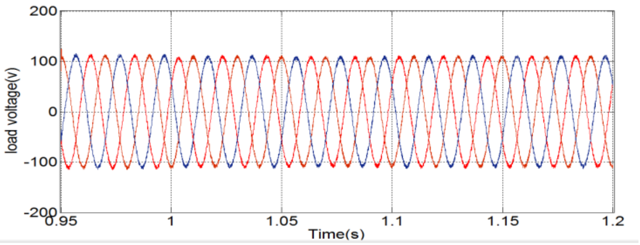


**Figure 23.** Dynamic compensation waveforms of load voltage by applying hybrid STATCOM using Fuzzy logic controller under different loading cases.

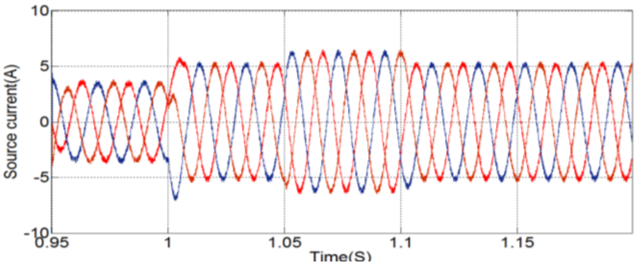


**Figure 24.** Dynamic compensation waveforms of Source current by applying hybrid STATCOM using Fuzzy logic controller under different loading cases.

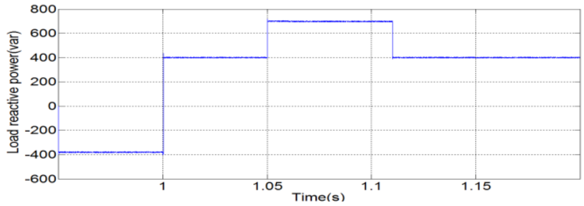


**Figure 25.** Dynamic compensation waveforms of Load Reactive power by applying hybrid STATCOM using Fuzzy logic controller under different loading cases.

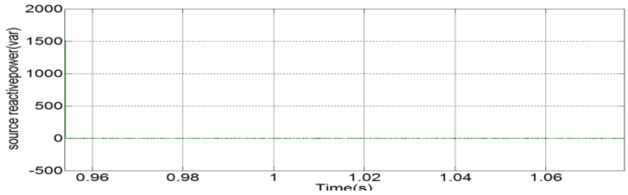


**Figure 26.** Dynamic compensation waveforms of Source reactive power by applying hybrid STATCOM using Fuzzy logic controller under different loading cases.

The dynamic compensation waveforms of load voltage, source current , load and source reactive power by applying hybrid STATCOM using Fuzzy logic controller are illustrated in fig.23,24,25,26. From the above waveforms the source current are compensated from 19.09 to 17.26 and the load voltage is from 3.13 to 1.15.So by using the fuzzy logic controller efficiency and the simplicity of design process is highly improved.

### TABLE II

COMPARISON OF THD$i_{sx}$ FFT ANALYSIS RESULTSFOR DYNAMIC COMPENSATION OF LOAD VOLTAGE AND SOURCE CURRENT BY APPLYING HYBRID STATCOM USING PI AND FUZZY LOGIC CONTROLLER

| | Proposed | Extension |
|---|---|---|
| Load voltage | 3.13 | 1.15 |
| Source current | 19.09 | 17.26 |

## IV. CONCLUSION

In this paper, a hybrid STATCOM in three-phase control system is proposed and examined as cost effective reactive power compensator for medium voltage level application.It is point out that there are huge reactive currents occurred in transmission line.So in this paper hybrid STATCOM is applied to provide wide compensation range.The system is tested by designing in matlab.PI Controller and Fuzzy Logic Controllers have used to implement the system.The obtained results have been presented.At last, the wide compensation range and low DC-link voltage attributes with great dynamic execution of the hybrid STATCOM were proved.

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