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TECHNOLOGY****A HYBRID STATCOM WITH WIDE COMPENSATION RANGE BY USING FUZZY  
LOGIC CONTROLLER FOR UNBALANCED LOADS****K. Bhavyasri<sup>\*1</sup> & K. Shalini<sup>2</sup>**<sup>\*1</sup>Department Of Electrical And Electronics Engineering, Sri Padmavathi Mahila Visvavidyalayam,  
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**ABSTRACT**

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 with fuzzy logic controller. As a result of these noticeable attributes, the system expenses can be significantly lessened. In this paper, the circuit setup of hybrid STATCOM is presented first. Its V-I characteristics is then broke down, examined, and contrasted and conventional STATCOM and capacitive-coupled STATCOM (C-STATCOM). The system parameter configuration is then proposed on the premise of thought of the reactive power pay range and shirking of the potential reverberation issue. From that point forward, a control methodology for hybrid STATCOM is proposed to permit operation under various voltage and current conditions, for example, lopsided current, voltage plunge, and voltage blame. 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. By using fuzzy logic controller we can reduce THD and maintain more voltage stability

**KEYWORDS:** Hybrid-STATCOM, P-Q theory, id-iq method, PI controller, fuzzy logic controller.**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. 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. 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 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. 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 series 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 series 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, the momentary d-q hypothesis, the quick id-iq technique, negative-and zero-arrangement control, the back spread (BP) control strategy, 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)

Nonetheless, this hybrid 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, if this 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 structures may experience the ill effects of a reverberation issue.

To defeat the inadequacies of various reactive power compensators] 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 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. 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.  $L_s$  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  $C_{dc}$ , 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.

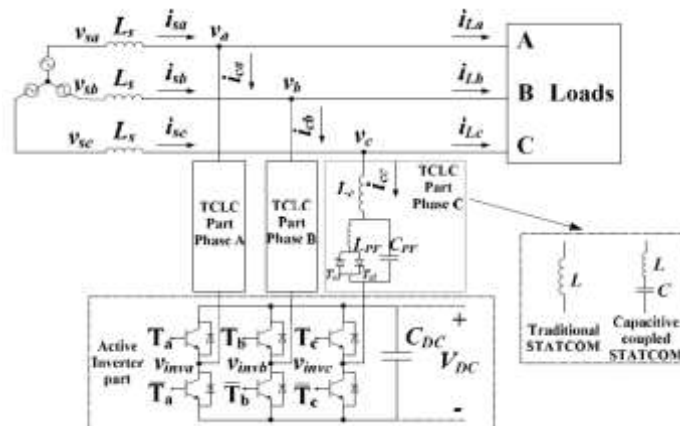


Fig. 1. Circuit configuration of the hybrid-STATCOM

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

The motivation behind the hybrid 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  $Q_{TCLC}$  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  $Q_{Lx}$ ,  $Q_{TCLC}$ , and  $Q_{invx}$  can be communicated as

$$Q_{Lx} = -Q_{cx} = -(Q_{TCLC} + Q_{invx}) \tag{1}$$

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

$$Q_{Lx} = v_x I_{Lqx} = -(X_{TCLC(\alpha x)} I_{Cqx}^2 + v_{invx} I_{Cqx}) \tag{2}$$

where  $X_{TCLC(ax)}$  is the coupling impedance of the TCLC part;  $\alpha x$  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  $I_{Lqx} = -I_{Cqx}$ . Therefore, (2) can be further simplified as

$$V_{invx} = v_x + X_{TCLC(\alpha x)} I_{Lqx} \tag{3}$$

where the TCLC part impedance  $X_{TCLC(ax)}$  can be expressed as

$$X_{TCLC(\alpha x)} = \frac{X_{TCR(\alpha x)} X_{CPF}}{X_{CPF} - X_{TCR(\alpha x)}} + X_{Lc} = \frac{\pi X_{Lpf} X_{CPF}}{X_{CPF}(2\pi - 2\alpha_x + \sin 2\alpha_x - \pi X_{Lpf})} + X_{Lc} \tag{4}$$

Where  $X_{Lc}$ ,  $X_{Lpf}$ , and  $X_{cpf}$  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  $\alpha x$ . And the minimum inductive and capacitive impedances (absolute value) of the TCLC part can be obtained by substituting the firing angles  $\alpha_x = 90^\circ$  and  $\alpha_x = 180^\circ$ , 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

$$X_{ind(min)(\alpha x=90)} = \frac{X_{Lpf} X_{CPF}}{X_{CPF} - X_{Lpf}} + X_{Lc} \tag{5}$$

$$X_{Cap(min)(\alpha x=180)} = -X_{CPF} + X_{Lc} \tag{6}$$

Ideally,  $X_{TCLC(\alpha x)}$  is controlled to be  $V_x \approx X_{TCLC(\alpha x)} I_{Lqx}$ , so that the minimum inverter voltage ( $V_{invx} \approx 0$ ) can be obtained as shown in (3). In this case, the switching loss and switching noise can be significantly reduced. A small inverter voltage  $V_{invx(min)}$  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  $V_{invx}$  will be slightly increased to further enlarge the compensation range. The coupling impedances for traditional STATCOM and C-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  $V_{invx}$ , the load reactive current  $I_{Lqx}$ , and the coupling impedance of traditional STATCOM and C-STATCOM can be expressed as

$$V_{invx} = V_x + X_L I_{Lqx} \tag{7}$$

$$V_{invx} = V_x - (X_c - \frac{1}{X_l}) I_{Lqx} \tag{8}$$

where  $X_L \gg X_C$ . 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  $V_x$  when the stacking is inductive. Conversely, the required  $V_{invx}$  is littler than  $V_x$  when the stacking is capacitive. Really, the required inverter voltage  $V_{invx}$  is near the coupling voltage  $V_x$ , because of the little benefit of coupling inductor L. For C-STATCOM as appeared in Fig. 2(b), it is demonstrated that the required  $V_{invx}$  is lower than  $V_x$  under a little inductive stacking range. The required  $V_{invx}$  can be as low as zero when the coupling capacitor can completely make up for the stacking reactive current. Conversely,  $V_{invx}$  is bigger than  $V_x$  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  $V_{invx}$  can be vast. For the proposed hybrid STATCOM as appeared in Fig. 2(c), the required  $V_{invx}$  can be kept up at a low (least) level ( $V_{invx}(min)$ ) 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  $V_{invx}$  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.

#### IV. 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  $Q_{cxTCLC}(\alpha_x)$  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  $X_{TCLC}(\alpha_x)$  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  $X_{TCLC}(\alpha_x)$  is the impedance of the TCLC part, which can be obtained from (4). In (9), when the  $X_{TCLC}(\alpha_x) = X_{Cap(maxcap)}$  ( $\alpha_x = 180^\circ$ ) and  $X_{TCLC}(\alpha_x) = X_{ind(maxcap)}$  ( $\alpha_x = 90^\circ$ ), the TCLC part provides the maximum capacitive and inductive compensating reactive power  $Q_{Cx(mincap)}$  and  $Q_{Cx(maxcap)}$ , respectively.

$$Q_{Cx(MaxCap)} = \frac{V_x^2}{X_{Cap(min)}(\alpha_x=180)} = -\frac{V_x^2}{X_{CPF}-X_{Lc}} \tag{10}$$

$$Q_{Cx(Maxind)} = \frac{V_x^2}{X_{ind(min)}(\alpha_x=90)} = \frac{V_x^2}{\frac{X_{LPF}X_{CPF}}{X_{CPF}-X_{LPF}}+X_{Lc}} \tag{11}$$

where the minimum inductive impedance  $X_{ind(min)}$  and the capacitive impedance  $X_{cap(min)}$  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

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

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

where  $\omega$  is the fundamental angular frequency and  $V_x$  is the RMS load voltage.

**A. 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  $n_d = 6n \pm 1$ th ( $n=1, 2, 3, \dots$ ) 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.

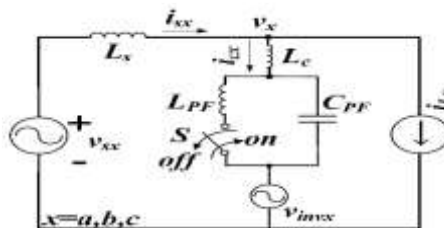


Fig. 3. Simplified single-phase equivalent circuit model of hybrid-STATCOM.

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  $L_c$  in 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

$$X_{Lc,n}(n) = \left| \frac{1 - (n\omega)^2 L_c C_{PF}}{n\omega C_{PF}} \right| \tag{14}$$

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

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

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

$$n_3 = \frac{1}{\sqrt{L_{PF} C_{PF} \omega^2}} \tag{17}$$

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.



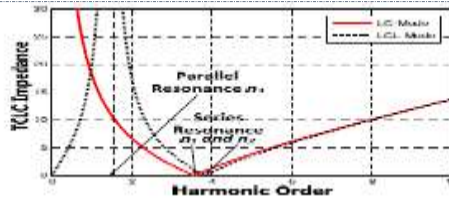


Fig. 4. TCLC impedance under different harmonic order

**B. Design of VDC**

Distinctive with the customary V<sub>DC</sub> plan technique for the STATCOM to repay greatest load reactive power, the V<sub>DC</sub> 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<sub>invx</sub> can likewise be communicated as

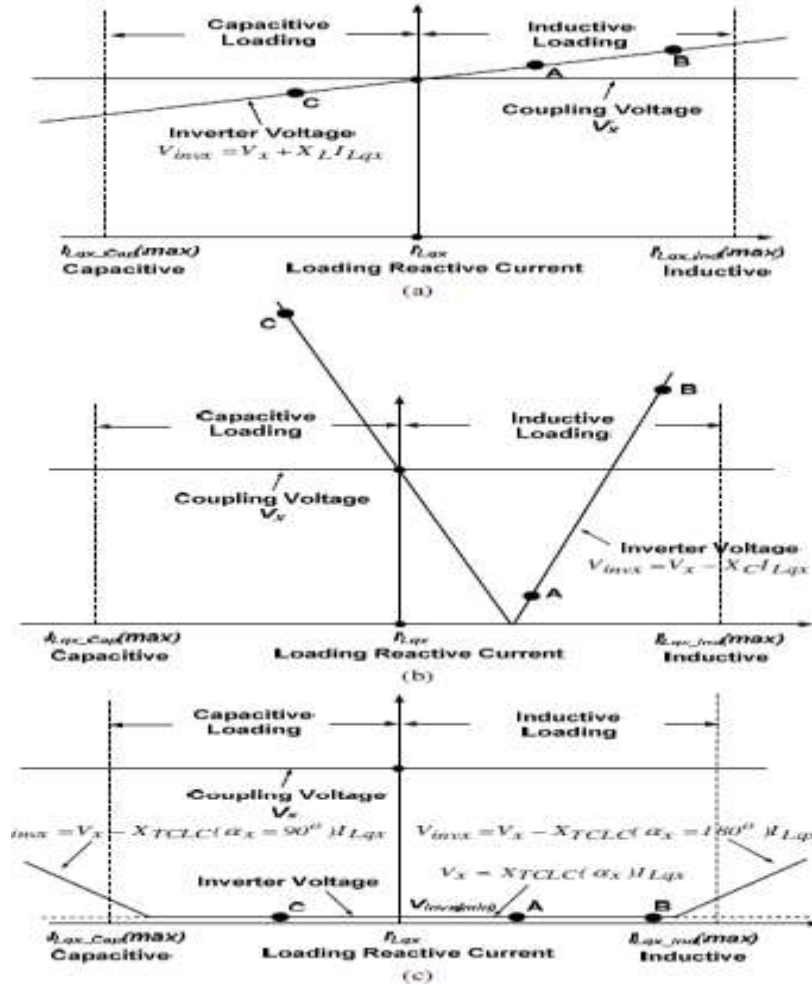
$$V_{invx} = V_x \left[ 1 + \frac{V_x I_{Lqx}}{V_x^2 / X_{TCLC(\alpha x)}} \right] = V_x + \left[ 1 + \frac{Q_{Lx}}{Q_{cx,TCLC(\alpha x)}} \right] \tag{18}$$

where Q<sub>Lx</sub> is the load reactive power, Q<sub>cx,TCLC(α<sub>x</sub>)</sub> is the TCLC part compensating reactive power, and V<sub>x</sub> is the RMS value of the load voltage. Combing (18) with V<sub>DC</sub> = 6V<sub>invx</sub>, the required DC-link voltage V<sub>DC</sub> for hybrid-STATCOM can be expressed as

$$V_{DC} = \sqrt{6} V_x \left| 1 + \frac{Q_{Lx}}{Q_{cx,TCLC(\alpha x)}} \right| \tag{19}$$

Ideally, Q<sub>cx,TCLC(α<sub>x</sub>)</sub> is controlled to be equal to -Q<sub>Lx</sub> so that the required V<sub>DC</sub> can be zero. However, in the practical case, the Q<sub>cx,TCLC(α<sub>x</sub>)</sub> may not be exactly equal to -Q<sub>Lx</sub> due to the firing angle mistuning problem. The worst case of mistuning Q<sub>Lx</sub>/Q<sub>cx,TCLC(α<sub>x</sub>)</sub> ratio can be pre-measured to estimate the required minimum V<sub>DC</sub> value. Finally, a slightly greater V<sub>DC</sub> value can be chosen.

Based on (12), (13), (16), and (19), the system parameters C<sub>PF</sub>, L<sub>pf</sub>, L<sub>c</sub>, and V<sub>DC</sub> of hybrid-STATCOM can be designed accordingly. In the following section, the control strategy of hybrid-STATCOM is proposed and discussed.



**V. 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 reactive power, to enhance its reaction time, the TCLC part control depends on the prompt pq hypothesis. The TCLC part is mostly used to repay the reactive current with the controllable TCLC part impedance  $X_{TCLC}$ . referring to (3), to acquire the base inverter voltage  $V_{invx} \approx 0$ ,  $X_{TCLC}$  can be ascertained with Ohm's law as far as the RMS estimations of the load voltage ( $V_x$ ) and the load reactive 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

$$X_{TCLC} = \frac{V_x}{I_{Lqx}} = \frac{\|v^2\|}{\sqrt{3}q_{Lx}} \tag{20}$$

where  $\|v\|$  is the norm of 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.

$$\|V\| = \sqrt{V_a^2 + V_b^2 + V_c^2} \tag{21}$$

$$\begin{bmatrix} q_{La} \\ q_{Lb} \\ q_{Lc} \end{bmatrix} = \begin{bmatrix} V_b \cdot i_{Lc} - V_c \cdot i_{Lb} \\ V_c \cdot i_{La} - V_a \cdot i_{Lc} \\ V_a \cdot i_{Lb} - V_b \cdot i_{La} \end{bmatrix} \tag{22}$$

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  $\alpha_x$  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  $\alpha_x$  and  $\omega_x$ , which is the phase edge of the load voltage  $v_x$ .  $\alpha_x$  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  $i_d$ - $i_q$  technique 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

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

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 a high-pass filter.  $i_d$  and  $i_q$  are obtained by

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\theta_a & -\sin\theta_a \\ -\sin\theta_a & \cos\theta_a \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{24}$$

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

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

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

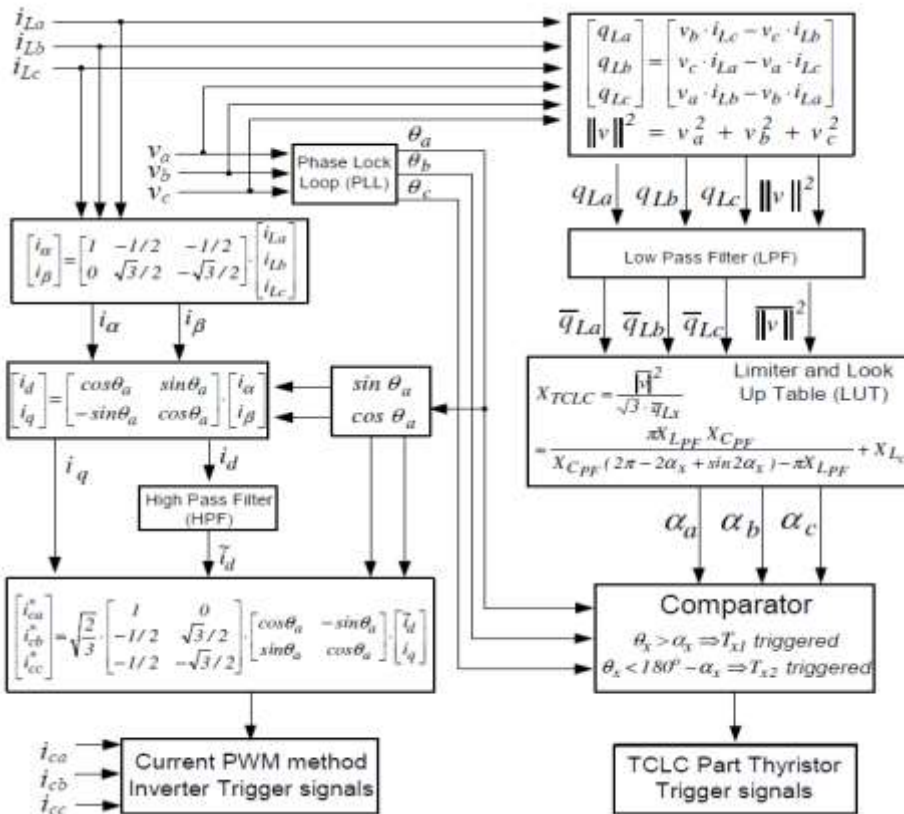
**C. Response time of hybrid-STATCOM**

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 pulse 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).

Fig. 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.

## VI. SIMULATION RESULTS

In this section, the simulation results among traditional STATCOM, C-STATCOM, and the proposed hybrid-STATCOM are discussed and compared. The previous discussions of the required inverter voltages (or DC-link voltage  $V_{dc} = 2 \times 3 \times \text{Vin}v_x$ ) for these three STATCOMs are also verified by simulations. The STATCOMs are simulated with the same voltage level as in the experimental results in Section VI. The simulation studies are carried out with Matlab/SIMULINK. The detailed simulation results are summarized in Table II. Finally, the dynamic response of hybrid-STATCOM is simulated and discussed in this section.

*Table II Compensation results by hybrid statcom (vdc= 50v) under different system and loading situations*

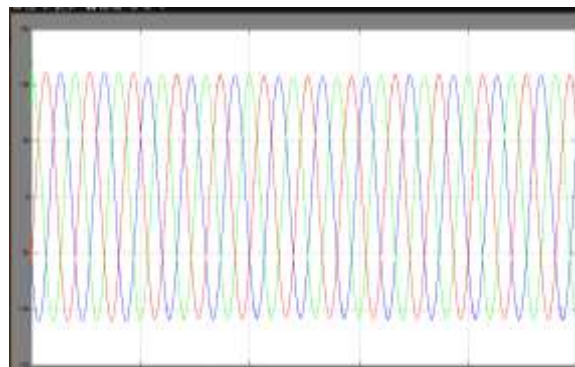
Different situations	With Hybrid STATCOM			Without Hybrid STATCOM		
	A	B	C	A	B	C
Capacitive load	5.3	5.3	5.3	3.1	3.0	3.05
Inductive load	3.4	3.4	3.4	1.0	1.0	1.00
Unbalanced loads	5.9	8.5	8.1	2.0	1.3	1.20
Voltage faults	4.7	9.3	6.4	2.2	2.5	1.60

In this section we also compare the THD and voltage level by using PI and fuzzy logic controller. The Table III the THD comparison is shown.

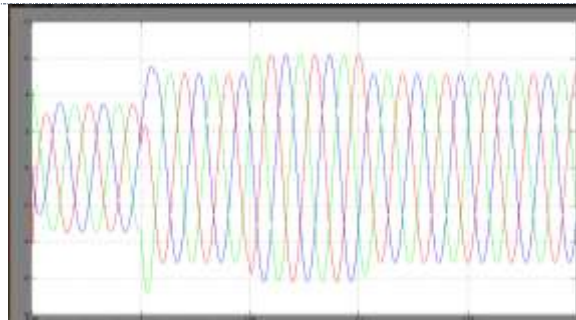
*TABLE III Comparison of proposed and extension*

PARAMETERS	PROPOSED (THD %)	EXTENSION (THD %)
Load voltage	3.13	1.15
Load current	20.16	17.31
Source current	19.09	17.26

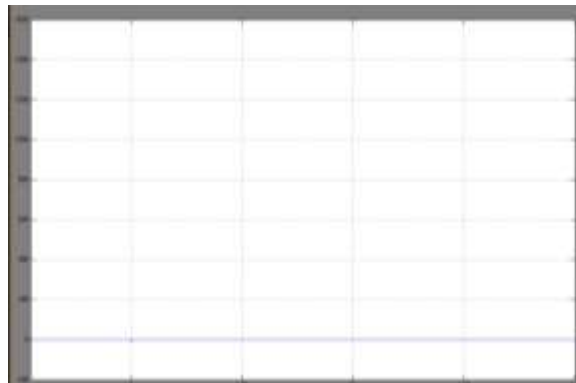
The dynamic results of the paper is shown below those are source current load voltage, load and source reactive power by using hybrid STATCOM with fuzzy logic controller.



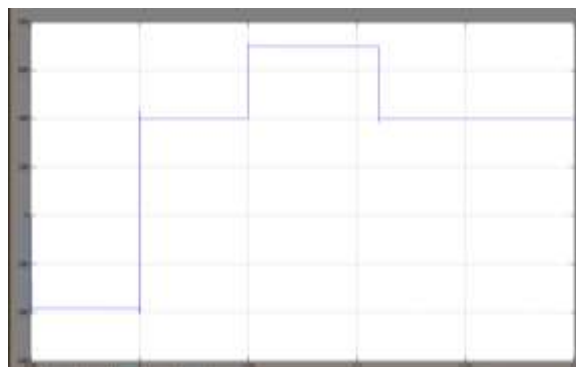
*Fig 6 Load voltage*



*Fig 7 source current*



*Fig 8 Source reactive power*



*Fig 9 Load reactive power*

## VII. CONCLUSIONS

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. The system design and V-I normal for the cross breed STATCOM are dissected, examined, and contrasted and customary STATCOM and C-STATCOM. Also, its parameter outline technique is proposed on the premise of thought of the reactive power pay range and avoidance of a potential reverberation issue. Besides, the control procedure of the hybrid STATCOM is produced under various voltage and current conditions. At last, the wide remuneration range and low DC-link voltage attributes with great dynamic execution of the hybrid STATCOM are demonstrated by both recreation and exploratory outcomes.

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