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A Wide Compensation Ranged Hybrid Statcom with Low Dc – Link Voltage

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Abstract:- A hybrid-STATCOM in three-phase power system is proposed and talked about as a financially savvy reactive power compensator for medium voltage level application in this paper. Accordingly these predominant attributes can incredibly diminish system expenses. By utilizing five-level inverter is created and connected for infusing active power of RES into grid to diminish switching power loss, electromagnetic interference, and harmonic distortion precipitated by switching operation of power electronic devices. It's V-I characteristics is then inspected, and contrasted with capacitive-coupled STATCOM (C-STATCOM) and conventional STATCOM. System configuration is then proposed hinged on consideration of reactive power compensation range and contraction of potential resonance issue. A control technique for hybrid-STATCOM is proposed to permit operation under various current and voltage conditions, i.e., voltage fault, unbalanced currents, and voltage sags. By utilizing simulation results we can check wide compensation range and good performance and low DC-link voltage qualities of proposed hybrid-STATCOM.

Keywords*:-Capacitive-coupled static synchronous compensator (C-STATCOM), hybrid-STATCOM, low dc-link voltage, STATCOM, wide compensation range.*

I. INTRODUCTION

A hybrid-STATCOM is proposed, with specific qualities of a significantly more broad compensation reach out than C-STATCOM [10] and distinctive series-type PPF-STATCOMs and a much lower DC-link voltage than standard STATCOM [4]-[9] and other parallel-related hybrid STATCOMs. To improve working displays of standard STATCOMs, C-STATCOMs, and other PPF-STATCOMs, an extensive variety of control techniques have been proposed.

The significant reactive current in transmission systems is a champion among most broadly perceived power issues that extends transmission losses and cuts down quality of a power system [1]. Use of reactive power ('Q') compensators is one of responses for this issue. Static VAR compensators (SVCs) are by and large employed to dynamically compensate reactive currents as loads change incidentally.

Regardless, SVCs encounter evil impacts of various issues, for instance, resonance issues, harmonic current implantation, and direct response [2]-[3]. To beat these shortcomings, STATCOMs and active power filters (APFs) were delivered for 'Q' compensation with speedier response, less harmonic current imbuement, and better execution [4]-[9]. However, STATCOMs or APFs as a rule require multilevel structures in a medium-or high-voltage level transmission system to decrease high-voltage stress over each power switch and DC-link capacitor, which drives up hidden and operational costs of system and besides extends control eccentrics. Another control scheme for hybrid-STATCOM is proposed to organize TCLC part and active inverter part for 'Q' remuneration under different current and voltage conditions, for instance, unequal current, voltage fault, and voltage dive.

To diminish present rating of STATCOMs or APFs, a hybrid combination structure of PPF in parallel with STATCOM was proposed. However, this hybrid compensator is submitted for inductive loading operation. When it is associated for capacitive loading pay, it viably loses its little active inverter rating characteristics.

To beat shortcomings of different 'Q' compensators [1] for transmission systems, this paper proposes a hybrid-STATCOM that involves a TCLC part and an active inverter part, as exhibited up in Fig. 1. TCLC part gives a wide 'Q' remuneration broaden and an extensive voltage drop between system voltage and inverter voltage with objective that active inverter part can continue working at a low DC-link voltage level [11]. Small evaluating of active inverter part is employed to upgrade displays of TCLC part by immersing harmonic currents created by TCLC part, refraining from mistuning of ending points, and keeping resonance issue.

II. CIRCUIT CONFIGURATION OF HYBRID-STATCOM

Fig 1. exhibits circuit configuration of hybrid-STATCOM, in which subscript "x" remains for phase a, b, and c in going with examination. vsx and vx are source and load voltages; is x, iLx, and icx are source, load, and reimbursing currents, independently. Ls is transmission line impedance. Hybrid-STATCOM includes a TCLC and an active inverter part. TCLC part consists of a parallel capacitor CPF, a thyristor-controlled reactor with LPF, and a coupling inductor Lc. TCLC part gives a wide and constant capacitive and inductive ‘Q’ compensation go that is controlled by controlling firing angles αx of thyristors.

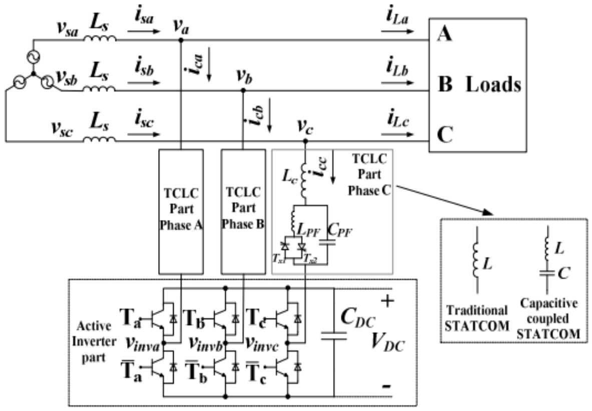


Fig 1:- Circuit configuration of hybrid-STATCOM

The active inverter part is made out of a voltage source inverter with a DC-link capacitor Cdc, and small assessing active inverter part is employed to improve execution of TCLC part. Moreover, coupling components of conventional STATCOM and C-STATCOM are also exhibited in Fig 1.

The traits of different ‘Q’ compensators and proposed hybrid-STATCOM for transmission system are taken a gander at and outlined in Table 1.

	Response time	Resonance problem	DC-link voltage	Compensation range	Cost
SVCs [2]-[3]	Slow	Yes	--	Wide	Low
STATCOMs [4]-[9]	Very Fast	No	High	Wide	High
C-STATCOMs [10]	Fast	No	Low	Narrow	Low
Series-type PPF-STATCOMs [11]-[19]	Fast	No	Low	Narrow	Low
PPF//STATCOM [20], [21]	Fast	Yes	High	Narrow	Medium
SVC//APF [22]	Fast	Yes	High	Wide	High
Hybrid-STATCOM	Fast	No	Low	Wide	Medium

Table 1. Characteristics of Different Compensators for Transmission System

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

The purpose behind hybrid-STATCOM is to give a vague measure of ‘Q’ from loadings (QLx) ate up, yet with opposite furthest point (Qcx=-QLx). hybrid-STATCOM reimbursing ‘Q’ Qcx is aggregate of ‘Q’ QTCLC that is given by TCLC part and ‘Q’ Qinvx that is given by active inverter part. Thusly, relationship among QLx, QTCLC, and Qinvx conceivably conveyed as

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

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

$$Q_{Lx} = V_x I_{Lqx} = -\left(X_{TCLC}(\alpha_x) I_{cqx}^2 + V_{invx} I_{cqx}\right) \qquad (2)$$

Where XTCLC(αx) is coupling impedance of TCLC part; αx is analogous firing angle; Vx and Vinvx are root mean square (RMS) values of coupling point and inverter voltages; and ILqx and Icqx are RMS value of load and compensating reactive currents, where ILqx=-Icqx. Therefore, (2) conceivably further interpreted as

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

Where TCLC part impedance XTCLC(αx) conceivably resembled as

$$X_{TCLC}(\alpha_x) = \frac{X_{TCR}(\alpha_x) X_{C_{pf}}}{X_{C_{pf}} - X_{TCR}(\alpha_x)} + X_{Lc} = \frac{\pi X_{L_{pf}} X_{C_{pf}}}{X_{C_{pf}}(2\pi - 2\alpha_x + sin2\alpha_x) - \pi X_{L_{pf}}} + X_{Lc} \qquad (4)$$

Where, XLc, XLPF, and XCPF are fundamental impedances of Lc, LPF, and CPF, respectively. In (4), it is exhibited that TCLC part impedance is controlled by firing edge αx. What's more, base capacitive and inductive impedances (total esteem) of TCLC part conceivably gotten by substituting firing angles αx=90□ and αx=180□, individually. In accompanying talk, base an incentive for impedances remains for its total esteem. Minimum inductive (Xind(min)>0) and capacitive (XCap(min)<0) TCLC part impedances conceivably resembled as

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

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

In a perfect world, XTCLC(αx) is controlled to be x ≈ α I)(XV LqxxTCLC , so base inverter voltage (invx ≈ 0V) conceivably acquired as resembled in (3). For this situation, switching misfortune and switching noise conceivably altogether lessened. A little Vinvx(min) is imperative to hold harmonic current made by TCLC part, to keep a resonance issue, and to refrain from mistuning firing angles. If loading capacitive present or inductive current is outside TCLC part compensating range, inverter voltage Vinvx will be insignificantly extended to furthermore build up compensation run.

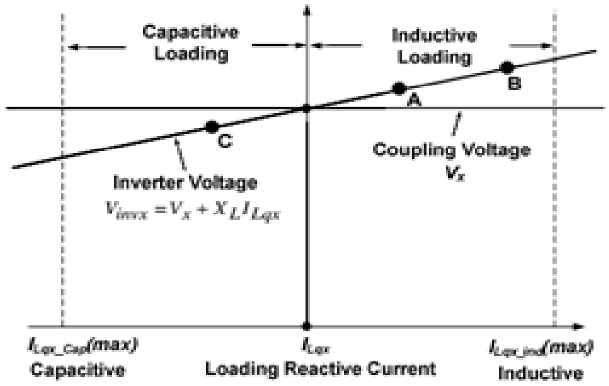
The coupling impedances for standard STATCOM and C-STATCOM, as exhibited up in Fig. 1, are settled as XL and XC-1/XL. Associations among load voltage Vx, Vinvx, load reactive current ILqx, and coupling impedance of conventional STATCOM and C-STATCOM conceivably conveyed as

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

$$V_{invx} = V_x - \left(X_C - \frac{1}{X_L}\right) I_{Lqx} \qquad (8)$$

Where, XL >> XC. Hinged on (3)- (8), V-I attributes of conventional STATCOM, C-STATCOM, and hybrid-STATCOM conceivably plotted as resembled in Fig. 2.

For conventional STATCOM as exhibited up in Fig. 2(a), required Vinvx is immense than Vx when loading is inductive. Interestingly, required Vinvx is humbler than Vx when loading is capacitive. Everything considered, required Vinvx is close to coupling voltage Vx, because of little advantage of coupling inductor L [5]-[8].



(a)

Fig 2:- V-I characteristic of (a) traditional STATCOM

For C-STATCOM as resembled in Fig. 2(b), it is exhiled that required Vinvx is lower than Vx under a little inductive loading range.

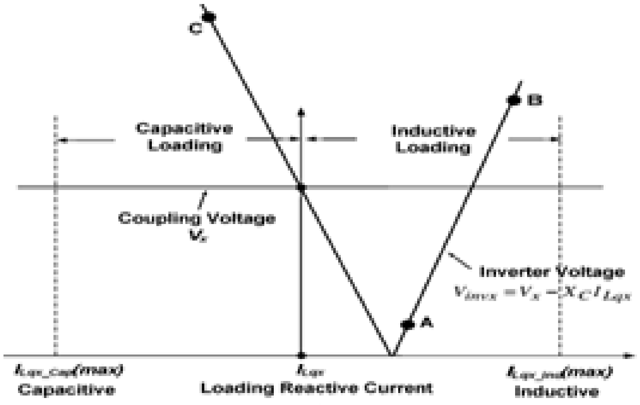
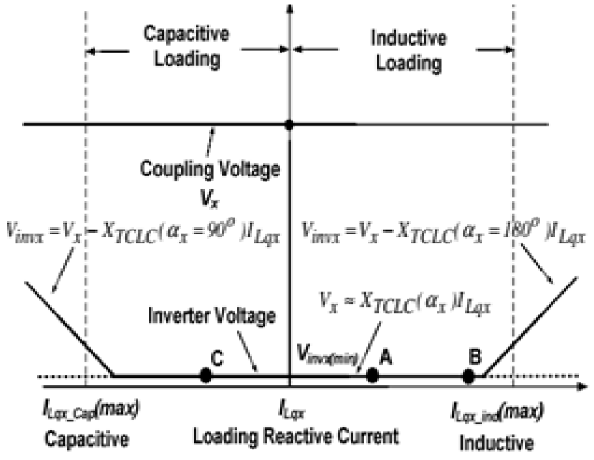


Fig 2:- V-I characteristic of, (b) C-STATCOM

The required Vinvx conceivably as low as zero when coupling capacitor can fully modify for loading reactive current. Then again, Vinvx is immense than Vx when loading is capacitive or outside its little inductive loading range. Thus, when loading reactive current is outside its arranged inductive range, required Vinvx is conceivably tremendous.

For proposed hybrid-STATCOM as exhibited up in Fig. 2(c), required Vinvx conceivably maintained at a low (least) level (Vinvx (min)) for a broad capacitive and inductive reactive current range.



(c)

Fig 2:- V-I characteristic of (c) hybrid-STATCOM

Besides, when loading reactive current is outside compensation scope of TCLC part, Vinvx will be somewhat expanded to additionally develop repaying range.

IV. PARAMETER DESIGN OF HYBRID-STATCOM

The proposed TCLC part is a recently proposed SVC structure which outlined hinged on consideration of 'Q' compensation run (for LPF and CPF) and anticipation of potential resonance issue (for Lc). active inverter part (DC-link voltage VDC) is intended to abstain from mistuning of firing point of TCLC part.

A. Design of CPF and LPF

The reason for TCLC part is to give a similar measure of compensating 'Q' Qcx, TCLC(αx) as 'Q' required by loads QLx yet with other way. Similarly, CPF and LPF are outlined hinged on maximum capacitive and inductive 'Q'. Compensating 'Q' Qcx range in term of TCLC impedance XTCLC(αx) conceivably resembled as

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

Where, Vx is RMS value of load voltage and XTCLC(αx) is impedance of TCLC part, which conceivably obtained from (4). In (9), when XTCLC(αx)=XCap(min)(αx =180o) and XTCLC(αx)=XInd(min)(αx =90o), TCLC part provides maximum capacitive and inductive compensating 'Q' Qcx(MaxCap) and Qcx(MaxInd), respectively.

$$Q_{cx(MaxCap)} = \frac{V_x^2}{X_{Cap(min)}(\alpha_x=180^0)} = -\frac{V_x^2}{X_{C_{PF}}-X_{L_C}} \tag{10}$$

$$Q_{cx(MaxInd)} = \frac{V_x^2}{X_{Ind(min)}(\alpha_x=90^0)} = -\frac{V_x^2}{\frac{X_{C_{PF}}X_{L_{PF}}}{X_{C_{PF}}-X_{L_{PF}}}+X_{L_C}} \tag{11}$$

Where minimum inductive impendence XInd(min) and capacitive impendence XCap(min) are obtained from (5) and (6), respectively.

B. Design of Lc

For energizing resonance issues, an adequate level of harmonic source voltages or currents must be available at or close to thunderous frequency. Similarly, Lc conceivably outlined.

The thyristors (Tx1 and Tx2) for each phase of TCLC part conceivably considered as a couple of bidirectional switches that produce low-arrange harmonic currents when switches change states. improved single-phase comparable circuit model of hybrid-STATCOM is resembled in Fig. 3.

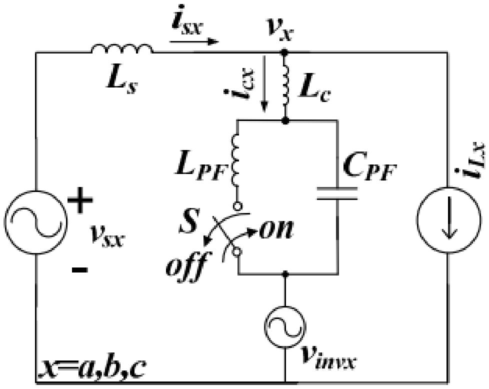


Fig 3:- Interpreted single-phase equivalent circuit model of hybrid-STATCOM

Referring to Fig. 3, when switch S is turned off, TCLC part is conceivably considered as Lc in series with CPF, which is called LC-mode. TCLC part harmonic impedances under LC-mode and LCL-mode at different harmonic order n conceivably plotted in Fig. 4 and resembled as

$$X_{LC,n}(n) = \left|\frac{1-(n\omega)^2 L_C C_{PF}}{n\omega C_{PF}}\right| \tag{12}$$

$$X_{LC,n}(n) = \left|\frac{n\omega(L_C+L_{PF})-(n\omega)^3 L_{PF}L_C C_{PF}}{1-(n\omega)^2 L_{PF}C_{PF}}\right| \tag{13}$$

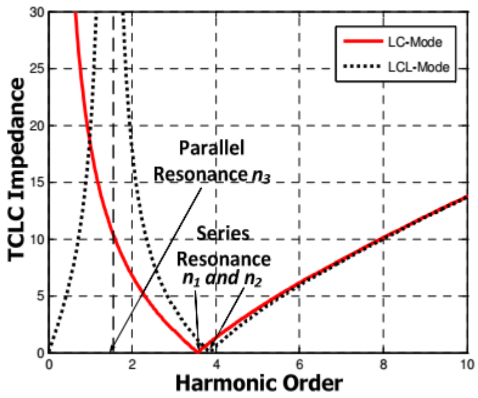


Fig 4:- TCLC impedance under different harmonic order

C. Design of VDC

Different with traditional VDC design method of STATCOM to compensate maximum load 'Q', VDC of Hybrid-STATCOM is design to solve firing angle mistuning problem of TCLC (i.e., affect 'Q' compensation) so that source 'Q' conceivably fully compensated. Reforming (3), Vinvx can also be resembled as

$$V_{incx} = V_x\left[1+\frac{V_x I_{Lqx}}{V_x^2/X_{TCLC}(\alpha_x)}\right] = V_x\left[1+\frac{Q_{Lx}}{Q_{cx,TCLC}(\alpha_x)}\right] \tag{14}$$

Where, QLx is load 'Q', Qcx, TCLC (αx) is TCLC part compensating 'Q', and Vx is RMS value of load voltage.

V. CONTROL SCHEME OF HYBRID-STATCOM

A control system for hybrid-STATCOM is proposed by planning control of TCLC part and active inverter part with goal that two sections can supplement each other's weaknesses and general execution of hybrid-STATCOM conceivably improved. Control procedure of hybrid-STATCOM is isolated into two sections for dialog: A. TCLC part control and B. Active inverter part control. Reaction time of hybrid-STATCOM is talked about to a limited extent C. control block diagram of hybrid-STATCOM is resembled in Fig. 5.

A. TCLC part control

Diverse with customary SVC control hinged on conventional meaning of 'Q' [2]-[3], to enhance its reaction time, TCLC part control is hinged on instantaneous pq theory [4]. TCLC part is mainly employed to repay reactive current with controllable TCLC part impedance XTCLC. Alluding to (3), to acquire base inverter voltage invx≈0V , XTCLC conceivably figured with Ohm's law as far as RMS estimations of load voltage (Vx) and load reactive current (ILqx).

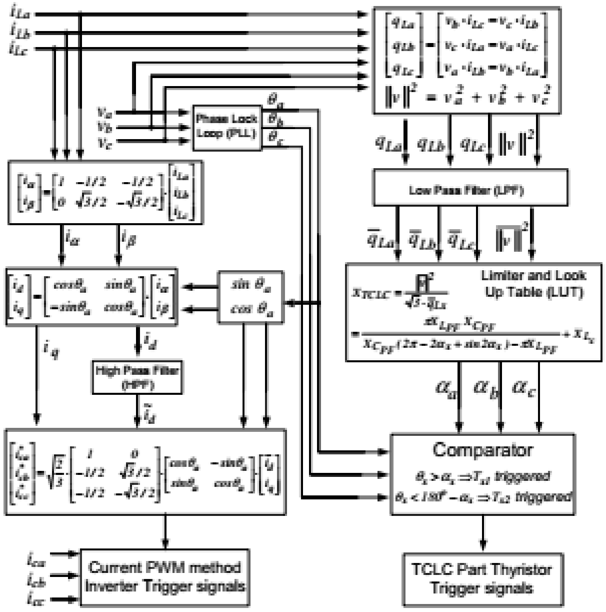


Fig 5:- Control block diagram of hybrid-STATCOM

However, to calculate XTCLC in real time, expression of XTCLC conceivably rewritten in terms of instantaneous values as

$$X_{TCLC} = \frac{V_x}{I_{Lqx}} = \frac{\|\bar{v}^2\|}{\sqrt{3}.\bar{q}_{Lx}} \qquad (15)$$

Where, v is norm of three-phase instantaneous load voltage and qLx is DC component of phase 'Q'.

B. Active inverter part control

In proposed control technique, instantaneous active and reactive current id-iq scheme [7] is actualized.

The figured icx* contains 'Q', lopsided power, and current harmonic components. By controlling compensating current icx to track its reference icx*, active inverter part can make up for load harmonic currents and enhance 'Q' compensation capacity and performance of TCLC part under various voltage conditions. icx* conceivably calculated as

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}}.\begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix}.\begin{bmatrix} \cos\theta_a & -\sin\theta_a \\ \sin\theta_a & \cos\theta_a \end{bmatrix}.\begin{bmatrix} \tilde{i}_d \\ i_q \end{bmatrix} \quad (16)$$

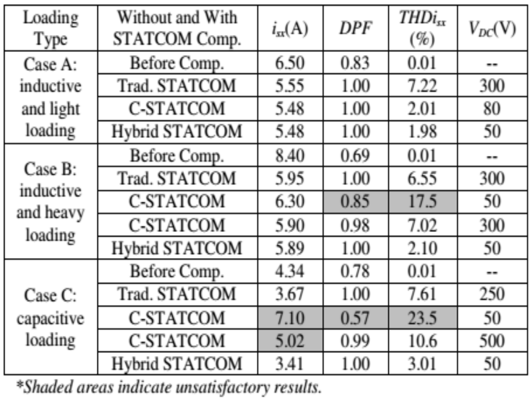
Where id and iq are instantaneous active and reactive current.

C. Response time of hybrid-STATCOM

The TCLC part has two back-to-back connected thyristors in each phase that are triggered alternately in every half cycle, so that control period of TCLC part is one cycle (0.02 s).

VI. SIMULATION RESULTS

In this section, simulation results among traditional STATCOM, C-STATCOM, and proposed hybrid-STATCOM are discussed and compared. The circuit implemented in [11] is used here for analysis. Detailed simulation results are summarized in Table 2.



Loading Type	Without and With STATCOM Comp.	i_{sx}(A)	*DPF*	*THDi*$_{sx}$ (%)	V_{DC}(V)
Case A: inductive and light loading	Before Comp.	6.50	0.83	0.01	--
	Trad. STATCOM	5.55	1.00	7.22	300
	C-STATCOM	5.48	1.00	2.01	80
	Hybrid STATCOM	5.48	1.00	1.98	50
Case B: inductive and heavy loading	Before Comp.	8.40	0.69	0.01	--
	Trad. STATCOM	5.95	1.00	6.55	300
	C-STATCOM	6.30	0.85	17.5	50
	C-STATCOM	5.90	0.98	7.02	300
	Hybrid STATCOM	5.89	1.00	2.10	50
Case C: capacitive loading	Before Comp.	4.34	0.78	0.01	--
	Trad. STATCOM	3.67	1.00	7.61	250
	C-STATCOM	7.10	0.57	23.5	50
	C-STATCOM	5.02	0.99	10.6	500
	Hybrid STATCOM	3.41	1.00	3.01	50

**Shaded areas indicate unsatisfactory results.*

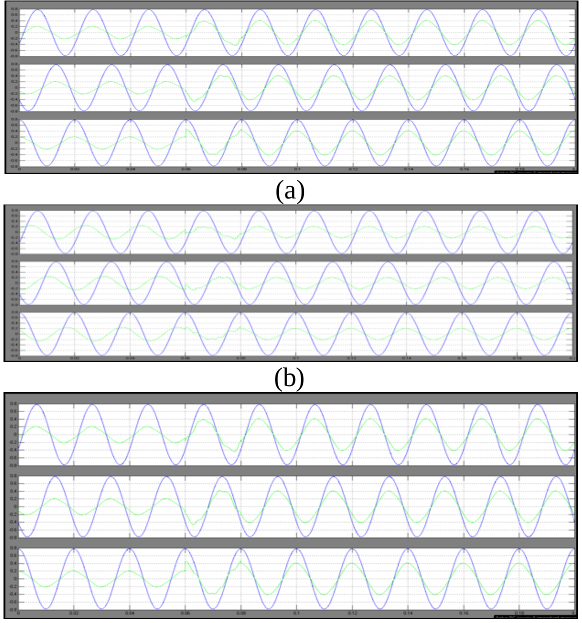
Table 2. Simulation Results for Inductive and Capacitive Reactive Power Compensation of Traditional Statcom, C-Statcom and Hybrid-Statcom

A. Inductive and light loading

When loading is inductive and light, traditional STATCOM requires a high DC-link voltage (Vdc> ·V2 −LL =269V, Vdc=300V) for compensation.

B. Inductive and heavy loading

To compensate for inductive and heavy loading, traditional STATCOM still requires a high DC-link voltage of Vdc=300V for compensation. Traditional STATCOM can obtain acceptable results (DPF = 1.00 and THDisx = 6.55%).



(a)

(b)

(c)

Fig 6:- Dynamic compensation waveforms of vx and isx by employing hybrid-STATCOM under (a) inductive load; (b) capacitive load; and (c) changing from capacitive load to inductive load

C. Capacitive loading

When loading is capacitive, with Vdc=250V (Vdc< −LL =· V269V2), compensation results of traditional STATCOM are acceptable, in which DPF and THDisx are compensated to unity and 7.61%.

D. Dynamic response of hybrid-STATCOM

Fig 7. shows dynamic performance of hybrid-STATCOM for different loadings compensation.

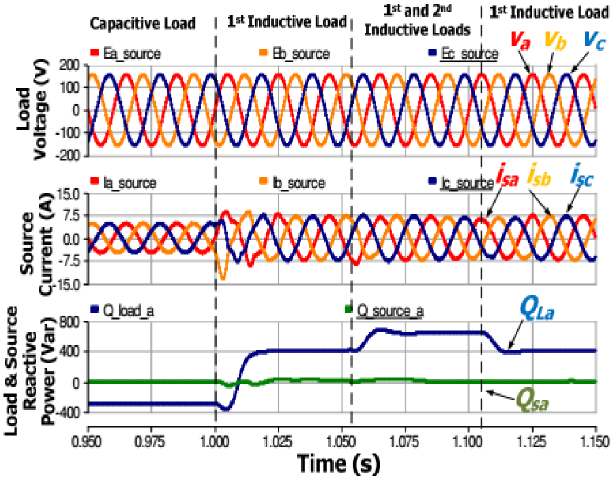


Fig 7:- Dynamic compensation waveforms of load voltage, source current, and load and source reactive powers by employing hybrid-STATCOM under different loadings cases

Meanwhile, fundamental 'Q' is remunerated to around zero notwithstanding amid transient time. In reasonable circumstances, load 'Q' only here and there all of a sudden changes from capacitive to inductive or other way around, and similarly hybrid-STATCOM can get great performance.

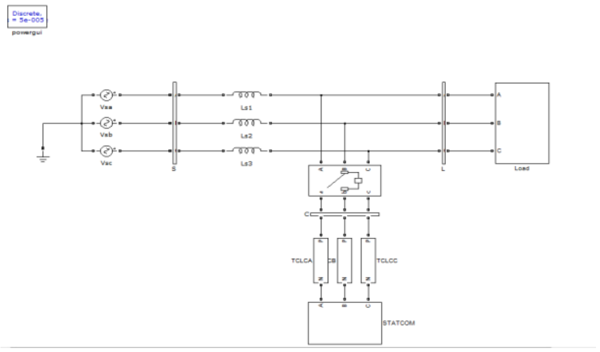


Fig 8:- Block diagram of simulation

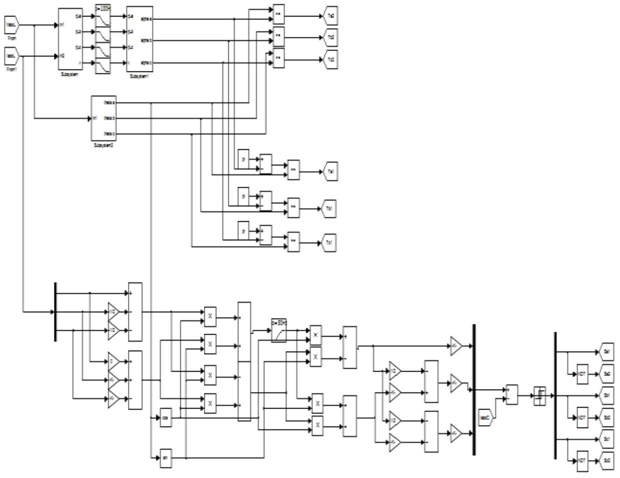


Fig 9:- Control block diagram of simulation

Different Situations	Comp.	i_{sx}(A)			*DPF*			*THDi*$_{sx}$ (%)		
		A	B	C	A	B	C	A	B	C
Inductive load	Before	7.13	7.14	7.34	0.69	0.70	0.70	1.1	1.2	1.2
	After	4.79	4.97	4.95	1.00	1.00	1.00	3.5	3.3	3.3
Capacitive load	Before	3.60	3.63	3.65	0.65	0.64	0.64	3.1	2.9	2.8
	After	2.92	2.80	2.85	1.00	1.00	1.00	5.4	5.4	5.2
Unbalanced loads	Before	4.80	3.83	5.74	0.36	0.69	0.64	2.0	1.4	1.2
	After	2.94	2.79	2.86	1.00	1.00	1.00	5.9	8.7	8.1
Voltage fault	Before	5.57	4.18	7.06	0.67	0.38	0.87	2.3	2.5	1.6
	After	4.30	3.98	4.00	0.99	1.00	0.99	4.7	9.3	6.2

Table 3. Experimental Compensation Results By Hybrid-Statcom (Vdc= 50v) Under Different System And Loading Situations

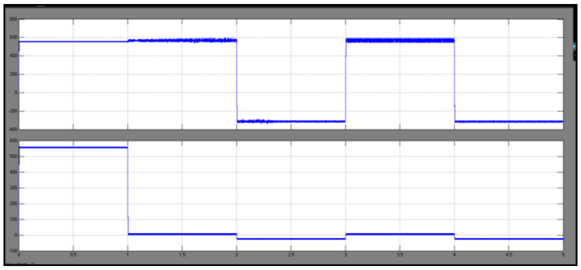
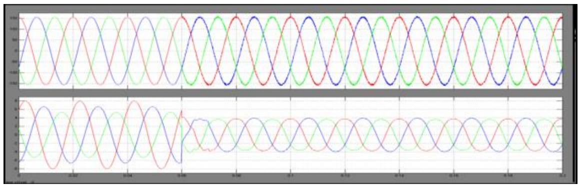


Fig 10:- Dynamic 'Q' compensation of phase a by employing hybrid-STATCOM



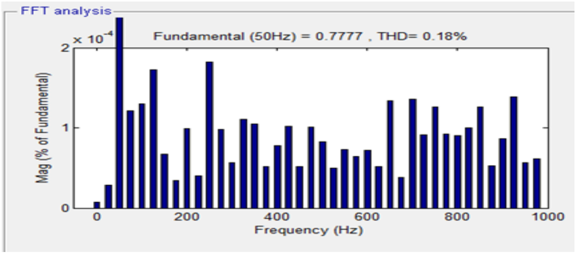


Fig 11:- Dynamic compensation waveforms ofvx and is xby employing hybrid-STATCOM under unbalanced loads

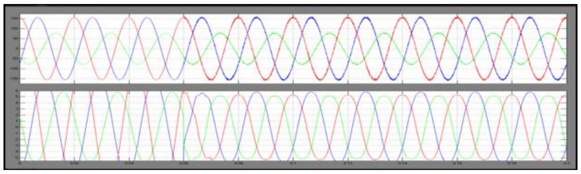


Fig 12:-Dynamic compensation waveforms of vx and is x by employing hybrid STATCOM under voltage fault condition

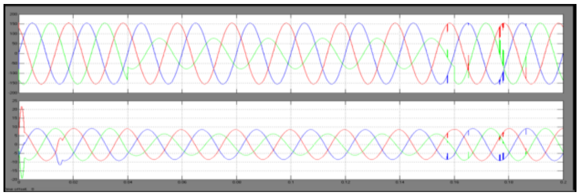


Fig 13:- Dynamic compensation waveforms of vx and is x by employing hybrid STATCOM during voltage dip

VII. CONCLUSIONS

A hybrid static synchronous compensator (hybrid-STATCOM) in a three-phase power transmission system that has a wide compensation range and low DC-link voltage is proposed in this paper. Differentiated and C-STATCOM and system configuration and V-I typical for hybrid-STATCOM are contrasted in this paper. Also, its parameter outline procedure is proposed hinged on consideration of 'Q' compensation range and suspicion of a potential resonance issue. What's more, control system of hybrid-STATCOM is created under different current and voltage conditions. By using five-level inverter is created and associated for injecting certifiable power of RES power into grid to diminish switching power loss, electromagnetic interference, and harmonic distortion accelerated by switching operation of PE devices. By using simulation results we can examine low DC-link voltage qualities and wide compensation range with incredible performance of hybrid-STATCOM.

REFERENCES

[1]. J. Dixon, L. Moran, J. Rodriguez, and R. Domke, "Reactive power compensation technologies: State-of-the-art review," Proc. IEEE, vol. 93, no. 12, pp. 2144–2164, Dec. 2005.

[2]. L. Gyugyi, R. A. Otto, and T. H. Putman, "Principles and applications of static thyristor-controlled shunt compensators," IEEE Trans. Power App. Syst., vol. PAS-97, no. 5, pp. 1935–1945, Sep./Oct. 1978.

[3]. T. J. Dionise, "Assessing the performance of a static var compensator for an electric arc furnace," IEEE Trans. Ind. Appl., vol. 50, no. 3, pp. 1619–1629, Jun. 2014.a

[4]. F. Z. Peng and J. S. Lai, "Generalized instantaneous reactive power theory for three-phase power systems," IEEE Trans. Instrum. Meas., vol. 45, no. 1, pp. 293–297, Feb. 1996.

[5]. L. K. Haw, M. S. Dahidah, and H. A. F. Almurib, "A new reactive current reference algorithm for the STATCOM system based on cascaded multilevel inverters," IEEE Trans. Power Electron., vol. 30, no. 7, pp. 3577–3588, Jul. 2015.

[6]. J. A. Munoz, J. R. Espinoza, C. R. Baier, L. A. Moran, J. I. Guzman, and V. M. Cardenas, "Decoupled and modular harmonic compensation for multilevel STATCOMs," IEEE Trans. Ind. Electron., vol. 61, no. 6, pp. 2743–2753, Jun. 2014.

[7]. V. Soares and P. Verdelho, "An instantaneous active and reactive current component method for active filters," IEEE Trans. Power Electron., vol. 15, no. 4, pp. 660–669, Jul. 2000.

[8]. M. Hagiwara, R. Maeda, and H. Akagi, "Negative-sequence reactive-power control by a PWM STATCOM based on a modular multilevel cascade converter (MMCC-SDBC)," IEEE Trans. Ind. Appl., vol. 48, no. 2, pp. 720–729, 2012.

[9]. B. Singh and S. R. Arya, "Back-propagation control algorithm for power quality improvement using DSTATCOM," IEEE Trans. Ind. Electron., vol. 61, no. 3, pp. 1204–1212, Mar. 2014.

[10]. M. C. Wong, C. S. Lam, and N. Y. Dai, "Capacitive-coupling STATCOM and its control," Chinese Patent for Invention, Granted, No. 200710196710.6, May 2011.

[11]. Lei Wang, Chi-Seng Lam, Member, and Man-Chung Wong, "A Hybrid-STATCOM with Wide Compensation Range and Low DC-Link Voltage", IEEE Transactions on Industrial electronics, No. 2016.2523922, December 2015.