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DESIGN ANALYSIS AND SIMULATION OF LINEAR CONTROLLER OF A HYBRIDE - STATCOM WITH WIDE COMPENSATION RANGE

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ABSTRACT—This paper proposes 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. Because of these prominent characteristics, the system costs can be greatly reduced. In this paper, the circuit configuration of hybrid-STATCOM is introduced first. Its *V–I* characteristic is then analyzed, discussed, and compared with traditional STATCOM and capacitive-coupled STATCOM (C-STATCOM). The system parameter design is then proposed on the basis of consideration of the reactive power compensation range and avoidance of the potential resonance problem. After that, a control strategy for hybrid-STATCOM is proposed to allow operation under different voltage and current conditions, such as unbalanced current, voltage dip, and voltage fault. Finally, simulation and experimental results are provided to verify the wide compensation range and low dc-link voltage characteristics and the good dynamic performance of the proposed hybrid- STATCOM.

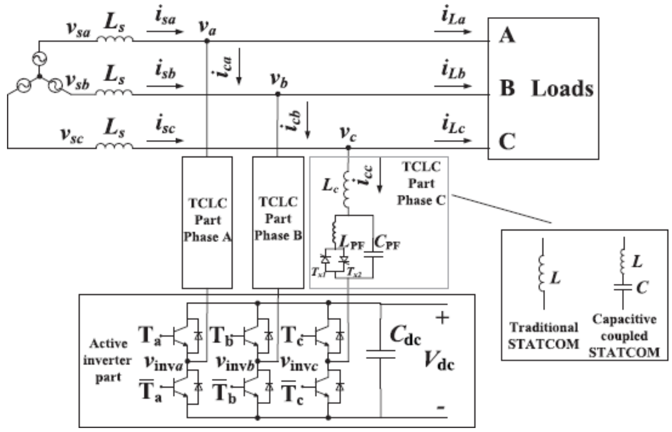
INDEX TERMS—Capacitive-coupled static synchronous compensator (C-STATCOM), hybrid-STATCOM, low dc-link voltage, STATCOM, wide compensation range.

INTRODUCTION

The big reactive present day in transmission structures is one of the maximum commonplace strength issues, which will increase transmission losses and lowers the stability of a electricity system [1]–[19]. Application of reactive power compensators is one of the answers for this problem. Static Var compensators (SVCs) are historically used to dynamically compensate reactive currents because the masses range every so often. However, SVCs suffer from many problems, together with resonance troubles, harmonic contemporary injection, and slow reaction [2], [3]. To conquer those risks, static synchronous compensators (STATCOMs) and lively energy filters (APFs) were advanced for reactive contemporary compensation with faster response, less harmonic present day injection, and higher overall performance [4]–[9]. However, the STATCOMs or APFs commonly require multilevel systems in a medium- or excessive-voltage level transmission device to reduce the excessive-voltage stress across every strength switch and dc-hyperlink capacitor, which drives up the preliminary and operational prices of the device and additionally will increase the manipulate complexity. Later, series-type capacitivecoupled STATCOMs (C-STATCOMs) have been proposed to reduce the gadget dc-link working voltage requirement [10], and other collection- kind hybrid structures that consist of different passive energy filters (PPFs) in collection with STATCOMs or APF structures (PPF-STATCOMs) have been implemented to power distribution systems [11]–[16] and traction strength structures [17]–[19]. However, C-STATCOMs and other series-kind PPFSTATCOMs include relatively slim reactive strength reimbursement ranges. When the specified compensating reactive electricity is out of doors their repayment ranges, their machine performances can substantially go to pot.

To enhance the working performances of the conventional STATCOMs, C-STATCOMs, and different PPF-STATCOMs, many one of a kind manipulate techniques were proposed, along with the on the spot p–q idea [4], [10], [11], [17]–[19], the instant d–q idea [5], [6], [14], the on the spot id–iq method [7], bad- and 0-collection manage [8], the again propagation (BP) control approach [9], nonlinear manipulate [12], Lyapunov-function-primarily based manipulate [13], on the spot symmetrical aspect concept [15], and hybrid voltage and present day manipulate [16].

To lessen the modern-day rating of the STATCOMs or APFs, a hybrid aggregate structure of PPF in parallel with STATCOM (PPF//STATCOM) become proposed in [20] and [21]. However, this hybrid compensator is dedicated for inductive loading operation. When it's far applied for capacitive loading repayment, it without difficulty loses its small active inverter rating traits. To enlarge the reimbursement variety and hold low contemporary score function of the APF, Dixon et al. [22] proposed some other hybrid combination structure of SVC in parallel with APF (SVC//APF) in 3-section distribution systems. In this hybrid structure, the APF is controlled to remove the harmonics and compensate for the small amounts of load reactive and unbalanced power left with the aid of the SVC. However, if this shape is applied in a medium- or excessive-voltage-stage transmission machine, the APF nonetheless requires a highly-priced voltage step-down transformer and/or multilevel structure. In addition, these parallel



connected- hybrid-STATCOM structures [15]–[17] may be afflicted by a resonance problem. To triumph over the shortcomings of various reactive strength compensators [1]–[22] for transmission systems, this paper proposes a hybrid-STATCOM that includes a

Fig. 1. Circuit configuration of the hybrid-STATCOM.

Thyristor-controlled LC (TCLC) part and an lively inverter part, as proven in Fig. 1. The TCLC part provides a wide reactive strength reimbursement variety and a large voltage drop between the machine voltage and the inverter voltage so that the lively inverter part can hold to operate at a low dc-hyperlink voltage stage. The small rating of the lively inverter part is used to enhance the performances of the TCLC element by soaking up the harmonic currents generated with the aid of the TCLC element, fending off mistuning of the firing angles, and preventing the resonance problem. The contributions of this paper are summarized as follows.

1. A hybrid-STATCOM is proposed, with the exceptional characteristics of a much wider repayment variety than C-STATCOM [10] and different series-kind PPFSTATCOMs [11]–[19] and a far lower dc-link voltage than traditional STATCOM [4]–[9] and other parallelconnected hybrid-STATCOMs [20]–[22].
2. Its V–I function is analyzed to provide a clean view of the blessings of hybrid- STATCOM in comparison with traditional STATCOM and C-STATCOM.
3. Its parameter layout method is proposed based totally on consideration of the reactive strength reimbursement range, prevention of the capability resonance hassle, and avoidance of mistuning of firing attitude.
4. A new control method for hybrid-STATCOM is proposed to coordinate the TCLC component and the energetic inverter component for reactive power reimbursement below exclusive voltage and cutting-edge situations, which includes unbalanced present day, voltage fault, and voltage dip.

The characteristics of various reactive electricity compensators and the proposed hybrid- STATCOM for the transmission machine are compared and summarized in Table I. In this paper, the machine configuration of the proposed hybrid-STATCOM is added in Section II. In Section III, the V–I characteristic of hybrid-STATCOM is proposed in comparison with conventional STATCOM and C-STATCOM. The parameter design and manipulate method of the hybrid-STATCOM are then proposed in Sections IV and V. Finally, the simulation (Section VI) and experimental results (Section VII) are furnished to show the huge reimbursement range and coffee dclink voltage traits and the dynamic overall performance of the proposed hybrid-STATCOM.

TABLE I
CHARACTERISTICS OF DIFFERENT COMPENSATORS FOR TRANSMISSION SYSTEM

	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

*Shaded areas indicate an unfavorable characteristic.

In energy gadget, real power and reactive electricity is managed via the voltage and phase attitude distinction among the sending quit and receiving quit respectively. Impedance of the transmission line also can be used to control real and reactive electricity. Flexible AC Transmission Systems (FACTS) are used to improve the energy switch capability of transmission line. FACTS is defined as 'Alternating present day transmission systems incorporating energy electronic based totally and other static controllers to enhance controllability and growth power switch functionality' [1]. FACTS Controller is described as 'a power digital based totally system and other static system that provide manage of one or extra AC transmission device parameters. They are labeled on the basis of their connection to the transmission line. They can be of series linked, shunt connected, mixed series-series related or blended shunt-collection related. Depending on the strength digital devices used to manipulate, FACTS controllers may be categorized as Variable Impedance kind and Voltage Source Converter (VSC) primarily based. Static VAR Compensator (SVC) comes underneath Variable Impedance type, while Static Synchronous Compensator (SSSC), etc. Are Voltage Source Converter based.

FACTS controllers provide voltage support at critical buses in the system (with shunt connected controllers) and regulate power flow in critical lines (with series connected controllers). The power electronic control is quite fast and this enables regulation both under steady state and dynamic conditions [2]. Static Synchronous Compensator (STATCOM) is basically a shunt connected FACTS controller. When the STATCOM is used in distribution networks, it is called DistributionSTATCOM (DSTATCOM). Main component of a STATCOM is a VSC, which is based on high power electronics technologies. S'I'A'I'COM injects reactive power to the transmission line when a voltage sag occurs. The amount of reactive power injected to the system can be controlled by changing the firing angle of the switch used in the VSC or by changing the value of DC voltage to the VSC. In this paper, a simulation study of the effect of STATCOM on the reactive power flow on a transmission system has been discussed. All the simulations are done on MATLAB/SIMULINK

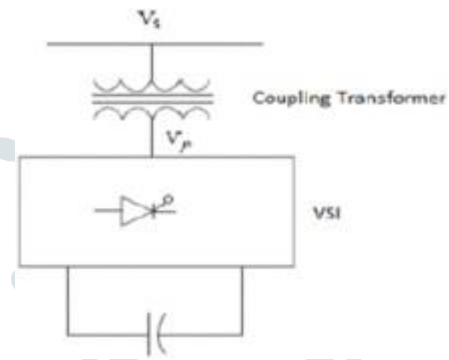
STATCOM – A REVIEW

STATCOM is a controlled reactive strength source. It presents the reactive electricity generation and absorption by using the use of a Voltage Source Converter (VSC).The lively electricity absorption or generation capability of the STATCOM is generally used under special occasions such as to beautify the constant nation and transient voltage manipulate, and to enhance the sag removal capability [3].

BASIC OPERATION

Voltage Source Converter converts an enter dc voltage into a three-segment output voltage at fundamental frequency. A STATCOM includes VSC, a coupling transformer and a DC voltage source (Capacitor or Battery).If a capacitor is used the consistent kingdom power change among the tool and AC machine could be reactive only, while a Battery is used energetic electricity additionally trade will takes region. Basic shape of STATCOM is shown in fig

BASIC STRUCTURE OF STATCOM



REACTIVE POWER CONTROL

There is a sturdy courting between voltage and reactive strength drift. The voltage in a distribution machine and to the purchasers must be maintained inside a sure variety across the rated device. Sudden load impacts or load needs beneath contingency running situations, while one or greater tie line circuits may be out of service, result in quick time or prolonged voltage dips.

$$\frac{\Delta Vs}{V} \approx \frac{\Delta Vr}{V} = \frac{\Delta Q}{Ssc}$$

Where,

Vs =Sending end voltage, Vr = Receiving end voltage, Q =Reactive Power, Ssc =Short circuit level of system

This method that the voltage regulation is same to the ratio of reactive strength trade to the quick circuit stage. This gives the apparent result that the receiving end voltage falls with the lower in machine brief circuit ability or boom in machine reactance. STATCOM is able to provide rated reactive present day below decreased voltage conditions. The capability to supply full capacitive current at low voltage makes it preferably appropriate for enhancing the temporary stability.

SAG MITIGATION:

The application of a shunt tool consisting of a STATCOM for mitigation of voltage sag has some benefits while in comparison with a sequence device, as a shunt devices can simultaneously be used for regular-kingdom voltage control, load strength oscillation damping and as a backup strength supply [5]. Some programs of STATCOM for voltage sag mitigation are provided in [6-8].

NEED FOR REACTIVE POWER COMPENSATION:

The foremost motive for reactive power repayment in a machine is: 1) the voltage regulation; 2) multiplied machine stability; 3) better utilization of machines linked to the gadget; four) lowering losses associated with the machine; and 5) to save you voltage disintegrate as well as voltage sag. The impedance of transmission strains and the want for lagging VAR by way of most 18machines in a generating machine results within the consumption of reactive strength, thus affecting the steadiness limits of the gadget in addition to transmission lines. Unnecessary voltage drops cause improved losses which needs to be furnished by the supply and in flip leading to outages within the line due to improved pressure on the system to carry this imaginary strength. Thus we can infer thatthe repayment of reactive energy not only mitigates these types of effects however also facilitates in better transient response to faults and disturbances. In current times there has been an expanded focus at the techniques used for the reimbursement and with better gadgets included within the technology, the compensation is made greater effective. It is very a whole lot required that the traces be relieved of the obligation to carry the reactive power, that is higher furnished close to the generators or the loads. Shunt reimbursement can be hooked up close to the weight, in a distribution substation or transmission substation.

CIRCUIT CONFIGURATION OF THE HYBRID-STATCOM

Fig. 1 suggests the circuit configuration of hybrid-STATCOM, in which the subscript x stands for section a, b, and c inside the following analysis. Vsx and vx are the supply and cargo voltages; isx, iLx, and icx are the source, load, and compensating currents, respectively. Ls is the transmission line impedance. The hybrid-STATCOM consists of a TCLC and an energetic inverter element.

The TCLC part consists of a coupling inductor Lc, a parallel capacitor CPF, and a thyristor- managed reactor with LPF. The TCLC component gives a huge and continuous inductive and capacitive reactive electricity reimbursement range this is managed with the aid of controlling the firing angles αx of the thyristors. The active inverter part is composed of a voltage source inverter with a dc-hyperlink capacitor Cdc, and the small score active inverter element is used to enhance the overall performance of the TCLC element. In addition, the coupling components of the conventional STATCOM and C- STATCOM also are presented in Fig. 1. Based on the circuit configuration in Fig. 1, the V–I traits of conventional STATCOM, C-STATCOM, and hybrid- STATCOM are as compared and mentioned.

V–I CHARACTERISTICS OF THE TRADITIONAL STATCOM, C- STATCOM, AND HYBRID-STATCOM

The motive of the hybrid-STATCOM is to provide the identical amount of reactive electricity as the loadings (QLx) consumed, however with the alternative polarity (Qcx = −QLx). The hybrid- STATCOM compensating reactive strength Qcx is the sum of the reactive energy QTCLC that is supplied with the aid of the TCLC element and the reactive power Qinvx that is provided by way of the lively inverter component. T

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

herefore, the relationship among *QLx*,*Q*TCLC, and *Q*invx can be expressed as

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

The reactive powers can also be expressed in terms of voltages and currents aswhere *X*TCLC(*αx*) is the coupling impedance of the TCLC part; *αx* is the corresponding firing angle; *Vx* and *V*invx are theroot-mean-squared (RMS) values of the coupling point and the inverter voltages; and *ILqx* and *Icqx* are the RMS value of the load and compensating reactive currents, where *ILqx* = −*Icqx*. Therefore, (2) can be further simplified as

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

where the TCLC part impedance *X*TCLC(*αx*) can be expressed as

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

where *XLc* , *XL*PF, and *XC*PF are the fundamental impedances of *Lc*, *L*PF, and *C*PF, respectively. In (4), it is shown that the TCLC part impedance is controlled by firing angle *αx*. And the minimum inductive and capacitive impedances (absolute value) of the TCLC part can be obtained by substituting the firing angles *αx* = 90◦ and *αx* = 180◦, 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

Ideally, XTCLC(αx) is managed to be Vx ≈ XTCLC(αx)ILqx, in order that the minimal inverter voltage (Vinvx ≈ zero) may be obtained as shown in (three). In this case, the switching loss and switching noise may be substantially decreased. A small inverter voltage Vinvx(min) is essential to take in the harmonic contemporary generated by the TCLC element, to save you a resonance trouble, and to avoid mistuning the firing angles. If the loading capacitive present day or inductive cutting-edge is out of doors

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

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

the TCLC part compensating variety, the inverter voltage Vinvx may be barely multiplied to similarly enlarge the reimbursement range.

The coupling impedances for traditional STATCOM and CSTATCOM, as shown in Fig. 1, are constant asXL andXC–1/XL. The relationships a few of the load voltage Vx, the inverter voltage Vinvx, the burden reactive present day ILqx, and the coupling impedance of traditional STATCOM and C-STATCOM can be expressed as

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

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

where *XL* >> *XC*. 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 larger than *Vx* when the loading is inductive. In contrast, the required *V*invx is smaller than *Vx* when the loading is Capacitive. Actually, the required inverter voltage Vinvx is close to the coupling voltage Vx, due to the small fee of coupling inductor L [5]–[8].

For C-STATCOM as shown in Fig. 2(b), it's miles shown that the desired Vinvx is decrease than Vx under a small inductive loading variety. The required Vinvx can be as little as 0 whilst the coupling capacitor can fully atone for the loading reactive contemporary. In evaluation, Vinvx is larger than Vx whilst the loading is capacitive or outdoor its small inductive loading variety. Therefore, whilst the loading reactive modern is outdoor its designed inductive variety, the specified Vinvx may be very big.

For the proposed hybrid-STATCOM as shown in Fig. 2(c), the desired Vinvx may be maintained at a low (minimum) degree (Vinvx(min)) for a huge inductive and capacitive reactive cutting-edge range. Moreover, while the loading reactive current is outside the repayment range of the TCLC component, the Vinvx could be slightly elevated to in addition enlarge the compensating variety. Compared with conventional STATCOM and C-STATCOM, the proposed hybrid-STATCOM has a superior V–I feature of a huge reimbursement variety with a low inverter voltage. In addition, three instances represented via factors A,B, and C in Fig. 2 are simulated in Section VI. Based on Fig. 1, the parameter design of hybrid-STATCOM is mentioned within the following phase.

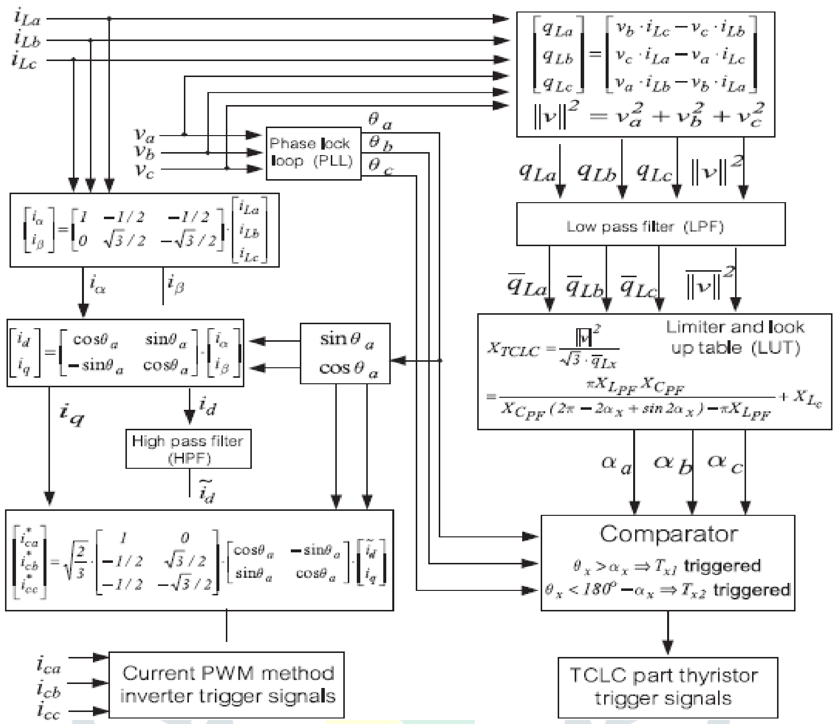


Fig.. Control block diagram of hybrid-STATCOM.

Based on (12), (13), (16), and (19), the system parameters *C*PF, *L*PF, *Lc*, and *V*dc of hybrid- STATCOM can be designed accordingly. In the following section, the control strategy of hybrid- STATCOM is proposed and discussed.

CONTROL STRATEGY OF HYBRID-STATCOM

In this phase, a control approach for hybrid-STATCOM is proposed via coordinating the manipulate of the TCLC element and the active inverter part so that the two elements can complement every different's risks, and the overall performance of hybrid-STATCOM can be improved. Specifically, with the proposed controller, the response time of hybrid-STATCOM can be quicker than SVCs, and the active inverter element can operate at decrease dc-link working voltage than the conventional STATCOMs. The control approach of hybrid-STATCOM is separated into two components for discussion: A. TCLC part control and B. Active inverter component manipulate. The response time of hybrid- STATCOM is discussed in element C. The control block diagram of hybrid-STATCOM is proven in Fig. Five.

TCLC Part Control

Different with the traditional SVC manipulate based at the traditional definition of reactive strength [2], [3], to enhance its reaction time, the TCLC element manipulate is based at the instantaneous pq idea [4]. The TCLC part is especially used to compensate the reactive cutting-edge with the controllable TCLC component impedance XTCLC. Referring to (three), to gain the minimal inverter voltage Vinvx ≈ zero, XTCLC may be calculated with Ohm's regulation in phrases of the RMS values of the burden voltage (Vx) and the burden reactive modern-day (ILqx). However, to calculate the XTCLC in actual time, the expression of XTCLC can be rewritten in phrases of immediately values as where _v_ is the norm of the three-phase instantaneous load voltage and ¯*qLx* is the dc component of the phase reactive power. The real-time expression of _v_ and ¯*qLx* can be obtained by (21) and (22) with low-pass filters

$$\|v\| = \sqrt{v_a^2 + v_b^2 + v_c^2}$$

$$\begin{bmatrix} q_{La} \\ q_{Lb} \\ q_{Lc} \end{bmatrix} = \begin{bmatrix} v_b \cdot i_{Lc} - v_c \cdot i_{Lb} \\ v_c \cdot i_{La} - v_a \cdot i_{Lc} \\ v_a \cdot i_{Lb} - v_b \cdot i_{La} \end{bmatrix}$$

In (21) and (22), *vx* and *qLx* are the instantaneous load voltage and the load reactive power, respectively. As shown in Fig. 5, a limiter is applied to limit the calculated *X*TCLC in (9) within the range of *X*TCLC > *X*ind(min) and *X*TCLC < *X*Cap(min)(*X*Cap(min) < 0). With the calculated *X*TCLC, the firing angle *αx* can be determined by solving (4). Because (4) is complicated, a look-up table (LUT) is installed inside the controller. The trigger signals to control the TCLC part can then be generated by comparing the firing angle *αx* with *θx*, which is the phase angle of the load voltage *vx*. *θx* can be obtained by using a phase lock loop (PLL). Note that the firing angle of each phase can differ if the unbalanced loads are connected [see (4) and (20)]. With the proposed control algorithm, the reactive power of each phase can be compensated, and the active power can be basically balanced, so that dc-link voltage can be maintained at a low level even under unbalanced load compensation.

Active Inverter Part Control

In the proposed control strategy, the instantaneous active and reactive current *id*–*iq* method [7] is implemented for the active inverter part to improve the overall performance of hybrid- STATCOM under different voltage and current conditions, such as balanced/unbalanced, voltage dip, and voltage fault. Specifically, the active inverter part is used to improve the TCLC part characteristic by limiting the compensating current *icx* to its reference value *i*∗ *cx* so that the mistuning problem, the resonance problem, and the harmonic injection problem can be avoided. The *i*∗ *cx* is calculated by applying the *id*–*iq* method [7] because it is valid for different voltage and current conditions. The calculated *i*∗ *cx* contains reactive power, unbalanced power, and current harmonic components. By controlling the compensating current *icx* to track its reference *i*∗ *cx*, the active inverter part can compensate for the load harmonic currents and improve the reactive power compensation ability and dynamic performance of the TCLC part under different voltage conditions. The *i*∗ *cx* can be calculated as

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

where *id* and *iq* are the instantaneous active and reactive current, which include dc components¯*id* and¯*iq*, and ac components ˜*I d* and˜*iq*.˜*id* is obtained by passing *id* through a high-pass filter. *id* and *iq* are obtained by

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

In (24), the currents (*iα* and *iβ*) in *α*–*β* plane are transformed from *a*–*b*–*c* frames by

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

where *iLx* is the load current signal.

Response Time of Hybrid-STATCOM

The TCLC element has lower back-to-again related thyristors in every phase which can be precipitated alternately in each half of cycle, in order that the manage length of the TCLC component is one cycle (zero.02 s). However, the proposed hybrid-STATCOM structure connects the TCLC component in collection with an instantaneous operated energetic inverter element, which could substantially improve its overall reaction time. With the proposed controller, the lively inverter part can restrict the compensating current icx to its reference price i∗ cx thru pulse width modulation (PWM) manage, and the PWM manage frequency is ready to be 12.Five kHz. During the brief state, the reaction time of hybrid- STATCOM can be one at a time mentioned in the following two instances. 1) If the burden reactive energy is dynamically converting in the inductive range (or inside the capacitive range), the reaction time of hybrid-STATCOM may be as fast as traditional STATCOM. 2) In evaluation, whilst the burden reactive energy adjustments from capacitive to inductive or vice versa, the hybrid- STATCOM may additionally take approximately one cycle to settle down. However, in realistic software, case 2 described above seldom takes place. Therefore, based totally at the above dialogue, the proposed hybrid-STATCOM can be taken into consideration as a fast-response reactive electricity compensator in which the dynamic performances of hybrid-STATCOM are proved with the aid of the simulation result (Fig. 6).

SIMULATION RESULTS

In this section, the simulation consequences among conventional STATCOM, C-STATCOM, and the proposed hybrid-STATCOM are mentioned and compared. The previous discussions of the specified inverter voltages (or dc-hyperlink voltage Vdc =√2 •√3 • Vinvx) for those three STATCOMs also are validated by means of simulations. The simulation research are completed with MATLAB.

When the loading is inductive and mild, traditional STATCOM requires a high dc-link voltage (Vdc >√2 •VL–L = 269V, Vdc = 300V) for reimbursement. After reimbursement, the source cutting-edge isx is reduced to five.55 A from 6.50 A, and the supply-side displacement electricity thing (DPF) becomes solidarity from 0.Eighty three. In addition, the source modern-day total harmonics distortion (THDisx) is 7.22% after compensation, which satisfies the global trendy [24] (THDisx < 15%).

For C-STATCOM, the coupling impedance contributes a big voltage drop between the burden voltage and the inverter voltage in order that the specified dc-hyperlink voltage can be small (Vdc = eighty V). The isx,DPF, and THDisx are compensated to 5.Forty eight A, unity, and a couple of.01%, respectively. For the proposed hybrid-STATCOM, the isx, DPF, and THDisx are compensated to five.48 A, unity, and 1.Ninety eight%, respectively. As discussed in the preceding segment, a low dc-link voltage (Vdc = 50 V) of hybrid-STATCOM is used to keep away from mistuning of firing angles, prevent resonance problems, and reduce the injected harmonic currents.

To catch up on the inductive and heavy loading, traditional STATCOM nevertheless requires a excessive dc-hyperlink voltage of Vdc = three hundred V for reimbursement. Traditional STATCOM can obtain applicable consequences (DPF = 1.00 and THDisx = 6.55%). The isx is decreased to 5.95 A from 8.40 A after reimbursement. With a low dc-hyperlink voltage (Vdc = 50 V), C-STATCOM can not offer nice compensation outcomes (DPF = 0.85 and THDisx = 17.5%). However, when the dc-hyperlink voltage is multiplied to Vdc = 300 V, the reimbursement effects (DPF = 1.00 and THDisx = 7.02%) are suitable and fulfill the worldwide widespread [24] (THDisx < 15%). The isx is decreased to

5.90 A from eight.Forty A after reimbursement. On the opposite hand, the proposed hybrid-STATCOM can still acquire applicable reimbursement results (DPF = 1.00 and THDisx = 3.01%) with a low dc- hyperlink voltage of Vdc = 50 V. The isx is reduced to 6.89 A from 8.40 A after reimbursement.

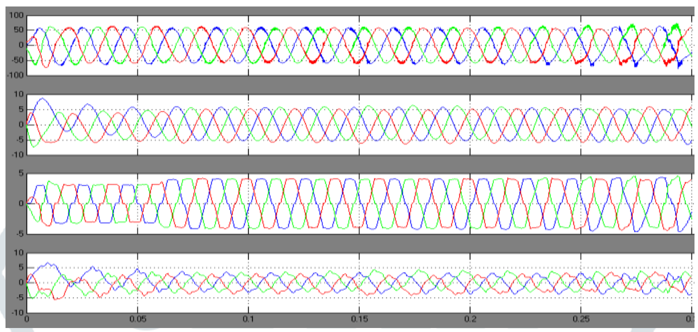


Fig 6. Dynamic compensation waveforms of source voltage, source current, and load current and compensating currents by applying hybrid-STATCOM.

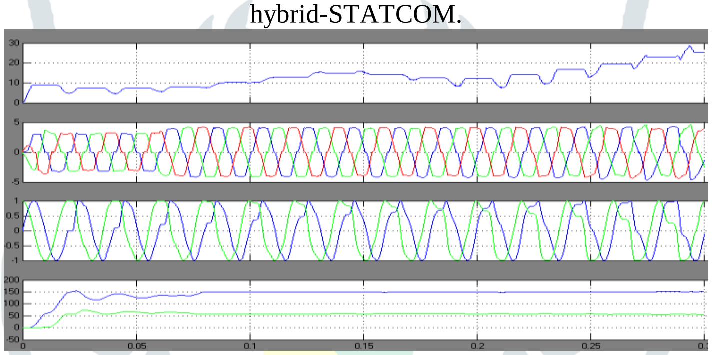


Fig 7. Dynamic compensation waveforms of dc bus voltage, load current sin cos angles and source active and reactive powers by applying hybrid-STATCOM.

CONCLUSION

In this paper, a hybrid-STATCOM in three-phase power system has been proposed and discussed as a cost-effective reactive power compensator for medium voltage level application. The system configuration and *V–I* characteristic of the hybrid-STATCOM were analyzed, discussed, and compared with traditional STATCOM and C-STATCOM. In addition, its parameter design method was proposed on the basis of consideration of the reactive power compensation range and prevention of a potential resonance problem. Moreover, the control strategy of the hybrid- STATCOM was developed under different voltage and current conditions. Finally, the wide compensation range and low dc-link voltage characteristics with good dynamic performance of the hybrid-STATCOM were proved by simulation results.

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