REACTIVE POWER COMPENSATION USING HYBRID STATCOM

Arif S. Tamboli
Student member, IEEE, M.Tech (Electrical Power Systems) Department of Electrical Engineering,
Rajarambapu Institute of Technology, Islampur-415414, India

Dr.H.T.Jadhav
Professor, Department of Electrical Engineering, Rajarambapu Institute of Technology, Islampur-415414, India

Abstract- **Now day, measure issue in the power system is maintaining the power quality. To maintain that power quality reactive power compensation is required. Maintaining the power quality under different loading condition and the under voltage sag and unbalanced current is important. For improving reactive power compensation Flexible AC transmission System (FACTS) devices is play important part in the system. SVC and STATCOM play important part in the reactive power compensation. Due to some drawbacks of the SVC, STATCOM is used in this paper. Traditional STATCOM have some drawbacks such slow response and low reactive power compensation range. Hence in this paper Hybrid STATCOM is used.**

Keywords- Reactive power compensation, FACTS devices, Traditional STATCOM, Hybrid STATCOM.

I. INTRODUCTION

In power system, quality of power is important aspects in day to day life for utility and consumer point. When the power quality is not sustained then large amount of losses can takes place which turns into the financial losses for both customer and the utility. Maintaining quality of power during normal condition as well as abnormal condition such as voltage dip or voltage sag condition is essential. Power quality contains both active and the reactive power. Reactive power compensation is required for maintaining the voltage regulation and maintaining power system stability [1]. Large reactive current in the transmission line is one important problem. Hence, to reduce that problem reactive power compensation is essential in the power system. Reactive power compensation is important for controlling the voltage profile and maintaining the quality of power. Voltage control in the electrical power system is required for proper operation of the equipment and reduces the transmission losses. To maintain the power system stability and reliability of system flexible AC transmission system (FACTS) devices are becoming more popular. FACTS devices are static devices which help for compensating reactive power. Traditionally, Static VAR compensator (SVC) has been used to solve this problem, but it has problem of current injection. Series connected type capacitive coupled were arranged to dc link operating voltage requirement. Passive power filters series with STATCOM used for the distribution purpose. C-STATCOM and series PPF STATCOM have low compensation range. Hence performance of the system reduces [2]. To reduce this problem STATCOM is used. Static synchronous compensator is connected in shunt to AC Power system for regulating the voltage by adjusting the active and reactive power. STATCOM is located to helps electricity network which has poor voltage regulation and poor power factor [2]-[5].

To overcome the shortcoming of reactive power compensation in the system Hybrid STATCOM is used in this paper. Hybrid STATCOM consists of the Active inverter part and thyristor controlled LC part.

II. CIRCUIT CONFIGURATION

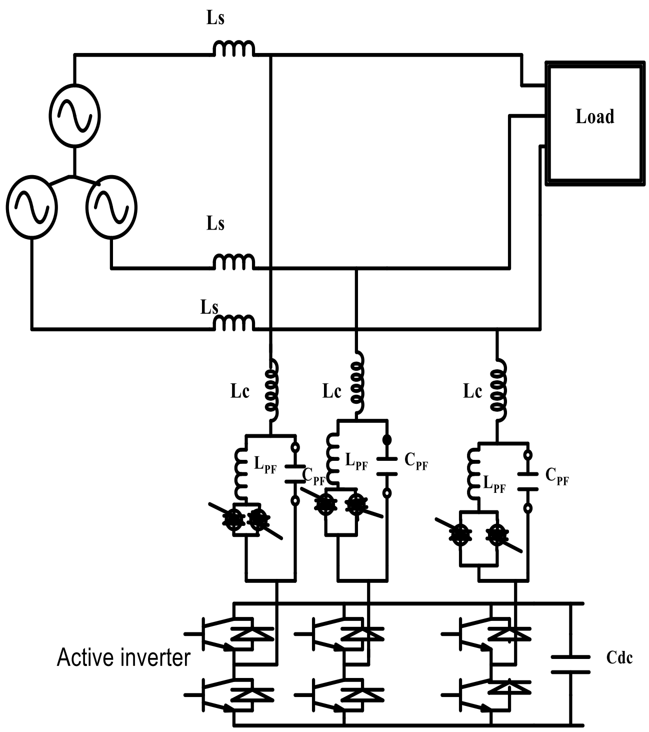

Fig.1. Diagram of hybrid STATCOM

Fig.1. shows the diagram of hybrid STATCOM.The hybrid STATCOM consist of the thyristor controlled LC part and active inverter part. In this $L_s$is the transmission line impedance and load is connected to the end of the transmission line. The combination of the thyristor controlled LC and Active inverter is directly connected to the transmission line at the common coupling point. TCLC part helps to provide large inductive and capacitive power range may be controlled by controlling the firing angle of the thyristor. The thyristor controlled LC part consists of the L_C as the coupling inductor, parallel connected capacitor $c_{PF}$and parallel to capacitor thyristor controlled reactor with the L_{PF}.

Thyristor controlled LC produce large inductive and capacitive power range that may be controlled by controlling the firing angles of the thyrisitor. The active inverter part consists of switches and DC capacitor C_{dc}. The active inverter is voltage source inverter which help to improve the performance of the Thyristor controlled LC part.

III. SINGLE PHASE EQUIVALENT MODEL OF HYBRID STATCOM

The equivalent model of hybrid STATCOM is shown in the Fig.2 In which two thyristor is connected in the antiparallel position and it acts like the bidirectional switches. When the switch is turn off, thyristor controlled LC part is considered as the $L_c$in the series with the C_{PF} which called the LC mode.When the switch is ON, L_{PF} is parallel with the C_{PF} and this combination is connected in series with the L_C which called the LCL mode.

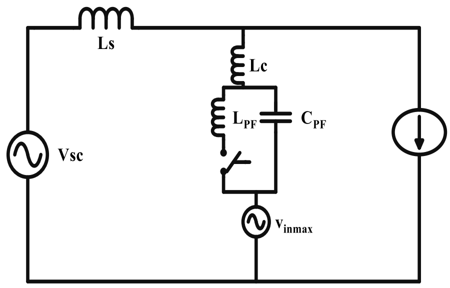

Fig.2. Equivalent model of hybrid STATCOM

The aim of the hybrid STATCOM is to supply the same quantity of reactive power is required to the load but with opposite polarity which is given by

$$Q_{CX} = -Q_{LX} \qquad (1)$$

Q_{LX} is the reactive power required by the load. Q_{CX} is the reactive power supply by the Combination of the thyristor controlled LC and Active inverter Part which is given by following equation

$$Q_{LX} = -Q_{CX} = -(Q_{TCLC} + Q_{inv}) (2)$$

Q_{TCLC} is the reactive power supplied by the Thyristor controlled LC part and $Q_{inv}$is the reactive power supplied by the Active inverter part. The reactive power can be given in term of the voltage and current as

$$Q_{LX} = V_X I_{Lqx} = -\left(X_{TCLC(\alpha_x)} I_{qcx}^2 + V_{invx} I_{cqx}\right) \quad (3)$$

Where $X_{TCLC}(\alpha_x)$ is the coupling impedance of the TCLC part. $\alpha_x$is the corresponding firing angle. $V_x$is the voltage at the coupling point and the $V_{invx}$is the inverter voltage.The harmonic impedance of the LC mode can be given in the following expression

$$X_{LC}\,(\mathrm{n}) = \frac{1-(n\omega)^2 L_C\, C_{PF}}{n\omega C_{PF}} \quad (4)$$

The harmonic impedance of the LCL mode can be givenas

$$X_{LC}\,(\mathrm{n}) = \frac{n\omega(L_C + L_{PF}) - (n\omega)^3 L_{PF} L_C\, C_{PF}}{1-(n\omega)^3 L_{PF} C_{PF}} \quad (5)$$

IV. PARAMETER OF HYBRID STATCOM

A. TCLC PART

Thyristor controlled LC Contains thyristor which is connected antiparallel to each other and series to that switch inductor L_{PF} is connected and parallel to that capacitor C_{PF} is connected. Inductor $L_c$is series connected to this combination.

i. Design of CPF and LPF

The compensating reactive power Q_{CX}range in term of TCLC impedance $X_{TCLC}(\alpha_x)$ can be expressed as

$$Q_{CX,}X_{TCLC}(\alpha_x) = \frac{V_x^2}{X_{TCLC(\alpha_X)}} \qquad (6)$$

Where,Vx is the RMS value of the load voltage and $X_{TCLC}(\alpha_x)$ is the impedance of the TCLC part.

The TCLC part supply the maximum capacitive and inductive compensating reactive power Qcx(MaxCap) and Qcx(MaxInd) respectively,

$$Q_{CX(Cap)} = \frac{V_x^2}{X_{C_{PF}} - X_{L_C}} (7)$$

Equation can be obtained as

$$Q_{CX(Ind)} = \frac{V_x^2}{\frac{X_{L_{PF}} X_{C_{PF}}}{X_{C_{PF}} - X_{L_{PF}}} + X_{L_C}} \qquad (8)$$

The parallel connected capacitor C_{PF} and inductor L_{PF} can be designed

$$C_{PF} = \frac{Q_{LX(Ind)}}{\omega^2 Q_{LX(Ind)} L_C + \omega V_x^2} \qquad (9)$$

L_{PF} can be obtained as

$$L_{PF} = \frac{V_x^2 + \omega L_C Q_{LX(Cap)}}{-\omega Q_{LX(Cap)} + \omega^3 L_c C_{PF} Q_{LX(cap)} + \omega^2 V_x^2 C_{PF}} (10)$$

ii. Design of Lc

The TCLC impedances under LC mode and LCL mode at different harmonic order n can be expressed as

$$X_{LC}\,(\mathrm{n}) = \frac{1-(n\omega)^2 L_C\, C_{PF}}{n\omega C_{PF}} \qquad (11)$$

LCL mode expressed as

$$X_{LC\,L}(\mathrm{n}) = \frac{n\omega(L_C + L_{PF}) - (n\omega)^3 L_{PF} L_C\, C_{PF}}{1-(n\omega)^3 L_{PF} C_{PF}} (12)$$

Lc can be expressed as

$$L_C = \frac{1}{(\omega n1)^2 C_{PF}} \qquad (13)$$

$$L_C = \frac{1}{\sqrt{(\omega n2)^2 C_{PF} - {}^{1}/_{L_{PF}}}} \qquad (14)$$

V. CONTROL METHOD OF HYBRID STATCOM-

Control method of Hybrid STATCOM is arranged with the combination of the TCLC and Active inverter system is shown in the Fig.3These two parts reduces the disadvantages of each other's. Control method of Hybrid STATCOM discuss in the two parts as follows

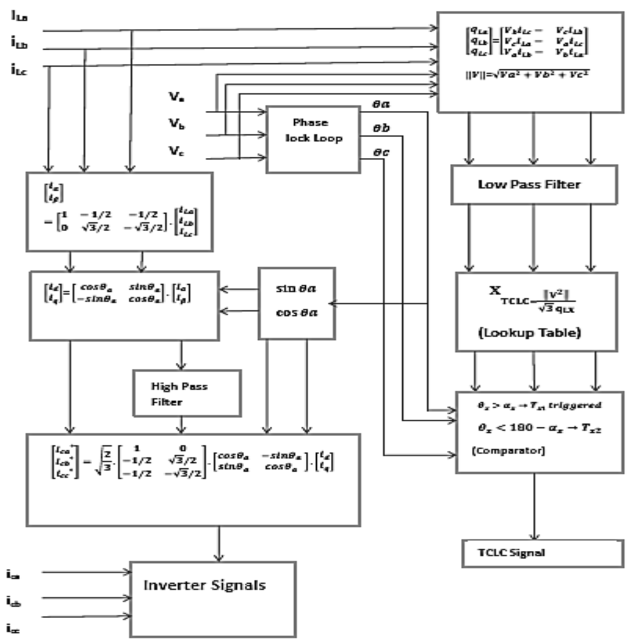

Fig.3. control Block Diagram.

A. TCLC PART CONTROL

Traditionally SVC based on the conventional definition of the reactive power. The TCLC part based on the instantaneous pq theory. TCLC is help for compensating reactive current with controllable TCLC part impedance. X_{TCLC} can be calculated with ohms law with RMS value of load voltage and load current. X_{TCLC} can be expressed in terms of [3], [4]

$$Q_{CX,} X_{TCLC}(\alpha_x) = \frac{V_x^{2}}{X_{TCLC(\alpha_X)}} \qquad (15)$$

Where, Vx is the RMS value of the load voltage and $X_{TCLC}(\alpha_x)$ is the impedance of the TCLC part.

B. ACTIVE INVERTER PART

Active inerter is electronic device which connected shut to the system. Active inverter system consists of voltage source inverter in which $C_{dc}$is dc link capacitor is connected [5]. This active inverter part helps to supply the ac voltage to line or helps to inject missing voltage to the line. The control strategy is based on the instantaneous active and reactive current id-iq method [6], [7].

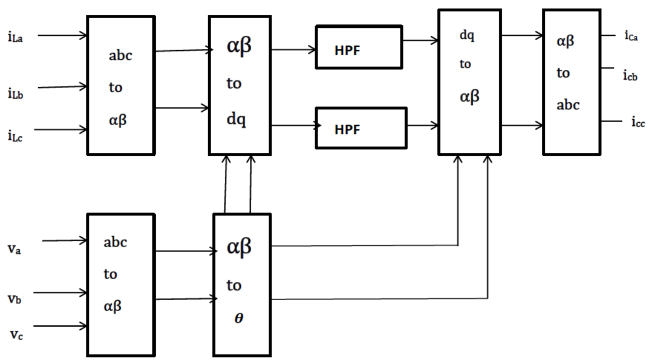

Fig.4. Control of Active inverter part

VI. V-I CHARACTERISTIC

A. V-I Characteristic of Traditional STATCOM

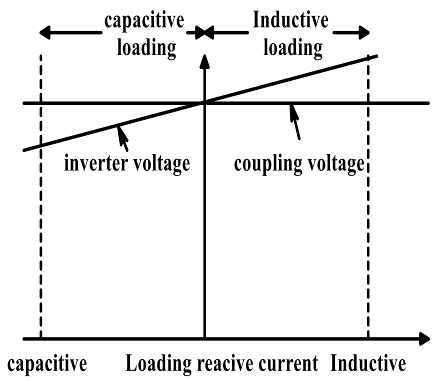

Fig.5.VI Characteristic of Traditional STATCOM

The characteristic of the traditional STATCOM in which inductive loading and capacitive loading is shown in Fig.5. Coupling voltage is reference voltage above and below which loading is decided.

The required inverter voltage $v_{invex}$is greater than $v_x$when the loading is inductive. The demanded $v_{invex}$is lower than $v_x$when loading is capacitive. The demanded inverter voltage is near to the coupling voltage.

B. V-I Characteristic of Hybrid STATCOM

The VI characteristic of Hybrid STATCOM is shown in Fig.6; the required inverter voltage is kept at Lowlevel for greater inductive and capacitive reactive current.

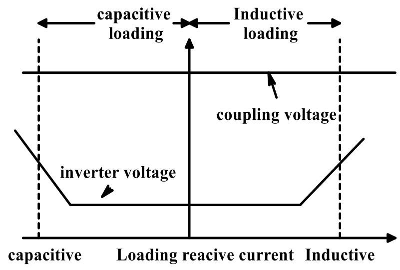

Fig.6. VI Characteristic of Hybrid STATCOM

VII. SIMULATION RESULT

A. During Voltage Dip

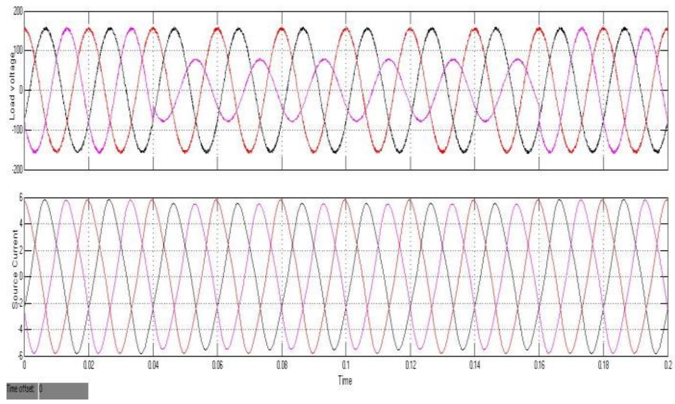

Fig.7. Load voltage and source current during voltage dip

Fig.7 shows the load voltage and source current of hybrid STATCOM during the voltage dip.Due to the voltage dip sudden decrease of the voltage takes place, which is shown in the above waveform. Voltage dip takes place for the shorter period of time after that STATCOM compensate the reactive power and waveform gets pure sin wave.

B. During Unbalanced Current

Fig.8shows the load voltage and source current during unbalanced current. Unbalanced occurs at the source side, hence source current waveform gets distorted for short starting period. Load voltage gets pure sine wave due to reactive power compensation.

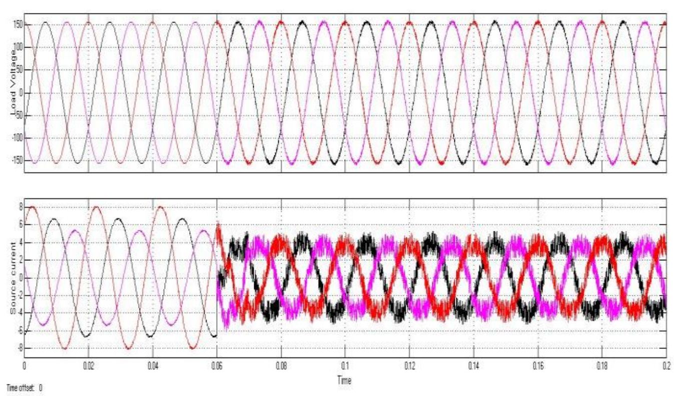

Fig.8. Load voltage and source current during unbalanced current

TABLE I shows the current condition after and before compensation.

TABLE I
Current During Different Condition

Different situation	compensation	Current (ampere)		
		A	B	C
Unbalanced current	Before	4.80	3.83	5.74
	After	2.94	2.79	2.86

C. During Fault Condition

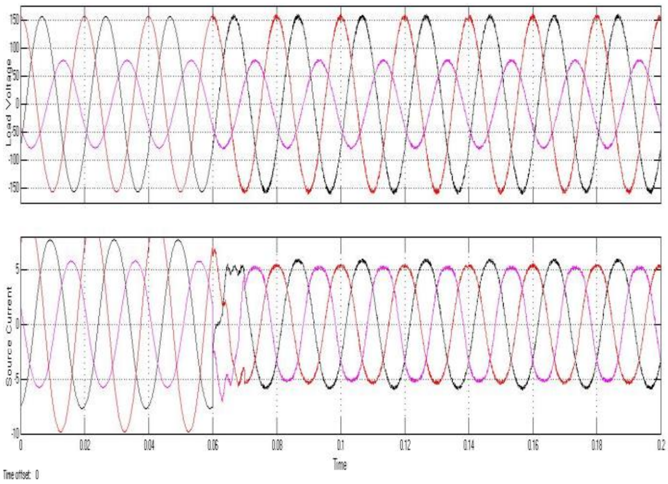

Fig.9.Load voltage and source current during fault condition

The waveform of the load voltage and source current during fault condition is shown in Fig.9. Fault is occurs on the one phase of the system and waveform gets distorted. Aftersome time STATCOM start operation and gets the pure sin wave at the source current as shown in the figure.

TABLE II shows the power factor of different loading condition before and after the compensation.

TABLEII
Power Factor during different condition

Different situation	compensation	Power factor		
		A	B	C
Inductive load	Before	0.69	0.70	0.70
	After	0.92	0.92	0.92
Capacitive load	Before	0.65	0.64	0.64
	After	0.95	0.95	0.95

Fig.10. Shows the load voltage and source reactive power under different loading condition

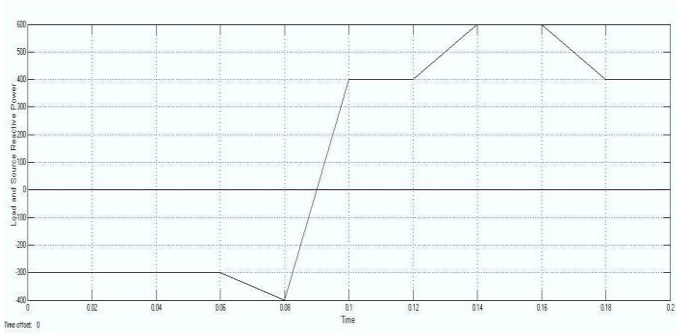

Fig.10.Load voltage and source reactive power

VIII. CONCLUSION

Simulation of Hybrid STATCOM is completed using the MATLAB Simulink in this paper. From the simulation the performance of the hybrid STATCOM is understand. Hybrid STATCOM is tested during voltage dip and unbalanced current conditions. The reactive power compensation capability of the hybrid STATCOM is very high than other STATCOM.

REFERENCES

[1] C. Kumar and M. Mishra, "An improved hybrid DSATCOM topology to compensate reactive and nonlinear loads," IEEE Trans. Ind. Electron., vol. 61, no. 12, pp. 65176527,Dec. 2014.

[2] K.-W. Lao, N. Dai, W.-G. Liu, and M.-C. Wong ,"Hybrid power quality compensator with minimum DC operation voltage design for high-speed traction power systems," IEEE Trans. Power Electron., vol. 28, no. 4,pp. 20242036, Apr. 2013.

[3] F. Z. Peng and J. S. Lai, "Generalized instantaneous reactive power theory for three-phase power systems," IEEE Trans. Inst rum.Meas., vol. 45, no. 1, pp. 293297,Feb. 1996.

[4] 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. 660669, Jul. 2000.

[5] 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. 21442164,Dec. 2005.

[6] A.Varschavsky, J. Dixon, M. Rotella, and L. Moran, "Cascaded nine level inverter for hybrid-series active power filter, using industrial controller," IEEE Trans. Ind. Electron., vol. 57, no. 8, pp. 2761–2767,Aug. 2010.

[7] Hirofumi Akagi, and Kohei Isozaki, "A Hybrid Active Filter for a Three-Phase 12-Pulse Diode Rectifier Used as the Front End of a Medium-Voltage Motor Drive," IEEE Transactions On Power Electronics, vol. 27, no. 1, January 2012.