International Journal of Research in Engineering, Science and Management
Volume-2, Issue-11, November-2019
www.ijresm.com | ISSN (Online): 2581-5792

A Hybrid-STATCOM with Wide Compensation Range

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***Abstract*: The hybrid-STATCOM consists of a thyristor controlled LC part (TCLC) and an active inverter part. The TCLC part provides a wide reactive power compensation range and a great voltage drop between the system voltage and the inverter voltage so that the active inverter part can continue to operate at a small DC-link voltage level. The small rating of the active inverter part is used to pick up the performances of the TCLC part by absorbing the harmonic currents generated by the TCLC part, avoiding mistuning of the firing angles, and preventing the resonance problem. Because of these characteristics, the system costs can be significantly condensed. The circuit arrangement of hybrid-STATCOM is introduced first. The hybrid-STATCOM is estimated to allow operation under diverse voltage and current conditions, such as unbalanced current, voltage dip, and voltage fault. A hybrid-STATCOM is proposed, with the distinctive characteristics of a much wider compensation range and a much lower DC-link voltage. The system parameter design is then projected on the basis of consideration of the reactive power compensation range and prevention of the potential resonance problem.**

***Keywords*: Capacitive-coupled static synchronous Compensator (C-STATCOM), hybrid static synchronous compensator (hybrid-STATCOM), static synchronous compensator (STATCOM).**

1. Introduction

Power Generation and Transmission is a composite process requiring the working of many components of the power system in tandem to maximize the output. One of the main components to form a main part is the reactive power in the system. It is required to maintain the voltage to distribute the active power through the lines. To improve the performance of ac power systems, we need to control this reactive power in an efficient way and this is known as reactive power compensation. Reactive power compensation embraces a wide and different field of both system and customer problems, especially related with power quality issues, since most power quality problems can be attenuated with an adequate control of reactive power [1]. Reactive power compensation is main for controlling the voltage profile and maintaining the quality of power. Voltage control in the electrical power system is required for appropriate operation of the equipment and reduces the transmission losses [2]. To maintain the power system stability and reliability of system flexible AC transmission system (FACTS) devices are becoming more accepted. FACTS devices are static devices which assist for compensating reactive power. Traditionally, Static VAR compensator (SVC) has been used to solve this problem, but it has problem of harmonic current injection, resonance problem [3]. Then to beat these disadvantages of SVC, STATCOM is used. But it has also required multilevel inverter therefore circuit complexity is increased [4]. Later, Capacitive-coupled STATCOM were proposed to minimize the DC-link voltage, but it contain relatively narrow reactive power compensation range. To overcome this advantages two hybrid combination structure of PPF in parallel with STATCOM and APF in parallel with SVC was proposed but these two parallel connected hybrid structures may suffer from resonance problem [5]-[6].

To beat the shortcomings of different reactive power compensators for transmission systems, a hybrid-STATCOM is proposed. Hybrid STATCOM consists of the Active inverter part and thyristor controlled LC part. The hybrid-STATCOM consists of a thyristor-controlled LC part (TCLC) and an active inverter part. The TCLC part provides a wide reactive power compensation range the small rating of the active inverter part is used to pick up the performances of the TCLC part by absorbing the harmonic currents generated by the TCLC part, avoiding mistuning of the firing angles, and preventing the resonance problem [7].

2. Details of implementation

The circuit configuration of hybrid-STATCOM is shown in Fig. 1, in which the subscript "x" stands for phase a, b, and c. V_{sx} and V_x are the source and load voltages; i_{sx}, i_{Lx}, and i_{cx} are the source, load, and compensating currents, correspondingly. Ls is the transmission line impedance. The hybrid-STATCOM is made of a TCLC and an active inverter part. The TCLC part is consist of a coupling inductor L_C, a parallel capacitor CPF, and a thyristor-controlled reactor with LPF. The TCLC part provides a broad and continuous inductive and capacitive reactive power compensation range that is controlled by controlling the firing angles of the thyristors. The TCLC part provides a broad reactive power compensation range and a large voltage drop between the system voltage and the inverter voltage so that the active inverter part may continue to operate at a low DC-link voltage level. The active inverter part is composed of a voltage source inverter with a DC-link capacitor

Cdc, and the little rating active inverter part is used to improve the performance of the TCLC part. The small rating of the active inverter part is used to improve the performances of the TCLC part by absorbing the harmonic currents generated by the TCLC part, avoiding mistuning of the firing angles, and preventing the resonance problem.

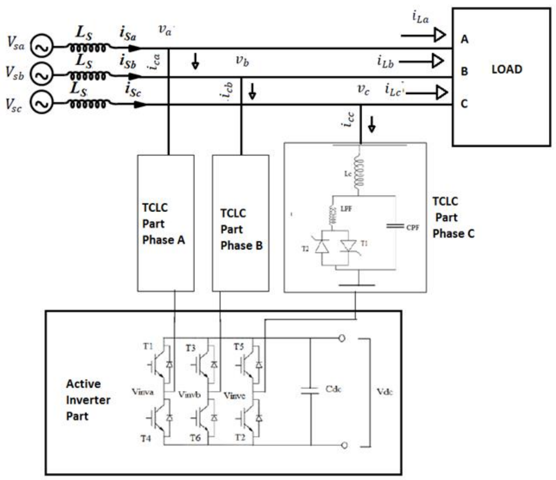

Fig. 1. Circuit configuration of hybrid STATCOM

3. Control Strategy for Hybrid Statcom

A. TCLC part control with p-q theory

To improve its response time, the TCLC part control is based on the instantaneous pq theory [8]. The TCLC part is mostly used to compensate the reactive current with the controllable TCLC part impedance X_{TCLC}.

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

To obtain the smallest amount inverter voltage $V_{invx} \cong 0$, X_{TCLC} can be calculated with Ohm's law in terms of the RMS values of the load voltage (V_x) and the load reactive current (I_{Lqx}). However, to compute the X_{TCLC} in real time, the expression of X_{TCLC} can be rewritten in terms of instantaneous values as

$$X_{TCLC} = \frac{V_x}{I_{Lqx}} = \frac{\overline{\|V\|^2}}{\sqrt{3}.\bar{q}_{Lx}}$$

Where $\|\bar{V}\|$the average of the three is-phases instantaneous load voltage and $\overline{q_{Lx}}$ is the DC component of the phase reactive power. The real-time expression of $\|\bar{V}\|$ and $\overline{q_{Lx}}$ can be obtained by subsequent equation with low-pass filters.

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

$$\begin{bmatrix} q_{La} \\ q_{Lb} \\ q_{Lc} \end{bmatrix} = \begin{bmatrix} v_{b.i_{Lc}} - V_{c.i_{Lb}} \\ v_{c.i_{La}} - V_{a.i_{Lc}} \\ v_{a.i_{Lb}} - V_{b.i_{La}} \end{bmatrix}$$

In above equation V_x and q_{Lx} are the instantaneous load voltage and the load reactive power, correspondingly. As shown in Fig 3.1, a limiter is useful to limit the calculated X_{TCLC} in 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 α_x can be resolute by solving

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

Because above equation is complex, a look-up table (LUT) is installed inside the controller. The trigger signals to manage the TCLC part can then be generated by comparing the firing angle $\alpha_x$with θ_x, which is the phase angle of the load voltage Vx.θ_x Can be obtained by means of a phase lock loop (PLL). Note that the firing angle of each phase can be different if the unbalanced loads are connected. With the projected control algorithm, the reactive power of each phase can be compensated and the active power can be balanced, so that DC-link voltage can be maintained at a low level even under unbalanced load compensation.

B. Active inverter part control with i_d-i_q theory

In the proposed control strategy, the instantaneous active and reactive current i_d-i_q method [9] is implemented for the active inverter part to get better the overall performance of hybrid-STATCOM under different voltage and current conditions, such as balanced and unbalanced and voltage fault. The active inverter part is used to improve the TCLC part characteristic by preventing the compensating current i_{cx} to its reference value i_{cx}^* so that the mistuning problem, the resonance problem, and the harmonic current injection problem can be avoided. The i_{cx}^* is designed by applying the i_d-i_q method because it is valid for dissimilar voltage and current conditions.

The calculated i_{cx}^* contains reactive power, unbalanced power, and current harmonic components. By calculating 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 performance of the TCLC part under diverse voltage conditions.

The i_{cx}^* can be calculated as

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

.

Where id and iq are the instantaneous active and reactive current, which contain DC components $\bar{i_d}$and$\bar{i}_q$, and AC components$\tilde{i}_d$ and $\tilde{i}_q$,$\tilde{i}_d$ is obtained by passing i_d through a high-pass filter. i_d & i_q Are obtained by

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

In above equation, the currents (i_α *and* i_β) in $\alpha - \beta$ plane are transformed from a-b-c frames by,

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

Where, i_{Lx} is the load current signal.

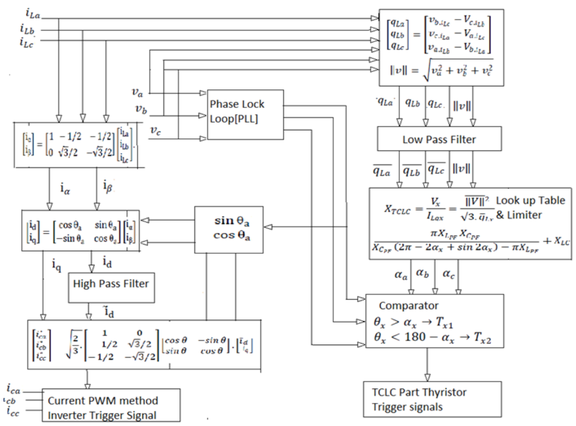

Fig. 2. Control strategy for hybrid STATCOM

C. *Performance Analysis (Simulation)*

The Matlab simulation of without statcom and hybrid Statcom consist of three phase voltage source is connected to load. The three different loads are used.

1. Light Inductive loading
2. Capacitive loading
3. High Inductive loading
4. Simulation model without STATCOM

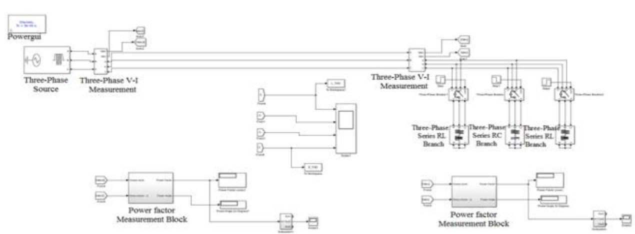

Fig. 3. Simulation model of Three Phase System without Hybrid STATCOM

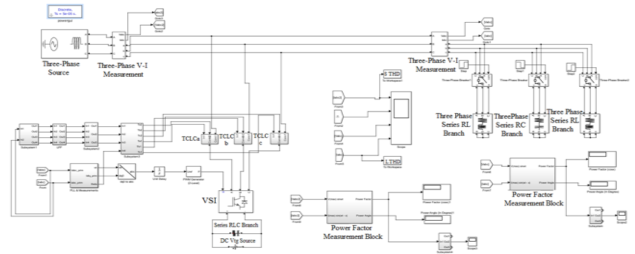

Fig. 4. Simulation model of Three Phase System with Hybrid STATCOM

4. Results

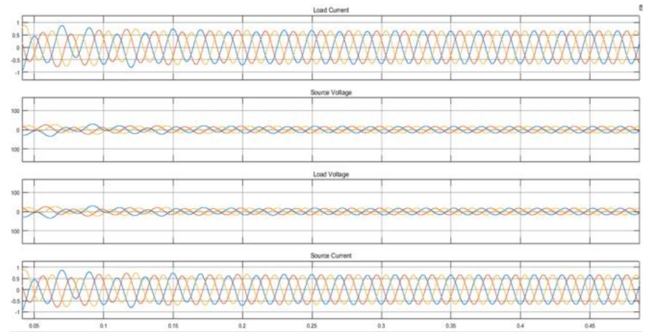

Fig. 5. Voltage and Current Waveform without Hybrid STATCOM

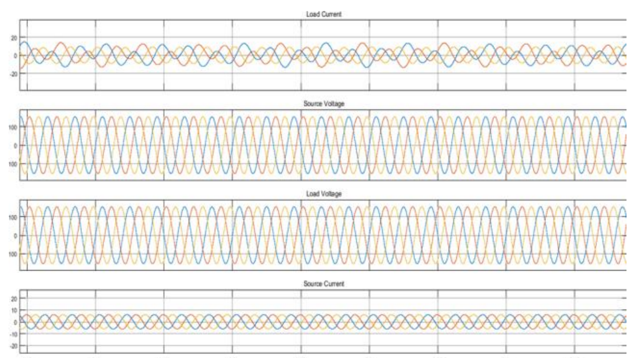

Fig. 6. Voltage and Current Waveform with Hybrid STATCOM

A. *Reactive power waveform*

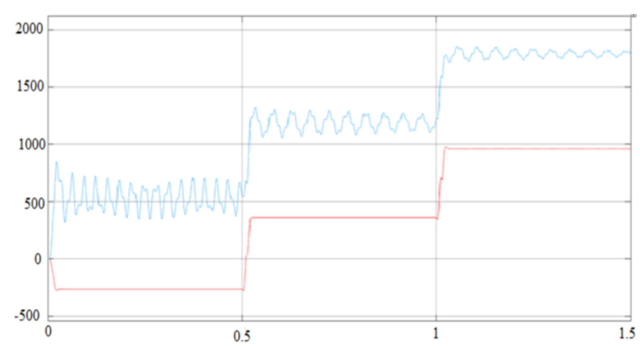

Fig. 7. Reactive Power Waveform for with hybrid STATCOM system

B. THD Responses

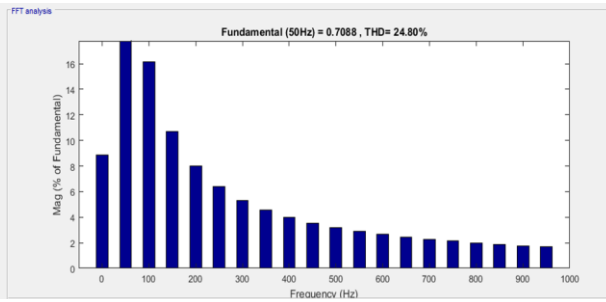

Fig. 8. THD source response for inductive and light loading for without STATCOM

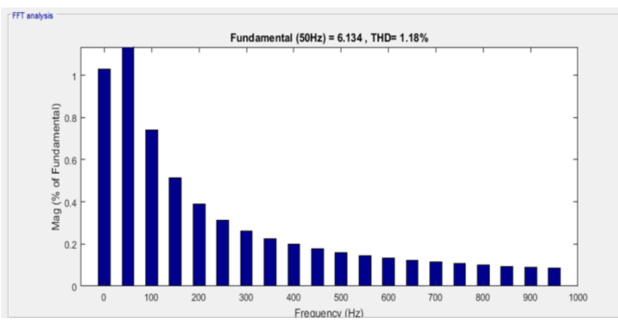

Fig. 9. THD source response for inductive and light loading for without STATCOM

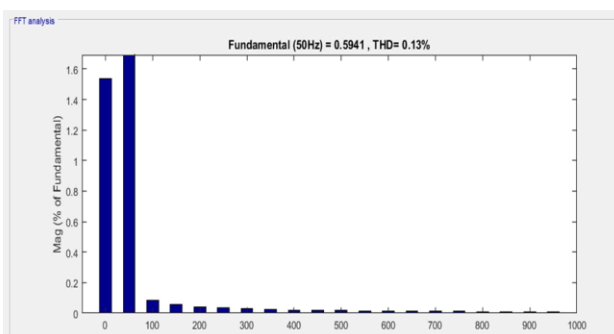

Fig. 10. THD source response for capacitive loading for without STATCOM

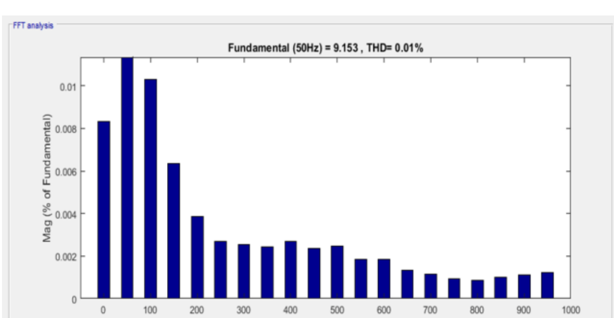

Fig. 11. THD source response for capacitive loading for with STATCOM

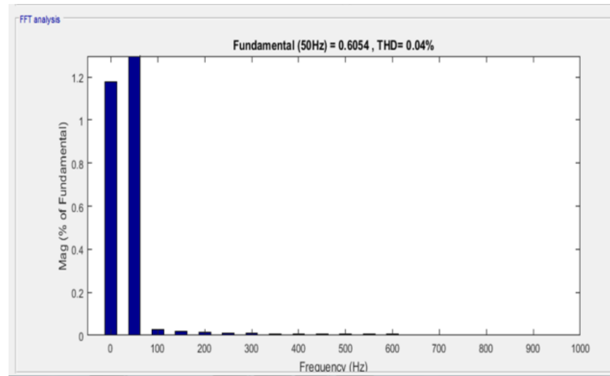

Fig. 12. THD source response for inductive and heavy loading for without STATCOM

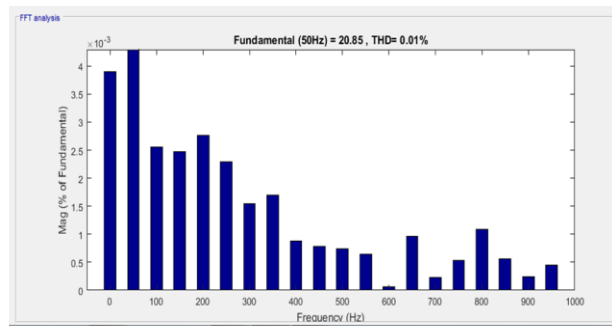

Fig. 13. THD source response for inductive and heavy loading for with STATCOM

5. Conclusion

A hybrid-STATCOM in three-phase power system is projected and discussed as a cost-effective reactive power compensator for medium voltage level application. Simulation of hybrid-STATCOM for three different load (light inductive, highly inductive and capacitive) is completed using MATLAB simulink. From the simulation, the concept of hybrid-STATOM is understood. Its parameter design method is anticipated on the basis of consideration of reactive power compensation range & prevention of potential resonance problem. The TCLC part improves the reactive power compensation range & LC is designed to avoid the resonance problem. Active inverter part is designed to avoid the mistuning of firing angle of TCLC part. Moreover, the control strategy of the hybrid-STATCOM is developed under diverse voltage and current condition. The response time of hybrid STATCOM is faster than other conventional reactive power compensator. Hybrid STATCOM obtains the best performance under both inductive and capacitive loading.

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