MLI HYBRID STATCOM WITH WIDE COMPENSATION RANGE AND LOW DC LINK VOLTAGE

#1 BONDALA DURGA, PG SCHOLAR

#2 G. ARUNA LAKSHMI, ASSISTANT PROFESSOR

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
KAKINADA INSTITUTE OF TECHNOLOGICAL SCIENCES, RAMACHANDRAPURAM, EGT, AP

ABSTRACT - A hybrid-STATCOM in three-phase power system is proposed and discussed as a cost-effective reactive power compensator for medium voltage level application is proposed in this paper. Because of these prominent characteristics, the system costs can be greatly reduced. By using five-level inverter is developed and applied for injecting the real power of the renewable power into the grid to reduce the switching power loss, harmonic distortion, and electromagnetic interference caused by the switching operation of power electronic devices. 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. By using the simulation results we can 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.

I. INTRODUCTION

A hybrid-STATCOM is proposed, with the distinctive characteristics of a much wider compensation range than C-STATCOM [10] and other series-type PPF-STATCOMs and a much lower DC-link voltage than traditional STATCOM [4]-[9] and other parallel-connected hybrid STATCOMs. To improve the operating performances of the traditional STATCOMs, C-STATCOMs, and other PPF-STATCOMs, many different control techniques have been proposed.

The large reactive current in transmission systems is one of the most common power problems that increases transmission losses and lowers the stability of a power system [1]. Application of reactive power compensators is one of the solutions for this issue.

Static VAR compensators (SVCs) are traditionally used to dynamically compensate reactive currents as the loads vary from time to time. However, SVCs suffer from many problems, such as resonance problems, harmonic current injection, and slow response [2]-[3]. To overcome these disadvantages, static synchronous compensators (STATCOMs) and active power filters (APFs) were developed for reactive current compensation with faster response, less harmonic current injection, and better performance [4]-[9]. However, the STATCOMs or APFs usually require multilevel structures in a medium- or high-voltage level transmission system to reduce the high-voltage stress across each power switch and DC-link capacitor, which drives up the initial and operational costs of the system and also increases the control complexity. A new control strategy for hybrid-STATCOM is proposed to coordinate the TCL part and the active inverter part for reactive power compensation under different voltage and current conditions, such as unbalanced current, voltage fault, and voltage dip.

To reduce the current rating of the STATCOMs or APFs, a hybrid combination structure of PPF in parallel with STATCOM was proposed. However, this hybrid compensator is dedicated for inductive loading operation. When it is applied for capacitive loading compensation, it easily loses its small active inverter rating characteristics.
To overcome the shortcomings of different reactive power compensators [1]-[10] for transmission systems, this paper proposes a hybrid STATCOM that consists of a thyristor-controlled LC part (TCLC) and an active inverter part, as shown in Fig. 1. The TCLC part provides a wide reactive power compensation range and a large voltage drop between the system voltage and the inverter voltage so that the active inverter part can continue to operate at a low DC-link voltage level. 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.

II. CIRCUIT CONFIGURATION OF THE HYBRID-STATCOM

Fig. 1 shows the circuit configuration of hybrid-STATCOM, in which the subscript \( x \) stands for phase a, b, and c in the following analysis. \( V_x \) and \( V_u \) are the source and load voltages, \( I_{xu} \) and \( I_{ex} \) are the source, load, and compensating currents, respectively. \( L_s \) is the transmission line impedance. The hybrid-STATCOM consists of a TCLC and an active inverter part. The TCLC part is composed of a coupling inductor \( L_C \), a parallel capacitor \( C_{PF} \), and a thyristor-controlled reactor with \( L_{PF} \). The TCLC part provides a wide and continuous inductive and capacitive reactive power compensation range that is controlled by controlling the firing angles \( \alpha_x \) of the thyristors.

The active inverter part is composed of a voltage source inverter with a DC-link capacitor and the small rating active inverter part is used to improve the performance of the TCLC part. In addition, the coupling components of the traditional STATCOM and C-STATCOM are also presented in Fig. 1.

The characteristics of different reactive power compensators and the proposed hybridSTATCOM for the transmission system are compared and summarized in Table I.

<table>
<thead>
<tr>
<th>TABLE I CHARACTERISTICS OF DIFFERENT COMPENSATORS FOR TRANSMISSION SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compensator</strong></td>
</tr>
<tr>
<td>SVG [2]-[3]</td>
</tr>
<tr>
<td>STATCOMs [4]-[9]</td>
</tr>
<tr>
<td>C-STATCOMs [10]</td>
</tr>
<tr>
<td>Series-type PPF-STATCOMs [11]-[19]</td>
</tr>
<tr>
<td>PPF/STATCOM [20], [21]</td>
</tr>
<tr>
<td>SVC/APF [22]</td>
</tr>
<tr>
<td>Hybrid-STATCOM</td>
</tr>
</tbody>
</table>

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

The purpose of the hybrid-STATCOM is to provide the same amount of reactive power as the loadings \( Q_{Lx} \), but with the opposite polarity \( Q_{ex} = -Q_{Lx} \). The hybrid-STATCOM compensating reactive power \( Q_{ex} \) is the sum of the reactive power \( Q_{TCLC} \) that is provided by the TCLC part and the reactive power \( Q_{invc} \) that is provided by the active inverter part. Therefore, the relationship among \( Q_{Lx}, Q_{TCLC}, \) and \( Q_{invc} \) can be expressed as

\[
Q_{Lx} = -Q_{ex} = -(Q_{TCLC} + Q_{invc}) \quad (1)
\]
The reactive powers can also be expressed in terms of voltages and currents as

\[ Q_L = V_x I_{Lq} = -(X_{TCLC}(\alpha_x) I_{Cq}^2 + V_{invx} I_{Cq}) \]  

(2)

where \( X_{TCLC}(\alpha_x) \) 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 \( I_{Lq} \) and \( I_{Cq} \) are the RMS value of the load and compensating reactive currents, where \( I_{Lq} = -I_{Cq} \). Therefore, (2) can be further simplified as

\[ V_{invx} = V_x + X_{TCLC}(\alpha_x) I_{Lq} \]  

(3)

where the TCLC part impedance \( X_{TCLC}(\alpha_x) \) can be expressed as

\[ X_{TCLC}(\alpha_x) = \frac{\delta_T C P L}{x_{cPf}} - \frac{x_{TCLC}(\alpha_x)}{x_{Lc}} + X_{Lc} = \frac{\pi L_p x_{cPf}}{x_{cPf}(2\pi - 2\alpha + \sin 2\alpha)} - \frac{\pi L_p x_{cPf}}{x_{cPf}(2\pi - 2\alpha + \sin 2\alpha)} + X_{Lc} \]

(4)

\[ \frac{1}{1!} + \frac{x}{2!} + \frac{x^2}{3!} + \cdots, \quad -\infty < x < \infty \]

IV. CONTROL STRATEGY OF HYBRIDSTATCOM

A control strategy for hybrid-STATCOM is proposed by coordinating the control of the TCLC part and the active inverter part so that the two parts can complement each other’s disadvantages and the overall performance of hybrid-STATCOM can be improved. The control strategy of hybrid-STATCOM is separated into two parts for discussion: A. TCLC part control and B. Active inverter part control. The response time of hybrid-STATCOM is discussed in part C. The control block diagram of hybrid STATCOM is shown in Fig. 5.

A. TCLC part control

Different with the traditional SVC control based on the traditional definition of reactive power [2]-[3], to improve its response time, the TCLC part control is based on the instantaneous pq theory [4]. The TCLC part is mainly used to compensate the reactive current with the controllable TCLC part impedance \( X_{TCLC} \). Referring to (3), to obtain the minimum inverter voltage \( V_{invx} \approx 0 \) can be calculated with Ohm’s law in terms of the RMS values of the load voltage and the load reactive current \( I_{Lq} \). However, to calculate the \( X_{TCLC} \) in real time, the expression of \( X_{TCLC} \) can be rewritten in terms of instantaneous values as

\[ X_{TCLC} = \frac{V_x}{I_{Lq}} = \frac{\| \bar{v} \|^2}{3 \| \bar{q} \|_{L_x}} \]  

(15)

where \( \bar{v} \) is the norm of the three-phase instantaneous load voltage and \( \| \bar{q} \|_{L_x} \) is the DC component of the phase reactive power.

B. Active inverter part control

In the proposed control strategy, the instantaneous active and reactive current id-iq method [7] is
Cascaded H-Bridge Multilevel Inverter:

The cascaded H-bridge multi level inverter is to use capacitors and switches and requires less number of components in each level. This topology consists of series of power conversion cells and power can be easily scaled. The combination of capacitors and switches pair is called an H-bridge and gives the separate input DC voltage for each Hbridge. It consists of H-bridge cells and each cell can provide the three different voltages like zero, positive DC and negative DC voltages.

H-bridge multi level inverter, 9- H-bridge clamped multi level inverter.

![FIG.2. H-bridge multi level inverter](image)

![FIG.3. Waveform of 5 level inverter](image)

V. SIMULATION RESULTS

In this section, the simulation results among traditional STATCOM, C-STATCOM, and the proposed hybrid-STATCOM are discussed and compared. The detailed simulation results are summarized in Table II.
TABLE II SIMULATION RESULTS FOR INDUCTIVE AND CAPACITIVE REACTIVE POWER COMPENSATION OF TRADITIONAL STATCOM, C-STATCOM AND HYBRID STATCOM

<table>
<thead>
<tr>
<th>Loading Type</th>
<th>Without and With STATCOM Comp.</th>
<th>( i_d (A) )</th>
<th>DPF</th>
<th>THD (_{i_d} ) (%)</th>
<th>( V_{dc} ) (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case A: inductive</td>
<td>Before Comp.</td>
<td>6.50</td>
<td>0.83</td>
<td>0.01</td>
<td>--</td>
</tr>
<tr>
<td>and light loading</td>
<td>Trad. STATCOM</td>
<td>5.55</td>
<td>1.00</td>
<td>7.22</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>C-STATCOM</td>
<td>5.48</td>
<td>1.00</td>
<td>2.01</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Hybrid STATCOM</td>
<td>5.48</td>
<td>1.00</td>
<td>1.98</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Before Comp.</td>
<td>8.40</td>
<td>0.69</td>
<td>0.01</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Trad. STATCOM</td>
<td>5.95</td>
<td>1.00</td>
<td>6.55</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>C-STATCOM</td>
<td>6.30</td>
<td>0.85</td>
<td>17.5</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Hybrid STATCOM</td>
<td>5.90</td>
<td>0.98</td>
<td>7.02</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Before Comp.</td>
<td>4.34</td>
<td>0.78</td>
<td>0.01</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Trad. STATCOM</td>
<td>3.67</td>
<td>1.00</td>
<td>7.61</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>C-STATCOM</td>
<td>7.10</td>
<td>0.57</td>
<td>23.5</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Hybrid STATCOM</td>
<td>5.02</td>
<td>0.99</td>
<td>10.6</td>
<td>500</td>
</tr>
<tr>
<td>Case C: capacitive</td>
<td>Before Comp.</td>
<td>3.41</td>
<td>1.00</td>
<td>3.01</td>
<td>50</td>
</tr>
<tr>
<td>loading</td>
<td>Hybrid STATCOM</td>
<td>5.02</td>
<td>0.99</td>
<td>10.6</td>
<td>500</td>
</tr>
</tbody>
</table>

*Shaded areas indicate unsatisfactory results.

A. Inductive and light loading

When the loading is inductive and light, traditional STATCOM requires a high DC-link voltage \( V_{dc} > \sqrt{2} V_L - L = 269V, V_{dc} = 300V \) for compensation.

B. Inductive and heavy loading

To compensate for the inductive and heavy loading, traditional STATCOM still requires a high DC-link voltage of \( V_{dc} = 300V \) for compensation. Traditional STATCOM can obtain acceptable results \((\text{DPF} = 1.00 \text{ and } \text{THD}_{i_d} = 6.55\%)\).

Dynamic reactive power compensation of phase a by applying hybrid-STATCOM

Dynamic compensation waveforms of \( V_x \) and \( i_{sx} \) by applying hybrid-STATCOM under unbalanced loads.

Dynamic compensation waveforms of \( V_x \) and \( i_{sx} \) by applying hybrid STATCOM during voltage dip.

Control block diagram of simulation
VI. CONCLUSION

In this paper, a hybrid-STATCOM in three-phase power system is 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 are analyzed, discussed, and compared with traditional STATCOM and C-STATCOM. In addition, its parameter design method is 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 is 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 are proved by both simulation and experimental results.

REFERENCES:


AUTHOR'S DETAILS:

BONDALA DURGA, Pursuing M-Tech (power system) in EEE from KITS college Ramachandrapuram

G. ARUNA LAKSHMI , Now She Working As Assistant Professor In Kits College, Department Of eee, Ramachandrapuram.