Volume : 4 | Issue : 2 | February 2015 • ISSN No 2277 - 8179

Research Paper

Modelling & Comparative Analysis of Statcom Utilising Cascaded Multilevel Inverter (H Bridge)

Engineering

KEYWORDS : Cascaded multilevel inverter (H-bridge), Static synchronous compensator, ABC coordinates

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ABSTRACT

This dissertation is dedicated to a comprehensive study of static synchronous compensator (STATCOM) systems utilizing cascaded-multilevel inverters. Among flexible AC transmission system (FACTS) controllers, the STATCOM have shown feasibility in terms of cost effectiveness in a wide range of problem-solving abilities from transmission to distribution levels. A cascade multilevel inverter is a power electronic device built to synthesize a desired AC voltage from several levels of DC voltages. A method is presented showing that a cascade multilevel inverter can be implemented using only a single DC power source and capacitors. To control the reactive power instantaneously, this system is modelled using the ABC transform which calculates the instantaneous reactive power. The simulation result of MATLAB/Simulink software indicates the superior performance of the proposed control system, as well as the precision of the proposed models.

1. INTRODUCTION

Among flexible AC transmission system (FACTS) controllers, the STATCOM have shown feasibility in terms of cost effectiveness in a wide range of problem-solving abilities from transmission to distribution levels. A cascade multilevel inverter is a power electronic device built to synthesize a desired AC voltage from several levels of DC voltages. A cascade multilevel inverter can be implemented using only a single DC power source and capacitors. To operate a cascade multilevel inverter using a single DC source, it is proposed to use capacitors as the DC sources. A standard cascade multilevel inverter requires 's' DC sources for 2s+1 level. To be able to operate in a high-voltage application, a large number of DC capacitors are utilized in a cascaded multilevel inverter-based STATCOM. To obtain a low distortion output voltage or a nearly sinusoidal output waveform, a triggering signal should be generated to control the switching frequency of each power semiconductor switch.

2. OBJECTIVE

The objective is to come out with a simulation model of STATCOM based cascaded multilevel inverter and analyzes its operation.

3. COMPARATIVE ANALYSIS OF CASCADED MULTILEVEL INVERTERS

Multilevel inverters include an array of power semiconductors and capacitor voltage sources, the output of which generate voltages with stepped waveforms. By increasing the number of levels in the inverter, the output voltages have more steps generating a staircase waveform, which has a reduced harmonic distortion. However, a high number of levels increases the control complexity and introduces voltage imbalance problems. For example, 11-level cascaded H-bridge inverters will have 5 SDCSs and 5 full bridges. Similarly, 13-level cascaded H-bridge inverters will have 6 SDCSs and 6 full bridges. And, 15-level cascaded H-bridge inverters will have 7 SDCSs and 7 full bridges.

The most attractive features of Cascaded Multilevel Inverters are as follows:

- They can generate output voltages with extremely low distortion and lower dv/dt.
- They draw input current with very low distortion.
- They generate smaller common-mode (CM) voltage, thus reducing the stress in the motor bearings. In addition, using sophisticated modulation methods, CM voltages can be eliminated.
- They can operate with a lower switching frequency.

4. POWER CIRCUIT AND SYSTEM MODELLING

4.1 Power Circuit and Operation Principle

An eleven level, three-phase STATCOM based on the cascading configuration is illustrated in Figure 1.

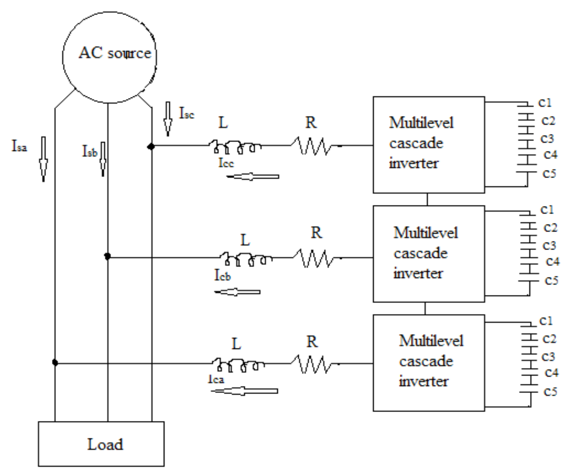

Figure 1 Structure of the STATCOM with cascade multilevel inverter

Figure 1 illustrates the connection diagram for a star connection 11-level inverter using the cascade voltage source H-bridge inverters. Each HBI can generate three level output, +Vdc, o and –Vdc. When the inverter output voltage is higher than the ac system voltage, leading reactive current is drawn from the system (vars are generated). When the inverter output voltage is lower than the ac system voltage, the lagging reactive current is drawn from the system (vars are absorbed). When the inverter output voltage is equal to the AC system voltage reactive power exchange is zero. The AC voltage controlled STATCOM can control the amplitude of AC voltage by causing a small amount of active power to power flow into or out of the STATCOM.

4.2 Control of Reactive Power

It is well known that the amount and type (capacitive or inductive) of reactive power exchange between the STATCOM and the system can be adjusted by controlling the magnitude of STATCOM output voltage with respect to that of system voltage. Figure 2 shows simulated circuit of STATCOM with 11-level cascaded multilevel inverter

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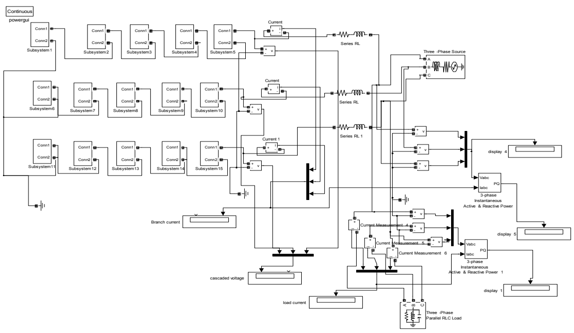

Figure 2 Simulated circuit of the STATCOM with 11-level cascaded multilevel inverter

The reactive power supplied by the STATCOM is given by equation,

$$Q = V_{statcom} - V_s Q = V_{statcom} - V_s \quad (1)$$

Where, Vstatcom and Vs are the magnitudes of STATCOM output voltage and system voltage respectively and X is the equivalent reactance between STATCOM and the system. When Q is positive, the STATCOM supplies reactive power to the system. Otherwise, the STATCOM absorbs reactive power from the system.

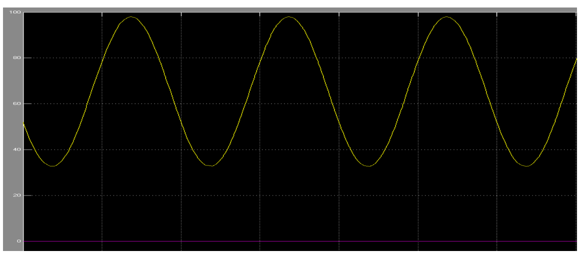

Figure 3 Reactive power in 3-phase cascaded eleven level inverter based STATCOM

Figure 3 shows reactive power of STATCOM with 11 level cascaded multilevel inverter. Since the modulating signals are the same for the inverters in the system, the fundamental component of the STATCOM output voltage is N time of that of each inverter, provided that the voltage across the DC capacitor of each inverter is the same. As a result, the STATCOM output voltage can be controlled by the Modulation index due to its ability to control the output voltage by the modulation index; the proposed STATCOM has extreme fast dynamic response to system reactive power demand.

4.3 Control of DC Capacitor Voltage

If all the components were ideal and the STATCOM output voltage were exactly in phase with the system voltage, there would have been no real power exchange between STATCOM and system therefore the voltages across the DC capacitors would have been able to sustain.

However, a slight phase difference between the system voltage and the STATCOM output voltage is always needed to supply a small amount of real power to the STATCOM to compensate the component loss so that the DC capacitor voltages can be maintained. This slight phase difference is achieved by adjusting the phase angle of the sinusoidal modulating signal. If the real power delivered to the STATCOM is more than its total component loss, the DC capacitor voltage will rise, and vice-versa. This real power exchange between STATCOM and the system is described by Equation (2) below,

$$P = \frac{V_s V_{statcom}}{X} \sin(\delta) \quad (2)$$

Where, is the phase angle difference between STATCOM voltage and the system voltage.

5. SIMULATION RESULT

Figure 4 shows the load current waveform of a single phase H-bridge inverter when the load is RL. For this type of load, current will not be in phase with output voltage and diodes connected in antiparallel with IGBTs will allow the current to flow when the main IGBTs are turned off.

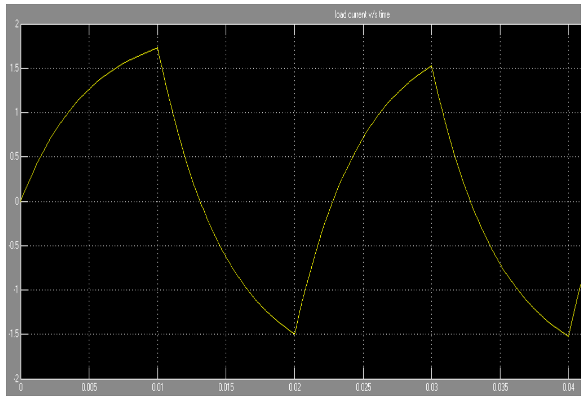

Figure 4 Load current v/s time

Figure 5 shows the three-phase ac supply voltage in STATCOM with cascaded multilevel inverter.

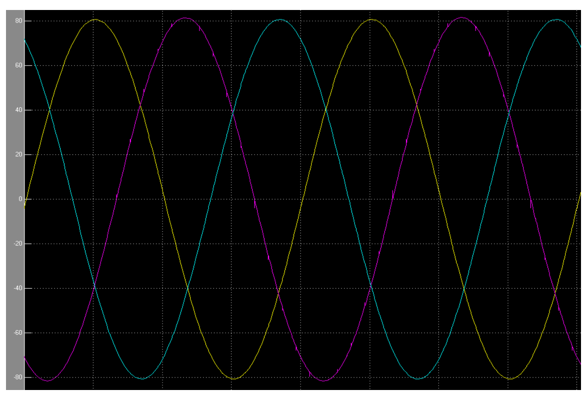

Figure 5 3-Φ ac supply voltage in STATCOM v/s time

Figure 6 shows the cascaded fifteen level inverter output phase voltage waveform. It can be seen that the sinusoidal waveform and the fifteen level cascaded inverter output waveform both are approximately same. But the square wave output has a high harmonic content, not suitable for certain AC loads such as motors or transformers.

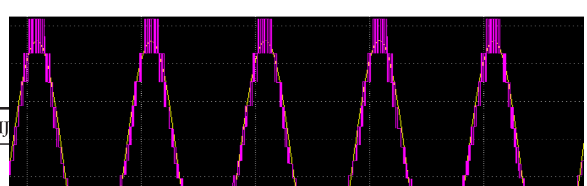

Figure 6 Approximately Sinusoidal Fifteen level inverter output phase voltages

Figure 7 and 8 shows that as the numbers of levels of the cascaded multilevel inverter are increase, the harmonic distortion with respect to nth order will be decreases.

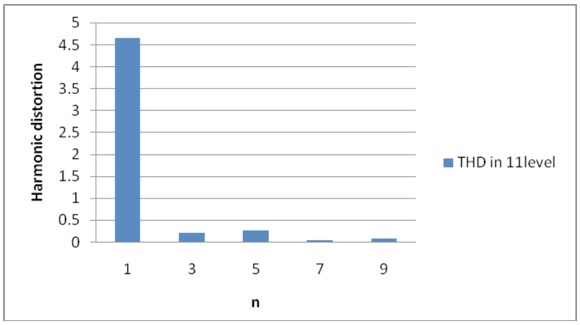

Figure 7 Harmonic distortions in STATCOM based cascaded eleven level inverter v/s nth order

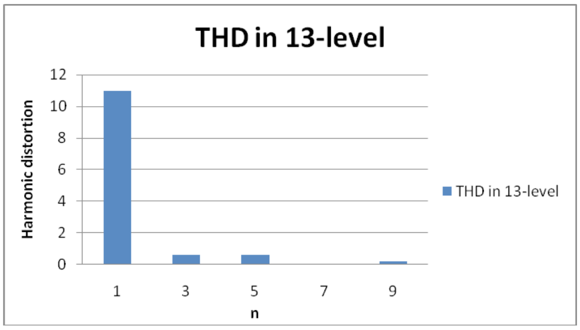

Figure 8 Harmonic distortions in STATCOM based cascaded thirteen level inverter v/s nth order

Figure 9 shows as the number of levels of the inverter increases, the harmonics in the output voltages are reduced.

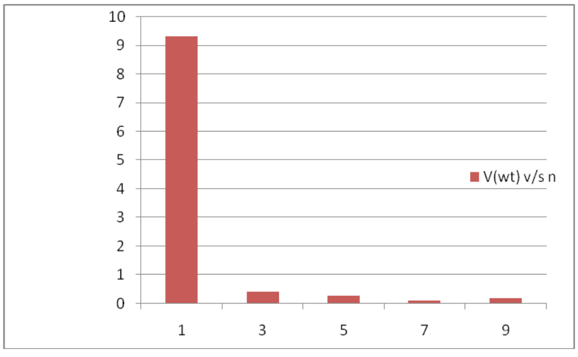

Figure 9 Harmonic distortions in output voltage of cascaded fifteen level inverter v/s nth order

6 CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

In conclusion, among the nature multilevel inverter topologies, the cascaded-multilevel VSC is the most promising alternative for the STATCOM application. It requires the least number of components to achieve the same number of output voltage levels. With its modularized structure, the Cascaded Multilevel Inverter can flexibly expand the output power capability and is favourable to manufacturing. Control complexity of the Cascaded Multilevel Inverter is, however, directly proportional to the number of H-bridge inverters. In the STATCOM application, the AC voltage of each H-bridge converter is derived from its DC capacitor voltage or supply voltage, which needs to be individually regulated. As the number of voltage levels increases, the voltage-imbalance problem becomes more of a concern.

To achieve as stable a system as possible, a well-defined model and an effective DC-link-balancing method are necessary. The cascaded seven-level, nine-level, eleven-level, thirteen-level and fifteen-level inverters have been used as the studied system. And, the cascaded fifteen level inverter based STATCOM is designed according to the simplified model in abc coordinates. The simulation results show superior performances of the designed abc coordinates inverter based STATCOM. The STATCOM has the great advantage of a fewer number of devices. The VSI is extremely fast in response to reactive power change. The simulation of the STATCOM is performed in the Simulink environment and the results are presented.

6.2 Future Scope

A multi-level Stat-Com/BESS is more versatile and flexible than a conventional Stat-Com because it can

- Control both active and reactive power simultaneously and independently
- Charge batteries by absorbing active power from the grid
- Be rated higher because of multilevel topology
- Be effective in power oscillation damp

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