Simulation of the static synchronous compensator for the system voltage unbalance and high current harmonics compensation from single phase non-linear load

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Abstract. This paper presents the STATCOM model in PSIM, which compensate grid voltage unbalance and current harmonics from the non-linear, two-phase load. Grid voltage unbalance level and harmonics current of non-linear load are given from measurement. The model of STATCOM is a 6-level voltage inverter. System voltage, and harmonics currents are controlled. All modes are realized and plots are plotted.

1. Introduction

STATCOM control strategy is categorized into primary control strategy and secondary control strategy. In given task primary control strategy offers system voltage unbalance control and high voltage harmonics compensation [1].

2. Simulation information

Due to the influence of adjacent non-linear single phase load, the 6.6kV busbar has serious background voltage imbalance. The highest three-phase voltage imbalance is 5% and the highest voltage distortion rate is 17%.

The field load reactive power is 1.5Mvar and active power is 1.0Mw. The 3rd harmonic component of the load current is 43A, the 5th is 39.2A, and the 7th is 31.4A. The three-phase short-circuit current of 6.6kV busbar is 7.48kA, and the short-circuit capacity is 85.5MVA. Should research compensation performance of delta-connection STATCOM in 6.6kV busbar with a capacity of 7Mvar. The expected effects are as follows:

- The voltage unbalance is 2% ~ 4%;
- The voltage distortion rate is 5% ~ 8%.
Table 1. STATCOM Comparison total harmonic distortion before and after compensation.

| Parameter          | Value | Unit |
|--------------------|-------|------|
| Rated capacity     | 7,0   | MVar |
| Rated current      | 613   | A    |
| Rated voltage      | 6,6   | kV   |
| Wiring connection  | Delta | -    |

3. Simulation model
In order to verify the compensation performance of STATCOM, a simulation model is built by using professional power electronics simulation software PSIM. Model of power cell is H-bridge inverter and is shown in Figure 1. These cells connected series and phases has delta connection, which is represented in Figure 2. The simulation model is shown in Figure 3. The power system presented as voltage source with voltage amplitude 16.1kV and resistive and inductive element characterise the short-circuit capacity 85.5MVA at 6.6kV bus bar. The load is equivalent to the ideal current source with known from measurement active, reactive and high harmonics currents.

Figure 1. Model of one STATCOM power cell.

Figure 2. Model of delta connected STATCOM.
4. Non-linear single phase load compensation simulation

4.1. Unbalance of grid voltage compensation

For the grid voltage imbalance caused by the background, STATCOM injects negative sequence current into the power grid. The negative sequence current and system impedance produce negative sequence voltage, the negative sequence voltage generated is counteracted with the background negative sequence voltage, and finally reduces the voltage imbalance of 6.6kV busbar.

The unbalance of background voltage is 5%, and the peak current in STATCOM’s phase is 500A. It can be seen from the figure that the grid voltage unbalance is reduced from 5% to 1.5%, and the output current STATCOM’s phase reaches the peak value of 500A.

Figure 4. Line voltage waveform and RMS curve of power grid before and after compensation.
Figure 5. Current waveform of STATCOM’s phase before and after compensation (peak value 500A)

Figure 6. Voltage unbalance curve before and after compensation

After analyzing the above waveforms, after the STATCOM is put into operation, the reactive power fluctuation becomes smaller, the maximum reactive power is 4.71 Mvar, and the instantaneous power factor is higher than 0.998. The reduction of reactive power results in a significant reduction in grid voltage fluctuations, which in turn leads to an increase in active power and an increase in the active power of 13% for the non-linear load.

4.2. Harmonic voltage compensation
If the field voltage distortion is caused by the background, STATCOM needs to inject harmonic current into the power grid to offset the harmonic voltage caused by the background in order to reduce the system voltage distortion rate of the field 6.6kV.

In first case. The background grid voltage is the ideal voltage source, and only the load harmonic current is considered for simulation. The simulation results are as follows. The simulation results show that the grid current and voltage distortion rate is improved obviously.
Figure 7. Waveform of load current, grid current and STATCOM current after compensation.

Figure 8. Frequency spectrum of load current and grid current.

Figure 9. Frequency spectrum of load current.
Analysis results of the total harmonic distortion rate before and after the compensation at the STATCOM connected point are shown in table 2.

Table 2. Comparison of harmonic current and voltage distortion before and after compensation

| Name | Before compensation | After compensation | Unit |
|------|---------------------|--------------------|------|
| 3rd  | 43                  | 1.11               | A    |
| 5th  | 39.2                | 2.07               | A    |
| 7th  | 31.4                | 2.92               | A    |
| THDv | 15                  | 1.5                | %    |

Next case is the background grid voltage contains harmonic wave, which are affected by the harmonic current of the load, resulting in the high voltage distortion rate of 6.6kV bus. The simulation results are as follows. The simulation results show that it is difficult to take into account the current and voltage distortion rate of power grid, and there are large harmonic components in the grid current while improving the voltage distortion rate.

Figure 10. Frequency spectrum of grid current.

Figure 11. Load current, grid current and SVG current waveforms after compensation.
Figure 12. Frequency spectrum of load current and grid current.

Figure 13. Power grid voltage waveform (before compensation).

Figure 14. Power grid voltage waveform (after compensation).
Analysis results of the total harmonic distortion rate before and after the compensation at the STATCOM connected point are shown in Table 3.

| Name | Before compensation | After compensation | Unit |
|------|---------------------|--------------------|------|
| 3rd  | 43                  | 321.4              | A    |
| 5th  | 39.2                | 97                 | A    |
| 7th  | 31.4                | 63.9               | A    |
| THDu | 15                  | 4.5                | %    |

5. Conclusions
For researching STATCOM capability to reduce negative impact from the one-phase nonlinear load to the power system the information concerning system parameters is defined, for determine voltage unbalance and distortion rate current measurement was made.

As could be seen from current waveform and spectrum there is high voltage imbalance and distortion in power system, which caused by non-linear load or due to power systems, which supply’s electric energy to another one phase non-linear load.

To prove STATCOM performance the simulation model was built. STATCOM presented as 6-level voltage inverter consisted on four H-bridge series connected inverter in each phase. This phase connected has delta connection. Power system parameters presented as equivalent voltage source with equivalent short circuit rate. Load presented as current source with harmonics current given from measurement.

Control system of STATCOM based on Q-compensation theory and designed as program. To reduce voltage unbalance STATCOM generates negative sequence current and for reduce voltage distortion rate generates current harmonics with opposite phase to current harmonics in the grid.

The simulation results indicate that after compensation, the power quality at the STATCOM connected point could meet and exceed the site assessment requirements. The performance indicators that the simulation can achieve are as follows:

- the voltage unbalance ≤ 2% ~ 4%;
- voltage distortion rate ≤ 5% ~ 8%.

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