Application of D-STATCOM for Harmonic Reduction using Power Balance Theory

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Abstract: In modern power systems due to prolific use of non-linear devices harmonics are present in the distribution system. To reduce the harmonics and source neutral current D-FACT along with a star-delta transformer and Power Filter is proposed in shunt. In this article, the three phase load has been taken from NTS Industries, which deals with FMCG products. This system includes 3 phase 3 wire system having industrial load such as mixer grinder, pulverizer, packaging machine, etc. A star-delta transformer along with three leg voltage source inverter and a capacitor used to filter out harmonics present in supply current. Power balance theory is used to control the D-FACT. A MATLAB Simulink model was created and the results were discussed.

Keywords: Total Harmonic Distortion, Power Filter, D-STATCOM, Star-delta Transformer.

1. Introduction

The use of non-linear devices in the domestic as well as industrial appliances has directly increase the amount of harmonics in the power supply. Earlier, the problem was rectified by passive power filters in the power system with use of capacitors and inductors. This method was of least cost however, affect significantly the load and system impedance characteristics. Also the compensation was provided steeply i.e. fixed conditions, component size was large, and could produce resonance condition. Now-a-days FACTS devices took place of passive filter and possess effective compensation for reactive power, current harmonics as well as power factor correction [1-15]. Chandan Kumar et al in [2] proposed instantaneous symmetric component theory for controlling active power filter, in [3] PV-DSTATCOM is proposed using adaptive reweighted zero attracting control algorithm. And many more control strategy are available in literature.

2. Distribution Static Compensator

It consist of coupling inductance, VSC (Voltage Source Converter) and a capacitor connected at the point of common coupling where three phase source and non-linear load is connected. The active power filter generates the desired amount of current to cancel out the harmonics present in the current. And supplies that generated current to load. And hence the source current regains the ideal condition that is sinusoidal nature. With the suitable control the D-FACT can also compensate the power factor of load.
3. MATLAB Model of System Configuration

Three phase AC supply is supplying three phase reactive unbalanced non-linear load, at PCC a D-FACT and star-delta transformer are connected, a single phase power filter is connected across a switch which is connected between neutral wire of source and neutral wire of star-delta transformer. That means when the switch is closed power filter is bypassed and when the switch is opened power filter comes in to operation.

4. Working of Proposed System

Due to the unbalance in system and non-linear devices there exist neutral current and harmonics in the power system. To eliminate the harmonics D-STATCOM as a D-FACTS device is connected which take care of positive and negative sequence component. Star delta transformer has low impedance route for zero sequence component of current. Power filter generates the required amount of neutral current and supply to load through star-delta transformer winding. Which results the harmonics and neutral current from source eliminated. Simulation of complete system has been designed on MATLAB 2015.

5. Power Balance Theory

There are many solutions available for generation of gate pattern for VSC of D-STATCOM [1-10]. In this article PBT is used for generation of firing pulse for D-STATCOM. The block diagram for PBT is shown in Fig. 3. PBT requires quadrature vector and in-phase vector to generate source current reference. The basic equation for elimination of harmonics present in current are given as follows

- Reference source current in-phase component

The amplitude of supply voltage VRYB (vr, vy, vb) considered sinusoidal at PCC is computed as:

\[ V_t = \left( \frac{2}{3} (v^2_r + v^2_y + v^2_b) \right)^{1/2} \]  (1)

The instantaneous value of the unity amplitude models is in phase with the instantaneous supply voltage, can be derived as:

\[ U_{srp} = v_r / V_t; \quad U_{sypp} = v_y / V_t; \quad U_{sbp} = v_b / V_t \]  (2)

- Evaluation of active power proportion and generation of in-phase reference current

The load current’s instantaneous active power is calculated as
\[ V_L = (i_{Lx}v_r + i_{Ly}v_y + i_{Lb}v_b) \]  
\[ P_L = P_{LDC} + P_{AC_{oscillating}} \]  
\[ I_{sm}^* = (2/3) P_L/V_S \]  
\[ I_{smd}^* = K_p V_{dce} + K_i \int V_{dce} \, dt \]  
\[ I_{smp}^* = I_{sm}^* + I_{smd}^* \]  
\[ I_{smp}^* = I_{sm}^* \times U_{smp} \quad I_{syp}^* = I_{sm}^* \times U_{syp} \quad I_{sbp}^* = I_{sm}^* \times U_{sbp} \]  
\[ U_{srx} = (-U_{syp} + U_{sbp})/\sqrt{3} \]  
\[ U_{syq} = (\sqrt{3}U_{srx} + U_{syp} - U_{sbp})/\sqrt{2}\sqrt{3} \]

Since instantaneous power is a mixture of both oscillating and non-oscillating component, a low pass filter is used to isolate the non-oscillating portion of load power.

The amplitude of the load current's fundamental active power portion is calculated as:

\[ I_{smp}^* = (2/3) P_L/V_S \]

The difference in voltage between the reference capacitor voltage and the sensed capacitors voltage of DSTATCOM is fed into a PI controller, whose output is represented by \( I_{smd}^* \).

\[ I_{smd}(ns) = K_p V_{dce} + K_i \int V_{dce} \, dt \]

Where DC bus PI voltage controller has \( K_p \) proportional gain and \( K_i \) integral gain constants. So reference supply current’s active component is:

\[ I_{sm}^* = I_{smp}^* + I_{smd}^* \]

Reference supply current’s three phase active power portion are:

\[ I_{srrp}^* = I_{sm}^* \times U_{srrp} \quad I_{srrp}^* = I_{sm}^* \times U_{srrp} \quad I_{sbrp}^* = I_{sm}^* \times U_{sbrp} \]

**Figure 3** Block diagram of power balance theory

- Evaluation of quadrature and reactive power component generation

The unit vector templates are 90° phase shift with quadrature components can be obtained as:

\[ U_{srx} = (-U_{syp} + U_{sbrp})/\sqrt{3} \]

\[ U_{sry} = (\sqrt{3}U_{srx} + U_{syp} - U_{sbrp})/\sqrt{2}\sqrt{3} \]
\[ U_{sbq} = (-\sqrt{3}U_{syr} + U_{syp} - U_{sby})/\sqrt{2}\sqrt{3} \]  

(11)

In the same way, another PI controller is used to control the terminal voltage. The terminal voltage amplitude is determined by equation (1) and the reference value is given to PI controller.

To maintain AC terminal voltage constant. The output of PI controller is given as:

\[ I_{sna}^* = K_{pa}V_{ace} + K_{ia} \int V_{ace} \, dt \]  

(12)

The load has instantaneous reactive power:

\[ Q_L = (1/\sqrt{3})\{(v_r - v_y)i_{tx} + (v_y - v_b)i_{ty} + (v_b - v_r)i_{tz}\} \]  

(13)

\( Q_L \) is the combination of oscillating and non-oscillating components, so low pass filter is used to extract load reactive power. The load current has reactive power fundamental component given by:

\[ I_{sq}^* = (2/3) Q_L/V_s \]  

(14)

The amplitude of reference supply current’s reactive power portion is:

\[ I_{sna}^* = I_{sna}^* - I_{sq}^* \]  

(15)

Reference supply current’s quadrature components are:

\[ I_{srq}^* = I_{srq}^* U_{srq} \quad I_{syq}^* = I_{syq}^* U_{syq} \quad I_{sbq}^* = I_{sbq}^* U_{sbq} \]  

(16)

- Reference Supply Current

The sum of quadrature and in-phase components of reference supply current gives the total 3-phase reference current:

\[ I_{sr}^* = I_{srq}^* + I_{sy}^* + I_{sb}^* \quad I_{sy}^* = I_{syp}^* + I_{syq}^* \quad I_{sb}^* = I_{sby}^* + I_{sbq}^* \]  

(17)

These obtained reference supply currents are compared with sensed supply current and the error between two is given to hysteresis based controller to produce the 6- gate pulse for IGBT’s of D-STATCOM.

Figure 4 Mathematical modelling of power balance theory in MATLAB
6. Control of Power Filter

Power filter is connected between neutral wire of transformer and load. A separate single phase AC source is used to energize the capacitor. The three phase load current is compared with neutral current of transformer and passed through PID controller which gives the error which is then compared to carrier wave to generate gate pulse as shown in Fig. 5. The population includes prospective teachers of Tirunelveli District.

7. Simulation Results and Discussion

Simulation result are shown in fig. 6. Where different output are shown on the scope of MATLAB. Where first output waveform shows the 3-phase supply voltage, second shows the 3-phase supply current, third shows the neutral current of source, fourth shows the voltage across the capacitor of D-FACT and fifth shows the transformer neutral current.

A small proportion of the gate pulse generated by using power balance theory is shown in fig. 9. The complete time line of simulation and the effect of compensation on THD is shown in fig. 10.

![Figure 5: Control method of power filter](image)

**Table 1.** Parameters used in simulation

<table>
<thead>
<tr>
<th>Simulation Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Source</td>
<td>415 Volts VL-L, 50 Hz</td>
</tr>
<tr>
<td>Source Impedance</td>
<td>R = 0.1 ohms and L = 0.001 H</td>
</tr>
<tr>
<td>Capacitor DC</td>
<td>4400 μF, 700 V</td>
</tr>
<tr>
<td>Star-delta transformer</td>
<td>A 3-phase two winding transformer</td>
</tr>
<tr>
<td></td>
<td>$\frac{V_L}{V_L} : \frac{V_L}{V_L}$ (240/240 Volts)</td>
</tr>
<tr>
<td>Induction motor</td>
<td>250 V, 2880 RPM, Single Phase 2 H.P.</td>
</tr>
<tr>
<td>Coupling Inductor</td>
<td>L = 2.5 mH</td>
</tr>
<tr>
<td>Switching frequency of PWM</td>
<td>10 kHz</td>
</tr>
</tbody>
</table>
Figure 6. Performance analysis of D-STATCOM with star-delta transformer and power filter.

Figure 7. THD of supply current without compensating device.

Figure 8. THD of supply current with compensating device.
Figure.9 Gate pulse generation of IGBT switch of D-STATCOM

Figure.10 Time line for simulation results

8. Conclusion
In this article a power balanced theory is implemented to extract the gate signals for the voltage source inverter used as active power filter. It can be concluded that THD obtained after compensation is 2.64% which is well within the limit of IEEE 519 standards. Also with the help of power filter and star-delta transformer neutral
The current of source also reduced to great extent. The simulated results shows that the THD before and after compensation. And the results are satisfactory lies in IEEE standards.

References

5. R. Hemalatha, M. Ramasamy, (2020). Microprocessor and PI controller based three phase CHBMLI based DSTATCOM for THD mitigation using hybrid control techniques, Microprocessors and Microsystems, 76.