A New Control Method for Operation of D-STATCOM under Unbalanced Conditions

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Abstract.
This paper presents a new control method for D-STATCOM operation under unbalanced condition. The aim of this method is to balance the load currents. The proposed method extracts the negative and positive sequence components for generating reference values of current that should be injected in order to compensate the load. The proposed method offers structural simplicity and less calculation complexity. Simulation results indicate that this method is effective and D-STATCOM has good performance under unbalanced conditions.

Key words
D-STATCOM, Unbalanced condition, d-q controller

1. Introduction
Power system voltages should ideally be balanced (i.e. with equal magnitudes and phases 120° apart), but in practice only generator voltages satisfy this criterion and upstream voltage may also be unbalanced [1]. The Distribution Static synchronous compensator (D-STATCOM) is a shunt connected device that generates a balanced set of three sinusoidal voltage or current at the fundamental frequency [2]. D-STATCOM in distribution network can be used for improvement of voltage quality such as voltage sags, voltage unbalance and etc [3-5]. Many studies show that the usage of D-STATCOM is effective to improve power and voltage quality problems. In [6] the limiting of dc side over current is studied but an extra inverter is used for the control of negative sequence. In [7] the study is carried out in per-unit value and investigates the D-STATCOM application under unbalanced conditions system voltages and it increases the capacitor size in order to obtain a better performance during unbalanced condition and it is not economical. In [8] the control scheme for the operation of D-STATCOM under unbalanced conditions is presented but the controller unbalances the compensator voltage in response the unbalanced system voltage.

The object of this study is to present a new method for control the D-STATCOM operation under the unbalanced conditions. In this method the load and compensator are considered as a comprehensive load. The proposed method extract the negative and positive sequence component for generating reference values of current that need to be inject in order to compensate the voltage. In this method the calculation the load reactive current is omitted.

The rest of the paper is organized as follows: section II present the D-STATCOM description. Section III explains the control method. The obtain simulation results are discussed in section IV and finally, section V concludes the paper.

2. Model of D-STATCOM

Fig.1 shows the schematic representation of D-STATCOM. It has a voltage source inverter that converts the dc input voltage into a three phase voltage at fundamental frequency. In the unbalanced conditions the line voltage is equal to the sum of negative and positive sequence so we will have:

\[ V_{nn} = \sqrt{2}V_{sp} \cos(\alpha) + \sqrt{2}V_{sn} \cos(\alpha + \varphi) \] (1)
\[ V_{s1} = \sqrt{2}V_{sp} \cos(\alpha - \frac{2\pi}{3}) + \sqrt{2}V_{sm} \cos(\alpha + \frac{2\pi}{3} + \phi_n) \]  
(2)

\[ V_{s2} = \sqrt{2}V_{sp} \cos(\alpha - \pi) + \sqrt{2}V_{sm} \cos(\alpha + \phi_n - \frac{\pi}{3}) \]  
(3)

\[ V_{s3} = \sqrt{2}V_{sp} \cos(\alpha + \frac{\pi}{3}) + \sqrt{2}V_{sm} \cos(\alpha + \phi_n - \pi) \]  
(15)

In the above equation, \( V_{sp} \) and \( V_{sm} \) are the RMS of positive and negative sequence component of the line voltages, respectively. By applying Kirchoff’s Voltage Law (KVL) and Kirchoff’s Current Law (KCL), we have:

\[ L \frac{d}{dt} i_{d1} + R_f i_{d1} = V_{s1} - V_1 \]  
(4)

\[ L \frac{d}{dt} i_{d2} + R_f i_{d2} = V_{s2} - V_2 \]  
(5)

\[ L \frac{d}{dt} i_{d3} + R_f i_{d3} = V_{s3} - V_3 \]  
(6)

Using of 'dq' transformer, the equations (7)-(9) are rewritten as follows:

\[ \frac{d}{dt} \begin{bmatrix} i_d \\ i_q \end{bmatrix} = -\alpha L \begin{bmatrix} V_m \\ V_q \end{bmatrix} + \begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} + \alpha L \begin{bmatrix} -i_q \\ i_d \end{bmatrix} \]  
(10)

The \( R_f \) and \( L \frac{d}{dt} \begin{bmatrix} i_{dt} \\ i_{qt} \end{bmatrix} \) are very small and can be neglected; so that:

\[ \frac{d}{dt} \begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} - \alpha L \begin{bmatrix} i_q \\ i_d \end{bmatrix} \]  
(11)

3. Proposed Control Method

3.1 Extraction of positive component

In order to extraction the positive component; first consider the line voltage by a \( \frac{\pi}{3} \) delay, as the below:

\[ V_{s1-1} = \sqrt{2}V_{sp} \cos(\alpha - \frac{\pi}{3}) + \sqrt{2}V_{sm} \cos(\alpha + \phi_n - \frac{\pi}{3}) \]  
(16)

\[ V_{s2-2} = \sqrt{2}V_{sp} \cos(\alpha - \pi) + \sqrt{2}V_{sm} \cos(\alpha + \phi_n - \frac{\pi}{3}) \]  
(17)

\[ V_{s3-3} = \sqrt{2}V_{sp} \cos(\alpha + \frac{\pi}{3}) + \sqrt{2}V_{sm} \cos(\alpha + \phi_n - \pi) \]  
(18)

The negative component of \( V_{s1-1} \) and \( V_{s2-2} \) are equal to [9]:

\[ V_{s1-1} = -(V_{s1} + V_{s3-3}) \]  
(13)

\[ V_{s2-2} = -(V_{s2} + V_{s4-4}) \]  
(14)

Eq (20) shows the relationship between line to line negative voltage and line to neutral negative voltages [9].

The line voltages are equal to sum of negative and positive sequence, so that [9]:

\[ V_{s1} = V_1 - V_n^+ \]  
(15)

Finally we can calculate the positive component by the Eq (16).

It should be noted that, this method does not need any Phase Lock Loop (PLL) to extract the positive component.

3.2 Application of dq controllers

The transformation matrix from 's1s2s3' into 'dq' frame can be defined as follows [9]:

\[ T = \frac{2}{3} \begin{bmatrix} \cos(\alpha) & \cos(\alpha + \frac{2\pi}{3}) & \cos(\alpha - \frac{2\pi}{3}) \\ \sin(\alpha) & \sin(\alpha + \frac{2\pi}{3}) & \sin(\alpha - \frac{2\pi}{3}) \end{bmatrix} \]  
(17)

We need the transformation of the Eqs (11) into conventional stationary \( '\alpha\beta' \) coordinates and the transformation matrix is equal to [9]:

\[ \begin{bmatrix} x_\alpha \\ x_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -1 & 1 \\ 2 & -2 & 2 \end{bmatrix} \begin{bmatrix} V_{s1}^- \\ V_{s2}^- \end{bmatrix} \]  
(18)

From Eq (18), we have:

\[ \cos(\alpha) = \frac{x_\alpha}{\sqrt{x_\alpha^2 + x_\beta^2}} \]  
(19)

\[ \sin(\alpha) = \frac{x_\beta}{\sqrt{x_\alpha^2 + x_\beta^2}} \]  
(20)

We need to decouple \( i_d \) and \( i_q \) for proper control design. Decoupling can be satisfied by introducing new parameters \( u_d \) and \( u_q \) [9].

\[ u_d = V_{sd} - \omega L_i_{sq} - \omega L_i_{dq} \]  
(21)

\[ u_q = V_{sq} - \omega L_i_{sd} + \omega L_i_{dq} \]  
(22)

Fig.2 shows the \( i_{dt} \) and \( i_{qt} \) controller; the transfer function of the closed loop of these controllers can be illustrated as the below:

\[ G_{clos} = \frac{G_d G_f}{1 + G_d G_f} = \frac{K_p e + K_i}{S^2 + \frac{R_d}{L_d} + K_p e + K_i} \]  
(23)

The parameters of PI controller can be selected as follows:

\[ K_p = 3.2 \omega_n - \frac{R_d}{L_d}, \quad K_i = \omega_n^2 \]  
(24)

3.3. DC voltage controller
Regulation the DC voltage at desired value in the application of the D-STATCOM is very important. It is obvious that the regulation of DC voltage is carried out by charging and discharging of the capacitor. The relationship between \( V_{dc} \) and \( i_d \) can be written as the below:

\[
\frac{d(V_{dc})}{dt} = -\frac{2(V_{dc})^2}{R_{dc}C} + \frac{3V_{d-PCC}i_d}{2CR_{dc}}
\]

(25)

where \( V_{d-PCC} \) is the d-axis component of point of common connection (PCC). By rearranging the Eq (25) we have:

\[
\frac{d(V_{dc})^2}{dt} + \frac{2(V_{dc})^2}{R_{dc}C} = K
\]

(26)

The schematic of the DC voltage controller is shown in Fig.3.

\[
i_d, i_{dq} = \frac{1}{s + \frac{1}{L}} \cdot \left( K_p + K_i \right) \cdot \left( V_a - V_{in} \right)
\]

Fig.2: Equivalent block diagram of the d-q controllers

Fig.3: Block diagram of DC voltage controller

4. Simulation Results

Fig.4 shows the load current in three phases that are unbalanced, but after the compensation by D-STATCOM application the currents at the source side are balanced with equal magnitude. Fig.5 shows the source currents in three phases that are balanced. Fig 6 illustrates the DC voltage that is fixed at 700V. Simulation results indicate that the proposed method is useful and the D-STATCOM has a good performance under the unbalanced conditions.

5. Conclusion

This paper described a new method for the application of D-STATCOM under the unbalanced condition. In this method the line current at the source side are balanced and only contains positive sequence while the load current is unbalanced. Simulation results show that the source only provides positive sequence and the structural of method is simple and does not have complicated calculation.

6. References


