Distribution Voltage Regulation Under Three-Phase Fault by Using D-STATCOM

Chaiyut Sumpavakup, and Thanatchai Kulworawanichpong

Abstract—This paper presents the voltage regulation scheme of D-STATCOM under three-phase faults. It consists of the voltage detection and voltage regulation schemes in the $dq$ reference. The proposed control strategy uses the proportional controller in which the proportional gain, $k_p$, is appropriately adjusted by using genetic algorithms. To verify its use, a simplified 4-bus test system is situated by assuming a three-phase fault at bus 4. As a result, the D-STATCOM can resume the load voltage to the desired level within 1.8 ms. This confirms that the proposed voltage regulation scheme performs well under three-phase fault events.

Keywords—D-STATCOM, proportional controller, genetic algorithms.

I. INTRODUCTION

Electric power distribution network becomes more increasingly important and plays an essential role in power system planning. This type of power systems has a major function to serve distributed customer loads along a feeder line, therefore under competitive environment of electricity market eservice of electric energy transfer must not be interrupted and at the same time there must provide reliable, stable and high quality of electric power. To complete this challenge, it requires careful design for power network planning. There exist many different ways to do so. However, one might consider an additional device to be installed somewhere in the network. Such devices are one of capacitor bank, shunt reactor, series reactors, automatic voltage regulators and/or recently developed dynamic voltage restorers, distribution STATCOM (our focus), or combination of them [1-2].

Problems of reactive compensation and power quality in power distribution network are to establish an efficient algorithm to command a power conditioning device. During the voltage sag, the load voltage at the bus in which the D-STATCOM is connected can be regulated by injecting compensating current into the system. The injected current is generated through power electronic circuits with a complicated control scheme. From literature there exist several control strategies which are usually based on mathematical approach [1-2]. In this paper, the proposed method to regulate load voltage under symmetrical short-circuit fault is described.

II. STRUCTURE AND MODELING OF D-STATCOM

D-STATCOM is one of shunt type power conditioners consisting of i) DC link capacitor, ii) separately phase-controlled switched-mode inverter, iii) isolating transformer, and iv) gate triggering circuit [3] as shown in Fig. 1.

In steady-state operation with heavy loading or some short-circuit events, D-STATCOM typically injects appropriate compensating current to the point of coupling connection, thus voltage at the load bus regulated by the D-STATCOM will be lifted close to the nominal or a given value. This implies that voltage-controlled source in parallel with impedance is sufficient to represent the D-STATCOM as shown in Fig. 2. In the figure, the D-STATCOM is assumed to be installed at bus 2 $v_{sa}$ and $R + jX$ represent phasor voltage and impedance of the D-STATCOM.
III. VOLTAGE DETECTION SCHEME

There are various voltage detection methods. This paper employs the $0dq$ transformation or alternatively called Park transform [4] as described in following explanation.

Let $V_{abc}$ and $V_{0dq}$ be voltage vectors referred to the $abc$ and $0dq$ reference frames, respectively. Any voltage vector in the $abc$ reference can be transformed to the $0dq$ reference, and vice versa, by using (1).

\[ V_{0dq} = R(\theta)P(\theta)V_{abc} \tag{1} \]

Where $\theta = \omega t = 2\pi f t$

\[
V_{abc} = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} ; \quad V_{0dq} = \begin{bmatrix} V_d \\ V_q \end{bmatrix}
\]

\[
R(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix}
\]

\[
P(\theta) = \sqrt{3} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \\ 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix}
\]

(1) can be rewritten in more detail as follows.

\[
V_0 = \frac{2}{3} \begin{bmatrix} 1/\sqrt{2} \\ \cos\theta \cos(\theta-2\pi/3) \cos(\theta+2\pi/3) \\ \sin\theta \sin(\theta-2\pi/3) \sin(\theta+2\pi/3) \end{bmatrix} V_a
\]

\[
V_q = \frac{2}{3} \begin{bmatrix} 1/\sqrt{2} \\ \cos\theta \cos(\theta-2\pi/3) \cos(\theta+2\pi/3) \\ \sin\theta \sin(\theta-2\pi/3) \sin(\theta+2\pi/3) \end{bmatrix} V_c
\]

As long as the voltage vector in the $abc$ reference is balanced, its associated $0dq$ components are dc signals. To detect any abnormal voltage condition, each of the $0dq$ components must be checked for its variation.

IV. VOLTAGE REGULATION SCHEME

To regulate the load voltage at the desired voltage level, a voltage regulation scheme is proposed. Although abnormal voltages can be caused by several events, e.g. supply interruption, sudden load change, arc furnace operation, short-circuit fault, etc, in this paper the voltage regulation under three-phase fault is only our particular study. To regulate the voltage level, its $0dq$ voltage components at a given load bus must be analyzed and compared with the $0dq$ desired voltage components. Difference of these two vectors must be reduced by injected the compensating current from D-STATCOM at the point of coupling connection. This control scheme can be done in the $0dq$ reference as shown in the block diagram of Fig. 3.
The following are some parameter setting for GADS command to obtain an optimal $k_p$ parameter.

- Generations: 500
- PopulationSize: 100
- StallGenLimit: 50
- PopInitRange: $k_{r_{0dq}} \in [10,13]$

With more than 30 trials, the best proportional parameter for each component in the $0dq$ reference is given as follows.

$$k_{r_{0dq}} = 11.7643$$

V. SIMULATION RESULTS

This section illustrates numerical results of a simplified 4-bus power system equipped with D-STATCOM at bus 3. Characteristics of the system resulting from the operation of the D-STATCOM are simulated by using the MATLAB simulation codes. The specification of the test system is given as follows.

- Input Voltage: 22 kV, 50 Hz
- Line Impedance1: 0.18 Ω, 0.4 mH
- Line Impedance2: 0.83 Ω, 1.2 mH
- Line Impedance3: 0.50 Ω, 1.08 mH
- Interface Impedance: 3 Ω, 28.6 mH
- Load: 400 kW, 180 kVar
B. D-STATCOM Case

With the presence of D-STATCOM, the load voltage at bus 3 can be compensated by the injecting current from the D-STATCOM. When the fault occurs at \( \tau = 0.1 \) s, the load voltage is sagged suddenly due to the fault current flowing through the faulted bus. With the help from the D-STATCOM, the load voltage can be resumed to its desired level within 1.8 ms. Figs 10-11 show variation of the \( \theta dq \) and \( abc \) components of the load voltage under the fault test. Unlike the base case, the source current as shown in Fig. 12 is reduced by 5-kA of the peak comparative with that of Fig. 9 due to the fault event.

VI. Conclusion

The voltage control scheme of D-STATCOM to regulate the load voltage under three-phase faults is described in this paper. Its voltage detection and voltage regulation schemes are working in the \( \theta dq \) reference. The proposed control strategy simply employs the proportional controller in which the proportional gain, \( k_p \), is tuned by using genetic algorithms. A simple 4-bus test system with the three-phase fault at bus 4 is used for test. As a result, the D-STATCOM can regulate the load voltage to the desired level as fast as 1.8 ms. This
confirms that the proposed voltage regulation scheme performs well under the three-phase fault event.

REFERENCES