Balanced and Unbalanced Voltage Sag Mitigation Using DSTATCOM

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Abstract:
DSTATCOM is one of the equipments for voltage sag mitigation in power systems. In this paper a new control method for balanced and unbalanced voltage sag mitigation using DSTATCOM has been proposed. This system has two controllers to regulate compensator current and load voltage. Delayed signal cancellation has been used for sequence separation. Performance of proposed method with balanced and unbalanced voltage sag has been considered. Simulation results shows appropriate operation of the proposed control system.

***Key words**: Custom power, voltage sag mitigation, power quality.*

I. INTRODUCTION

Power quality is one of the most important topics that electrical engineers have been noticed in recent years. Voltage sag is one of the problems related to power quality. This phenomenon happens continuously in transmission and distribution systems.

During voltage sag, amplitude of the effective load voltage may decrease from 0.9 of the nominal load voltage to 0.1 in very short time (less than one minute). Short circuit, transformer energizing, capacitor bank charging etc are causes of voltage sag. Voltage sag has been classified in 7 groups of A-G [1]. According to this classification most of voltage sags are companion with phase angle jump (types C, D, F and G). Phase angle jump for power electronic systems such as ac-ac and ac-dc converters and motor drives is harmful [2]. Therefore, phase angle jump compensation is one of the voltage sag mitigation goals.

Most industries and companies prefer electrical energy with high quality. If delivered energy to these loads has poor quality, products and equipment of these loads such as microcontrollers, computers, motor drives etc are damaged. Hurt of this phenomenon in companies that dealing with information technology is serious. According to a study in U.S., total damage by voltage sag is amounts to 400 Billion Dollars [3]. For these reasons power quality mitigation in power systems is necessary.

Nowadays, Custom Power equipments are used for this purpose. DSTATCOM is one of these equipments [3] which will be installed in parallel to sensitive loads. This device mitigates the load voltage by injecting the necessary current to the system. Figure 1 shows how DSTATCOM connects to the power system and depicts its structure.

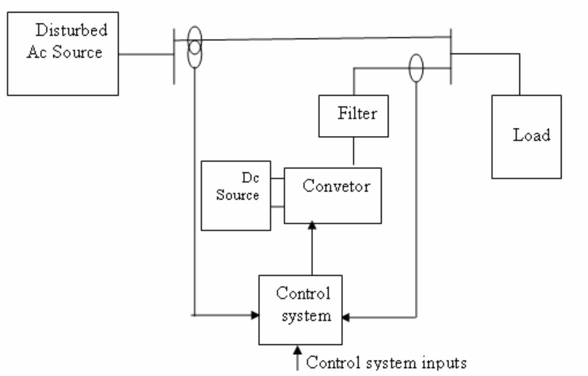

Figure1: DSTATCOM constituents and it' s connection to system

Some methods that have been allocated for voltage sag mitigation using DSTATCOM only take balanced voltage sag into account [4-5]. However, most of the voltage sags are unbalanced. Unbalanced three phase voltage in synchronous reference frame (SRF) generates two components (d and q components) that oscillate with twice frequency of the fundamental frequency. This specialty is not suitable for control purposes.

In references [6] and [7] for improvement of these imperfections, sequence components of voltage and current have been separated in synchronous reference frame. After transformation of three phase voltages or currents to positive synchronous reference frame, a dc component and oscillating component with twice frequency of fundamental frequency are generated. For elimination of oscillating component, an appropriate filter is applied, thus, positive sequence of synchronous reference frame is generated [6].

Delayed signal cancellation (DSC) is considered as a simple method for sequence separation [8]. Sequence components generated by this method are dc quantities; which are desired for control purposes.

The proposed control method in this paper is formed by two control loops. One loop is considered for

compensator current regulation and the other one for point of common coupling (PCC) voltage regulation. Vector current control (VCC) [9] has been used for compensator current regulation. The reference control currents for current control loop generated by the voltage control loop. Measured three phase voltages at PCC are transformed into positive and negative sequence components in synchronous reference frame and compared with the reference quantities. Error signals are then passed through PI controllers to produce reference currents. These reference quantities are fed to the current control loop so that reference voltages are generated. According to the reference voltage, PWM unit generates switching pulses.
In this paper the performance of this system with the presence of linear loads has been studied.

II. CONTROL STATEGY

Figure 2 depicts the control system of compensator where three phase voltage at PCC are transformed into sequence components and compared with reference values. Error signals are exerted into PI controllers in order to produce reference currents for current control loop. Sequence components of reference voltage are:

$$u^*_{dp} = \max(V_{L-L}); u^*_{dn} = 0; u^*_{qp} = 0; u^*_{qn} = 0$$

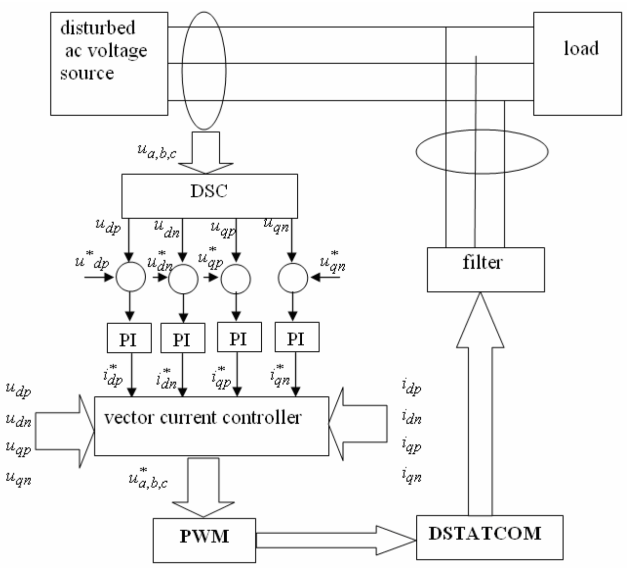

Figure 2: proposed control system for voltage sag mitigation using DSTATCOM

In order to separate sequence components, delayed signal cancellation (DSC) method have been used [8]. Equations (1) and (2) shows that how sequence components are obtained by use of this method.

$$u_p^{dqp}(k) = (u^{dqp}(k) + u^{dqp}(k - \frac{f_s}{4f_g})) \quad (1)$$

$$u_n^{dqn}(k) = (u^{dqn}(k) + u^{dqn}(k - \frac{f_s}{4f_g})) \quad (2)$$

Figure 3 shows block diagram of equations (1) and (2). According to this figure, firstly three phase components (a, b, c) are transformed into a, b components and by use of phase lock loop (PLL) a, b components are transformed into positive and negative synchronous reference frame (u_p^{dqp}, u_n^{dqn}). The obtained signals are then delayed by T/4 and added to initial signals and then multiplied by ½ to generate sequence components.

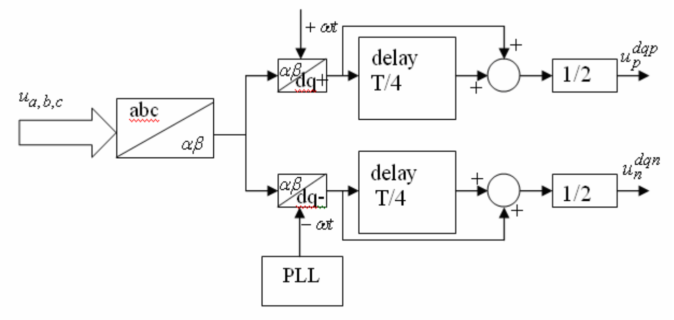

Figure 3: Delayed signal cancellation block diagram

VECTOR CURRENT CONTROLLER

The aim of vector current controller is to follow the reference control current by compensator current. For this purpose converter switching should be regulated. Inputs of vector current controller consist of: sequence components of PCC voltage $(u_{dp}, u_{dn}, u_{qp}, u_{qn})$, sequence components of reference current generated by voltage controller loop $(i^*_{dp}, i^*_{dn}, i^*_{qp}, i^*_{qn})$ and sequence components of injected current by the compensator to the system $(i_{dp}, i_{dn}, i_{qp}, i_{qn})$.

Sequence components of reference voltage applied to the PWM module are obtained from equations (3)-(6) [9].

$$u^*_{dp} = u_{dp} + R_f i_{dp} - (wL_f)(i_{qp} + i^*_{qp}) + PI(i^*_{dp} - i_{dp}) \quad (3)$$

$$u^*_{dn} = u_{dn} + R_f i_{dn} + (wL_f)(i_{qn} + i^*_{qn}) + PI(i^*_{dn} - i_{dn}) \quad (4)$$

$$u^*_{qp} = u_{qp} + R_f i_{qp} - (wL_f)(i_{dp} + i^*_{dp}) + PI(i^*_{qp} - i_{qp}) \quad (5)$$

$$u^*_{qn} = u_{qn} + R_f i_{qn} + (wL_f)(i_{dn} + i^*_{dn}) + PI(i^*_{qn} - i_{qn}) \quad (6)$$

In above equations, R_f is filter resistance and L_f is filter inductance where the filter is placed in series with the compensator. Reference voltages are transformed into three phase coordinates and exerted to PWM unit so that switching pulses are generated.

III. SIMULATION RESULTS

In order to assess the operation of the proposed system, the system depicted in figure 2 has been simulated using MATLAB/SIMULINK and the performance of this system has been considered with linear load. Simulated system parameters have been introduced in Table 1.

Table 1- simulated system parameters

Source resistance	0.7 ohm
Source inductance	2.5 mH
Switching frequency	10 kHz
Sampling frequency	30 kHz
Source frequency	50 Hz
$\max(V_{L-L})$	680 V

COMPENSATION OF LINEAR LOAD VOLTAGE

Figure 4 shows uncompensated R-L load Voltage. Load parameter is R=8 ohm , L=23 mH. According to these figures at 0.8 second voltage sag happens and continues for 0.2 second. In cases of unbalanced voltage sag, at the start and end of voltage sag phase angle jump take places.

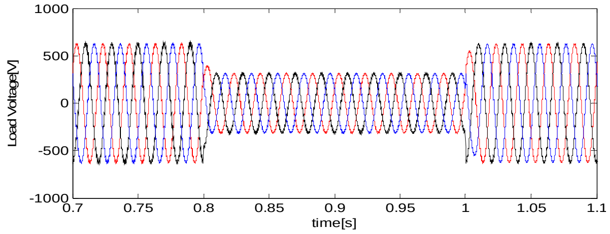

Figure 4- a

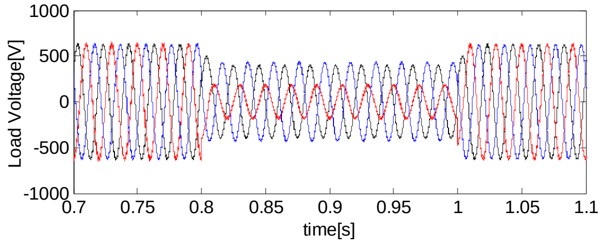

Figure 4-b

Figure4: simulated voltage sag a) balanced voltage sag b) unbalanced voltage sag

Figure 5 shows load voltage after compensation. According to this figure load voltages in balanced and unbalanced voltage sag are successfully compensated. Phase angle jump has also been compensated so that control system capability for phase angle jump mitigation is approved.

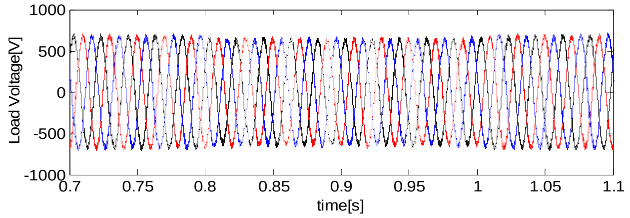

Figure 5-a

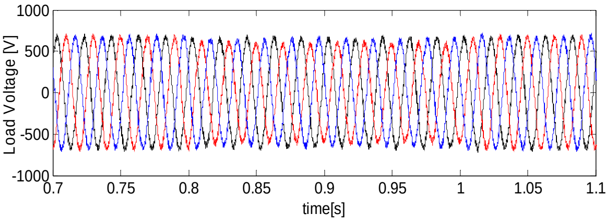

Figure 5-b

Figure 5: load voltage after compensation a) balanced voltage sag b) unbalanced voltage sag unbalanced

Figure 6 shows the injected current to power system for voltage sag compensation. According to this figure in balanced voltage sag injected current is balanced and in unbalanced voltage sag injected current is unbalanced. In this case the decrease of the voltage of one phase voltage is higher than others, therefore, the amplitude of injected current in one phase is higher than two other phases (figure 6-b).

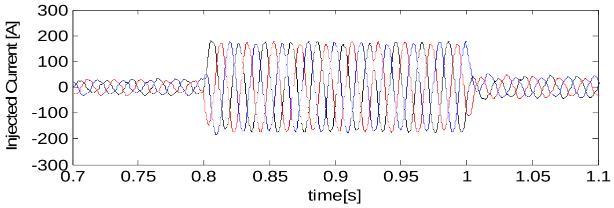

Figure 6-a

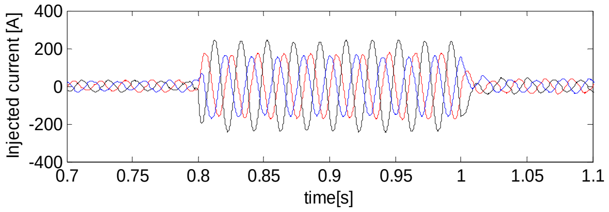

Figure 6-b

Figure6: injected current by compensator a) balanced voltage sag b) unbalanced voltage sag

Mentionable that for decreasing the load voltage harmonics, multilevel converters and other switching methods can be used. Figure 7 shows sequence components of injected current to system. It is obvious that these components are dc. According to figure 7-a, injected current in balanced voltage sag is balanced so that only d component of positive sequence (i_{dp}) exists and other components are zero.

Figure 7-b shows sequence components of injected current in unbalanced voltage sag conditions. The injected currents are also unbalanced so that in addition to d component of positive sequence other components also exist.

It is obvious that amplitude of the injected current by compensator is related to depth of voltage sag. If the voltage sag is deep, the amplitude of injected current is high.

Other types of voltage sag have been simulated and compensated by this method. The chracteristics of simulated voltage sag have been introduced in Table 2. The injected active and reactive power for compensation of these types of voltage sag are also calculated and shown in Table 3.

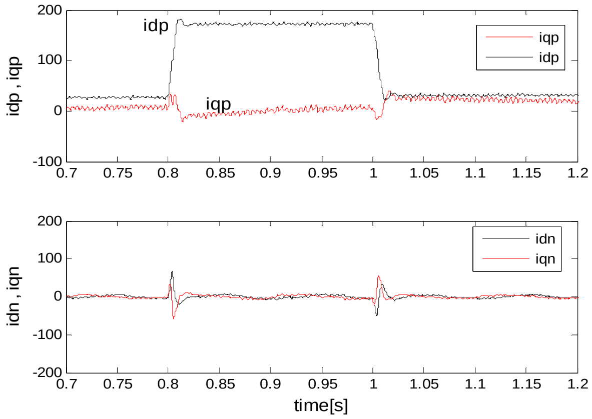

Figure 7-a

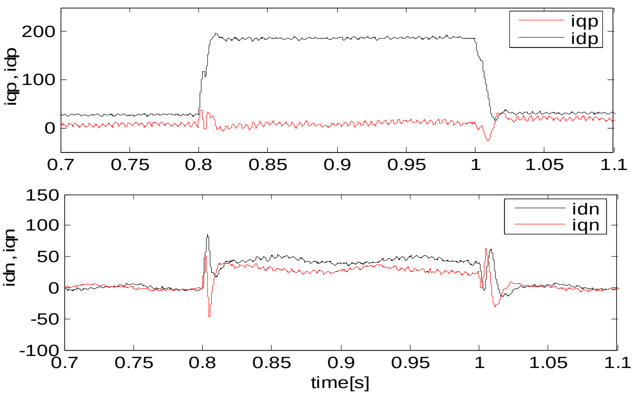

Figure 7-b

Figure 7: sequence component of compensator current a)balanced voltage sag b)unbalanced voltage sag

Table 2: Chracteristics of different types of voltage sags

Type A	Type B	Type C	Type F	Type G
$200\angle 0^{0}$ $200\angle -120^{0}$ $200\angle 120^{0}$	$200\angle 0^{0}$ $400\angle -120^{0}$ $400\angle 120^{0}$	$400\angle 0^{0}$ $265\angle -140^{0}$ $265\angle 140^{0}$	$200\angle 0^{0}$ $361\angle -106^{0}$ $361\angle 106^{0}$	$334\angle 0^{0}$ $241\angle -134^{0}$ $241\angle 134^{0}$

According to Table 3, the types of voltage sag that companion with phase angle jump (types C, F and G) need more active power for phase angle jump compensation than other types of voltage sag. Also for amplitude compensation reactive power is needed so that the deeper voltage sag, more reactive power for compensation is required.

Table 3: Injected active and reactive power by compensator

Voltage sag type	Injected Active Power (kW)	Injected Reactive Power (kVar)	(THD)%
Type A	20	120	5.83
Type B	20	40	5.26
Type C	40	95	5.10
Type F	45	60	5.11
Type G	40	70	5.3

IV. CONCLUSION

In this paper a new control method for voltage sag mitigation using DSTATCOM is proposed. Three phase voltages and currents are transformed to sequence components thus control variables are dc quantities. This specialty causes to control system simplicity. The proposed control system includes two controllers: one for compensator current regulation and other for load voltage regulation.

Voltage controller consists of four PI controllers to control the compensator current and load voltage. By proper adjustment of PI gains, compensated voltage harmonic contents can be controlled. According to the simulation results, the proposed method can mitigate the balanced and unbalanced voltage sags and phase angle jump. Performance of the proposed control system has been studied with different types of voltage sags. According to the simulation results the capability of the compensation system in presence of linear loads is investigated.

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