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A Novel method for voltage sag compensation using AC chopper

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ABSTRACT

A unified technique is proposed to compensate voltage sag and unbalance problem online by developing a robust topology and simple switching scheme. In the Present day Power Quality (PQ) controllers, which are based on Voltage Source Inverter (VSI) the onsite performance and capability is solemnly limited by charging and discharging capacity of the DC source namely battery/ high capacity condensers. To overcome this, in this paper a new power electronics based custom power device is proposed without VSI and totally free from any DC source with the added advantage of simple reference phasor voltage calculation. The reference phasor for compensating both the magnitude and phase deviation is identified by simple mathematical derivation and obtained from other two healthy phase components. Here an AC-Chopper specifically operates on any one of the other two healthy phases was controlled with proper switching sequence obtains the specified phasor and injected in series with the fault line compensates for the deviation. As an initial study, the proposed technique is modeled and the simulation results are verified using SIMULINK in MATLAB. The analytical and simulation study proves superior performance.

Keywords*:* power quality; voltage sag and unbalance; buck-boost ac chopper; phasor addition; phase shifter

1. INTRODUCTION

Voltage sag and unbalance are the interminable Power frequency voltage disturbance that challenges most of the sensitive loads and industries. Hence it is required to increase the reliability and quality of power supplied to loads by installing custom power (Akagi, 1995). Such custom power devices are DVR, STATCOM and UPFC. In a balanced sinusoidal supply system the three line-neutral voltages are equal in magnitude and are phase displaced from each other by 120 degrees. Any deviations that exist in three voltage magnitudes and/or a shift in phase separation from 120 degrees are defined as an unbalanced supply. Voltages that are balanced at generation level become unbalanced due to unequal system impedances and unequal distribution of single phase loads. There are many possible causes of voltage sag or swell events in electrical system including line switching surges, lighting impulses, line to ground faults, unbalanced single phase loads, high impedance connections and malfunctioning of voltage regulators. Different types of electrical equipment behave in different ways under voltage sag events. The impact of a voltage sag disturbance depends on the sensitivity of the equipment to voltage sags. When a voltage sag event occurs, the supply voltage may alter in magnitude and or in phase depending on nature of the fault. Voltage sags can be classified as balanced or unbalanced depending on the nature of the phase-neutral voltages. If the voltages on the three phases sag equally, then balanced sag results. However, if the phase voltages have unequal voltage magnitudes or phase relationships other than 120°, the sag are considered as unbalanced. Three phase short circuits and large motors such as induction motors starting may cause balanced three phase sags and unbalanced sags are as a result of lightning.

Over the past few decades, several methodologies have been proposed based on series and shunt compensation to mitigate the above concerned power quality issues. But all these techniques employ Voltage source Inverter (VSI) in series with capacitor bank to inject the compensating voltage. Since capacitor bank can store limited energy, DVR is not suitable for compensating long duration voltage sag. Further, the regulation of dc link voltage requires additional power conversion stages. Hence, the size, controllability, cost and losses associated with switching elements will increase.

Direct ac-ac power compensators are proposed in different configurations for series regulation (Anaya, 2002) and (Kolar, 2007). In all these ac-ac converter topologies, the compensation of voltage in a particular phase is performed with the compensator connected to the same phase. Also these techniques cannot restore phase deviation due to phase jumps. An interphase ac-ac topology is proposed (Montero Hernandez OC and Enjeti PN, 2000). However, the converter is able to correct only up to 50% three phase sag. Additionally, in this topology a single power conversion module requires two ac choppers and two isolation transformer. Thus the size and cost of the compensator will increase along with switching losses.

2. PROPOSED UNBALANCE COMPENSATOR

A new topology is proposed for compensating voltage sag and phase unbalance. The principle of this technique is to utilize voltages from any one of the other two phases, i.e., the input power for a voltage unbalance compensator is drawn from the other healthy phase. Unlike the other topologies, this compensator is capable of fixing single-phase and three-phase voltage sags up to 100%. The proposed compensator can also compensate phase unbalance in case of a three phase system with all modules connected in respective phases. Due to presence the of single ac chopper module with two switches, there is substantial reduction in size, cost, control complexity and power losses. The schematic diagram of proposed voltage unbalance compensator for compensating voltage sag and phase deviation in phase-a is shown in Fig. 1.

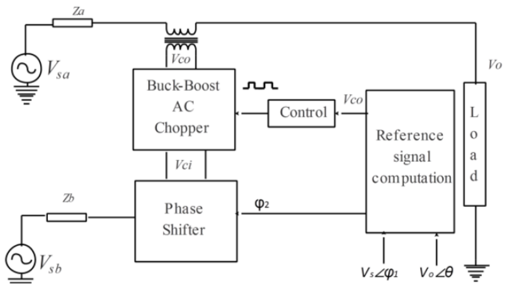

Fig.1.Schematic of proposed voltage unbalance compensator

This compensator is connected in series with the line where the sensitive load is connected. When voltage disturbance is detected in phase-a, the compensator injects a proper voltage vector in series with the fault line and restores the magnitude and phase deviation. The proposed configuration consists of buck-boost ac chopper, phase shifting unit and an injection transformer.

Reference signal computation block works on the principle of phasor addition and offers the magnitude *(V_{co})* and phase ($\emptyset_2$) of the compensating vector.

Let V_{sa} be the phase-a voltage with magnitude and phase deviation and is given by,

$$V_{sa} = V_{sam}\sin(\omega t \pm \varphi_1) \quad (1)$$

Where,

V_{sam} - the peak value of terminal voltage of phase-a

ω- Angular frequency.

φ_1 - Phase deviation

Let V_{sb} be the phase-b voltage and is given by

$$V_{sb} = V_{sbm}\sin(\omega t - 120^o) \quad (2)$$

Where,

V_{sbm} - the peak value of terminal voltage of phase-b

and ω - angular frequency.

Phase B shifting unit connected in the phase-b line uses opamp to delay the phase-b voltage by an angle ($\emptyset_2$)

Let V_{ci} be the output voltage of phase shifter and is given by

$$V_{ci} = V_{sbm}\sin(\omega t - 120^o \pm \varphi_2) \quad (3)$$

Where, φ_2-phase of compensating voltage

The magnitude of delayed phase-b voltage is controlled by varying the duty cycle of buck-boost ac chopper and is injected in series with phase-a line.

The output voltage of ac chopper for phase-a compensation is expressed as,

$$V_{co} = -\frac{D}{1-D}\,V_{ci} = -\frac{D}{1-D}\,V_{sbm}\sin(\omega t - 120^o \pm \varphi_2) \quad (4)$$

Finally the phasor addition of input voltage (V_s), and the chopper output voltage (V_{co}) results in compensated output voltage (V_o). i.e., $\vec{V_o} = \vec{V_s} + \overrightarrow{V_{co}}$

The compensator injects this compensating voltage in series with the supply when fault is detected. Loads connected downstream of the chopper are thus protected from the voltage disturbances.

3. REFERENCE SIGNAL COMPUTATION

This paper presents an original scheme that employs only simple calculations to extract the reference phasor desired for compensation. The phasor diagram illustrating the phenomenon of phasor addition of input source voltage with chopper output voltage is shown in Fig. 2.

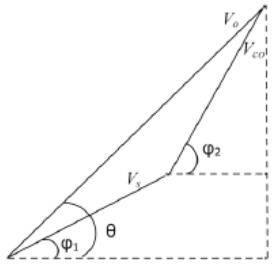

Figure.2.Phasor Illustration

Voltage control is achieved by adding the series voltage V_{co} to V_s, thus giving the load voltage V_o as shown in Fig. 2. The equations describing phasor addition of two voltages is given below.

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The magnitude of resultant voltage is given as,

$$V_0^2 = V_s^2 + V_{co}^2 + 2V_s\, V_{co}\, \cos(\varphi_1 - \varphi_2) \qquad (5)$$

Where, $V_o\angle\theta -$ Desired output voltage, $V_s\angle\emptyset_1$- Source voltage, $V_{co}\angle\emptyset_2 -$ Chopper output voltage

The controller reference signal is generated by deriving phasor using Fig. 2.

The magnitude of reference voltage is given as,

$$V_{co} = \frac{V_o\, \cos\theta - V_s\, \cos\varphi_1}{\cos\varphi_2} \qquad (6)$$

and the desired phase obtained is given by

$$\emptyset_2 = \tan^{-1}\left(\frac{V_o\, \sin\theta - V_s \sin\emptyset_1}{V_o\, \cos\theta - V_s \cos\emptyset_1}\right) \qquad (7)$$

4. PHASE SHIFTING UNIT

The phase shift circuit as shown in Fig.3 produces a sinusoidal signal at the output V_{ci} which is equal to the sinusoidal input V_{sb} with a defined phase shift (φ_2).

By varying the value of R, the desired phase shift can be obtained using eqn(8)

$$R \frac{= -\tan\left(\frac{\emptyset_2}{2}\right)}{C\omega} \qquad (8)$$

Where, φ_2- Desired phase shift, C- Capacitance, ω - Frequency of Input signal

In the above equation, the value of R is varied such that φ2 can be varied from 0 to -180 without any magnitude change.

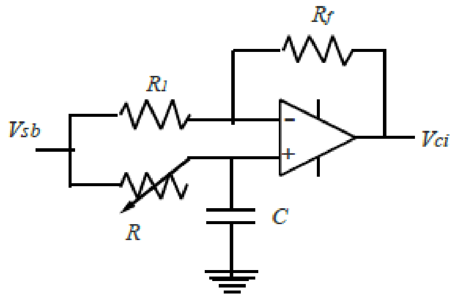

Fig. 3. Phase shift circuit Interchanging the capacitor and potentiometer changes the phase lag to a phase lead

5. BUCK-BOOST AC CHOPPER

A buck-boost voltage regulator delivers an output voltage which may be less than or greater than the applied input voltage and the output voltage polarity is opposite to that of the input voltage. The circuit diagram of buck-boost regulator is shown in Fig.4.

The output to input voltage ratio of AC-AC Chopper is given by

$$V_{co} = -\frac{D}{1-D}\, V_{ci} \qquad (9)$$

Where, V_{co} = Chopper output voltage, V_{ci} = Chopper input voltage

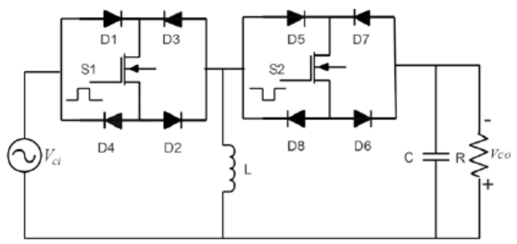

Fig. 4. Circuit diagram of Buck-Boost AC Chopper

The circuit operation during positive half cycle of the input voltage can be divided into two modes. During mode 1, switch S1 is turned on and diodes D1 and D2 are forward biased. The input current, which rises, flows through inductor L and switch S1. During mode 2, switch S1 is turned off and S2 is turned on. The current which was flowing through L, would flow through L, C, D5, D6, and the load. The energy stored in inductor L would be transferred to the load. The duty cycle for chopper circuit is obtained using the Fig.5 which is designed based on equation 9.

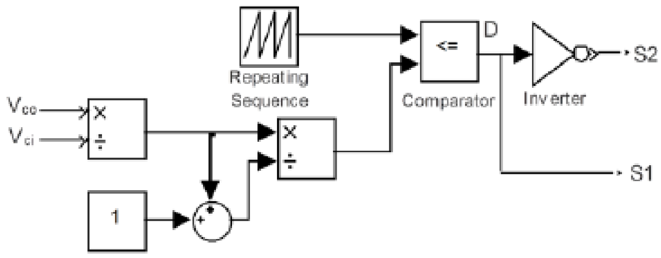

Fig. 5. Duty cycle control for AC Chopper

The waveform associated with the duty cycle control circuit is shown in Fig. 6.

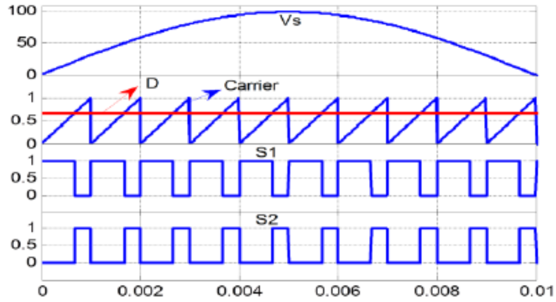

Fig.6.Gate signals during positive half cycle

$D = \frac{T_{ON}}{T_{ON}+T_{OFF}}$ = Duty cycle; $T = T_{ON} + T_{OFF}$

$f = \frac{1}{T}$ - Chopping frequency

$$V_{co} = -\left(\frac{T_{ON}}{T - T_{ON}}\right) V_{ci}$$

From the above equation it is clear that V_{co} can be controlled either by controlling T_{ON} or by f.

6. SIMULATION RESULTS

1. Source voltage, ($V_{sa} = 50\angle 40^o$) with magnitude as well as phase unbalance is shown in Fig. 7(a).
2. Input voltage to chopper ($V_{ci} = 100\angle{-27.52^o}$) is obtained by shifting phase-b voltage (V_{sb}) as shown in Fig. 7(b).
3. Fig. 7(c) shows the compensating voltage ($V_{co} = 69.57\angle{-27.52^o}$) injected by AC-Chopper.
4. The phasor addition results in magnitude and phase adjusted output voltage as shown in Fig. 7(d).

ie ., $\vec{V_o} = \vec{V_s} + \vec{V_{co}} = 100\angle 0^o$

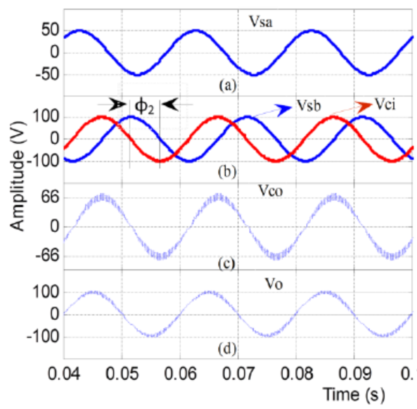

Fig.7.Simulation of single phase compensation

7. CONCLUSION

In this paper, a topology is proposed that can compensate long duration voltage sag as well as phase unbalance and a simple algorithm for reference signal generation has been derived. The compensator is capable of compensating single phase deviation using only two switches and requires no capacitor bank. Further research is focusing on developing a prototype to validate the simulation results and their extension to three phase applications.

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