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MITIGATION OF SINGLE PHASE VOLTAGE SAG, SWELL AND OUTAGE USING VOLTAGE CONTROLLED VOLTAGE SOURCE

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Keywords

Dynamic Voltage Restorer (DVR), Multi winding Transformer, voltage sag, voltage swell, single phase outage, Voltage Controlled Voltage Source, Total Harmonic Distortion

ABSTRACT

In this paper, a single phase sag and swell compensator is realized using a voltage controlled voltage source to mitigate voltage sag and swell in one phase when the voltages in other two phases are in rated condition. Each single phase compensator is constructed using one multi winding transformer, two bidirectional switches, voltage controlled voltage source and a series transformer. As each converter operates independently the compensator can properly compensate single phase voltage sag and swell. They can also compensate long-time voltage sags and swells as the power required for compensation is taken from the grid. For compensation, the other two phase voltages are added using a multi winding transformer. The added voltage is maintained at one end of the series transformer while the other end is connected to a voltage controlled voltage source. The voltage of the voltage controlled voltage source in controlled by the voltage at the phase where the compensation is needed. No modulation technique, controller and filters are required. The simulation results verify that the proposed topology can mitigate single phase voltage sag of 100% and swell of 100% with the THD of 0%.

I. Introduction

Power quality issues are very important problem and could be classified as voltage sags, swells, harmonics, unbalances, and flickers [1-3]. These issues may cause malfunction of sensitive devices in factories, buildings, and hospitals which leads to heavy losses in economy and also data [4-6]. The Dynamic Voltage Restorers (DVR) is able to compensate voltage harmonics, sags and swells thus maintaining a clean regulated voltage. The basic operation of DVR is to synthesis the compensating voltage of required magnitude, phase angle, and frequency and injecting the compensating voltage in series with the load voltage to mitigate sag and swell [7-11]. Conventionally, they depend on devices to store energy, like large capacitors or battery banks. So the duration of compensation depends upon the rating of the energy storage devices.

In the proposed topology only two bi-directional switches are used. This topology is based on direct ac/ac converter which eliminates costly and bulky energy storage elements. In this work, switches are not controlled by any PWM technique but the switches will be either in on state when the voltage disturbance occurs or in off state when the voltage is in rated condition. As a result, computation is avoided, control is simpler and compensation range of voltage sag is 100% and of the voltage swell is 100% under the condition that the other two phase voltages should be at rated condition. The simulation results are presented to clarify the capabilities of the DVR in voltage restoration.

II. SYSTEM TOPOLOGY

Fig. 1 shows the schematic diagram of the proposed system topology. It is composed of two bidirectional controlled switches, a multi winding transformer, a voltage controlled voltage source and a series transformer for each phase. The following equation can be obtained from Fig. 1:

$$\begin{aligned} Vla &= Vga + Vcon.a \\ Vlb &= Vgb + Vcon.b \\ Vlc &= Vgc + Vcon.c \end{aligned} \quad (1)$$

In (1), the first subscripts “l, g and con” indicates the load, grid, and compensating quantities respectively and the second subscript refers to the corresponding phase respectively. Considering only phase ‘a’, the voltages can be expressed as follows:

$$\begin{aligned} Vla &= Vla\sin(wt) \\ Vga &= Vga\sin(wt) \\ Vcon.a &= Vcon.a\sin(wt+\phi) \end{aligned} \quad (2)$$

In the above equations, and are the peak values of load, grid, and injected voltages, respectively. , is the phase angle of the injected voltage and is defined as follows:

$$\phi = \begin{cases} 0^\circ \ \textit{for sag} \\ 180^\circ \ \textit{for swell} \end{cases} \quad (3)$$

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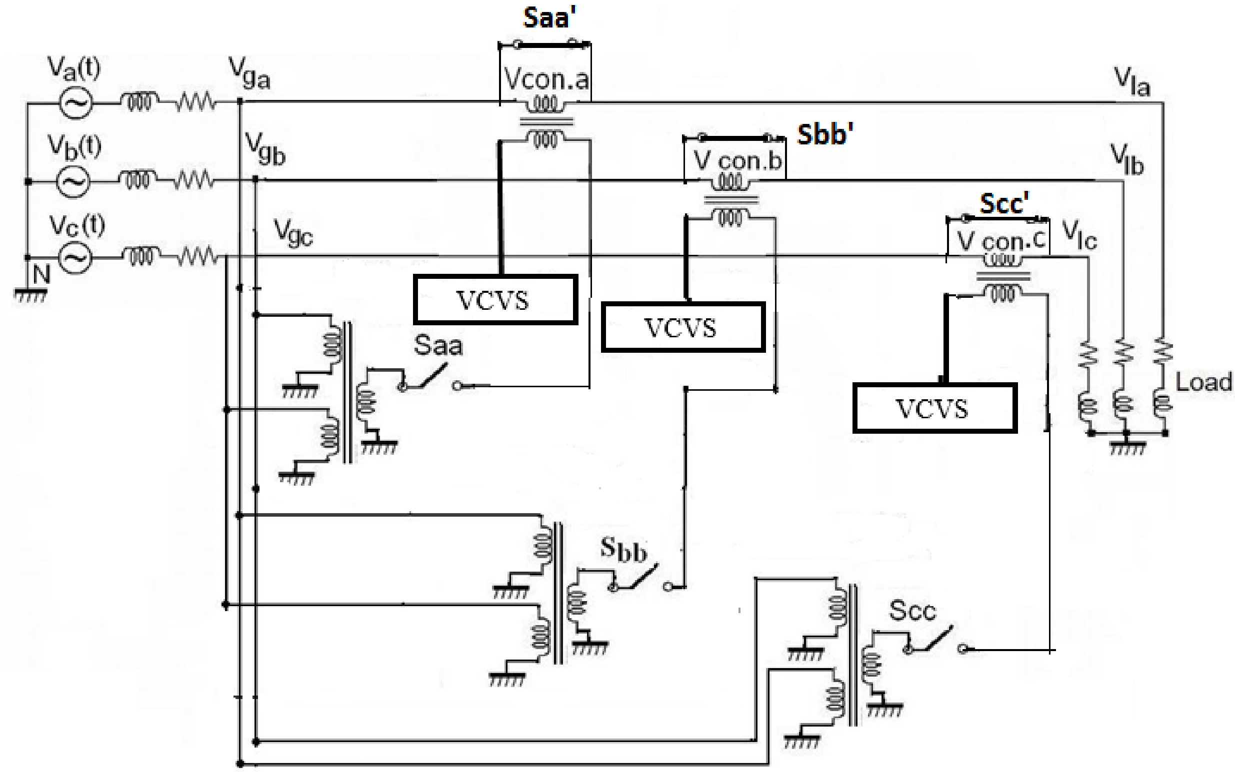

Fig 1. Proposed Topology

The bypass switches connected across the series transformers are normally closed to short-circuit the series transformer. In the case of voltage distortion, the bypass switches are opened and the system starts the compensation process.

III. CONTROL METHOD

It is assumed that the voltage sag or swell is occurred only at phase 'a' and the other phase voltages are under rated condition and also the grid and load voltages are having the same phase angle. According to Fig. 1, the following equation can be written:

$$Vla = Vga + Vcon.a \quad (4)$$

In order to mitigate the sag the injected voltage Vcon should be in phase with grid voltage. So the switch Saa is switched on and the output voltage of the multi winding transformer is –(vgb + vgc). The one end of the primary winding of the transformer is connected to the phase 'a' of the grid and the other end is connected the switch Saa. The relation between Vgb, Vgc and Vcona can be expressed as

$$Vcon.a = [-(Vgb + vgc) - Vga] \quad (5)$$

When the phase "b" and phase "c" voltages are under rated condition

$$(Vgb + Vgc) = -Va \quad (6)$$

From (5) and (6) the injected voltage $V_{con,a}$ can be represented as

$$Vcon.a = Va - Vga \quad (7)$$

From (4) and (7), the load voltage can be expressed as

$$Vla = Vga + Va - Vga \tag{8}$$

$$Vla = Va \tag{9}$$

From (9) it can be concluded that under all conditions if the other two phase voltages are under rated condition then it is possible to maintain phase ‘a’ voltage at rated condition. The above equation is valid as the transformation ratio of the series transformer is 1:1.

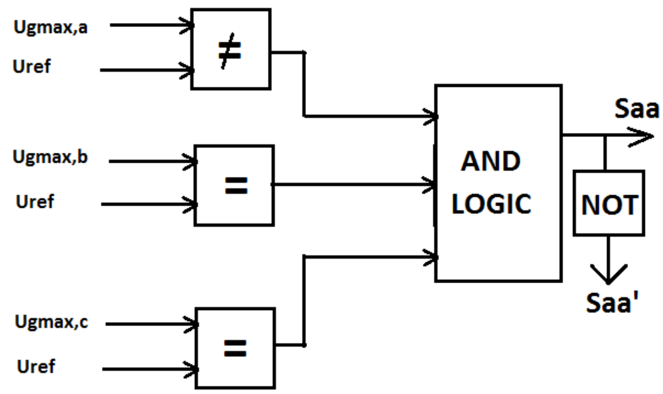

Fig. 2. Block diagram of switching pulse generation

Using the peak value of phase voltages obtained from single phase dq theory [12] the condition of the other two phase voltages are identified. When the phase ‘a’ voltage has sag or swell or outage and the phase ‘b’ and phase ‘c’ voltages are at rated condition then the switch Saa is on, and the switch saa’ is off. As voltage at one end of the series transformer is the voltage of the voltage controlled voltage source whose voltage is equal to the phase ‘a’ voltage and the other end of the series transformer is the phase ‘a’ rated voltage which is offered by adding the rated phase ‘b’ and rated phase ‘c’ voltage using two winding transformer, the difference between the voltages will be added in the line to mitigate sag, swell or outage in phase ‘a’. If the other two phase voltages are not at rated condition the compensator will not compensate even if a voltage disturbance occurs in phase ‘a’. A detailed block diagram of switching pulse generation is shown in the Fig.2.

IV. Simulation results

In the normal condition, the supply voltage is at 230V rms, 50-Hz frequency and the turns ratios of the injection transformers is 1:1. The MATLAB/SIMULINK software has been used for simulation. Fig 3 shows the ability to mitigate single phase voltage sag. Fig 4 shows the single phase voltage swell mitigating capacity. Figure 5 and figure 6 shows the compensation of swell in transient condition and single phase outage respectively.

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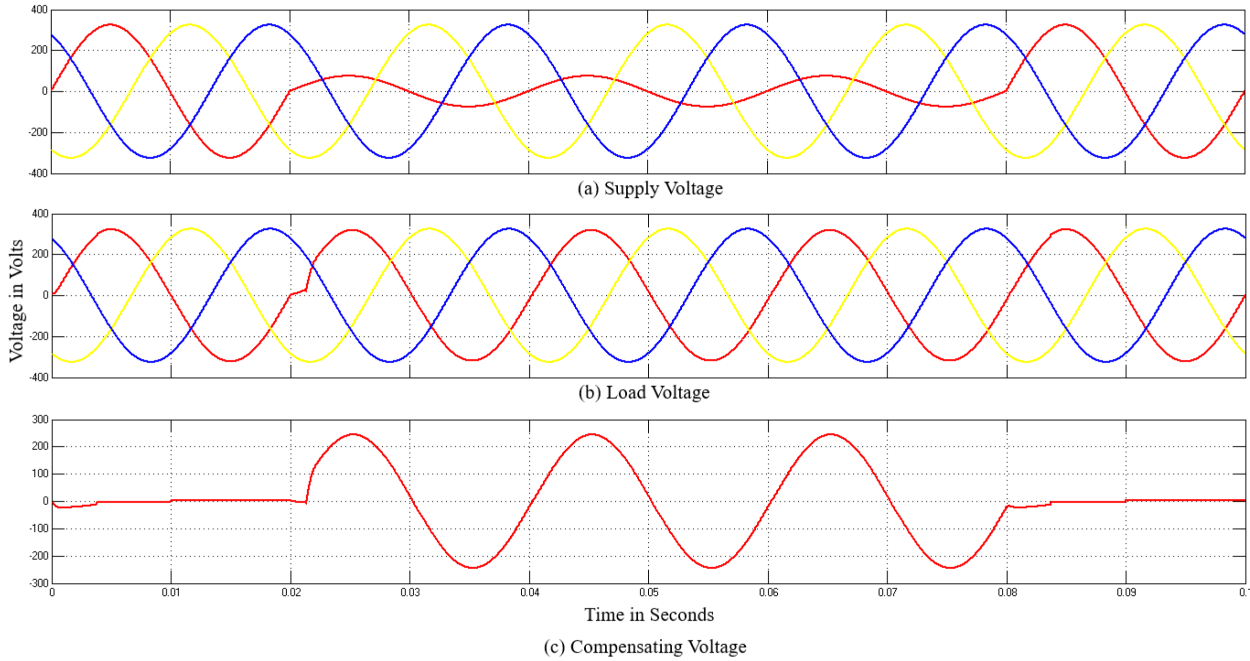


Fig 3. Mitigation of balanced voltage sag (a) Supply voltage (b) Load voltage (c) Compensating voltage

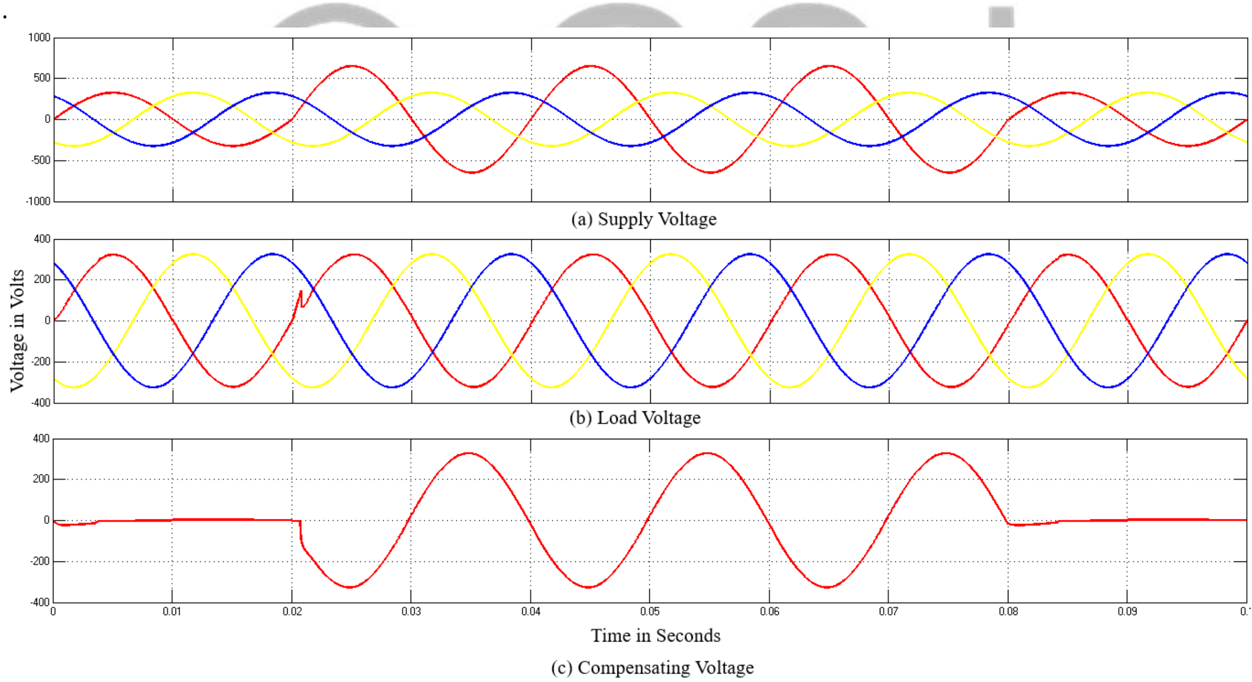
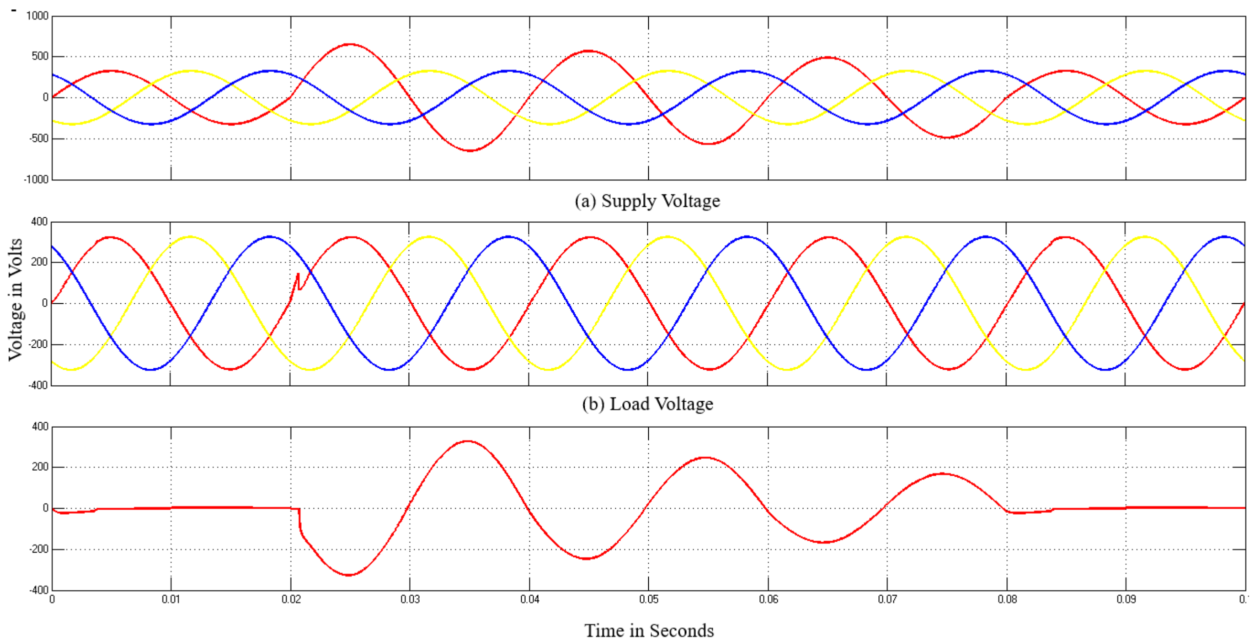


Fig 4. Mitigation of balanced voltage swell (a) Supply voltage (b) Load voltage (c) Compensating voltage

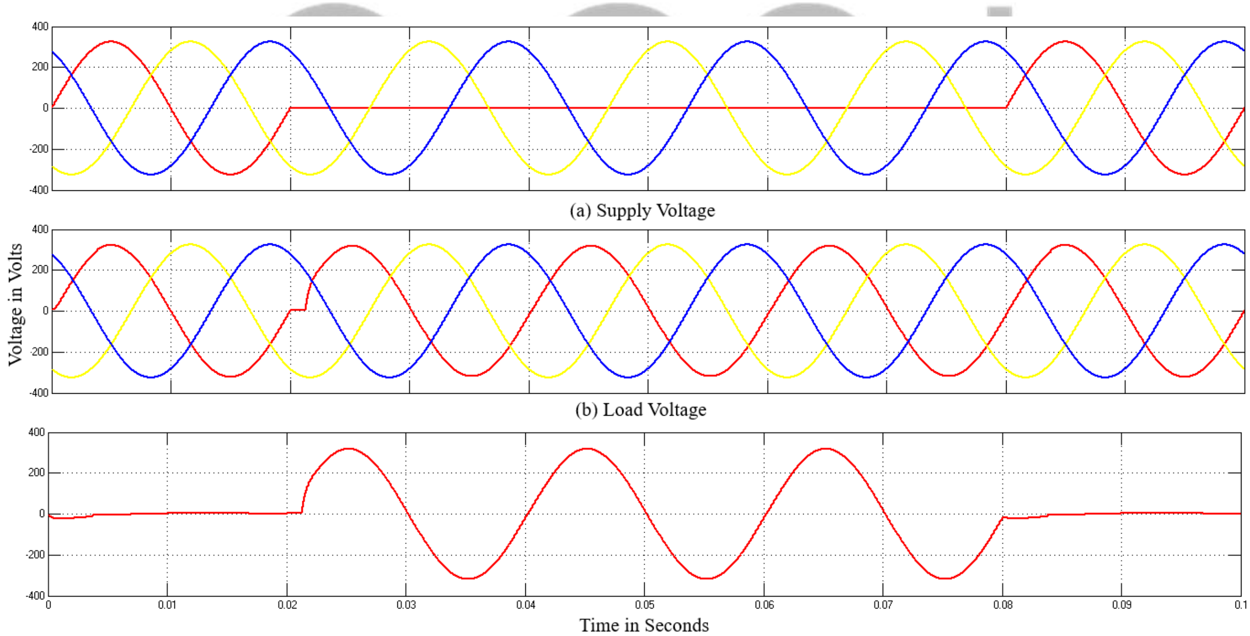


(a) Supply Voltage

(b) Load Voltage

(c) Compensating Voltage

Fig 5. Mitigation of voltage swell in transient condition (a) Supply voltage (b) Load voltage (c) Compensating voltage



(a) Supply Voltage

(b) Load Voltage

(c) Compensating Voltage

Fig 6. Mitigation of single phase outage (a) Supply voltage (b) Load voltage (c) Compensating voltage

VI. CONCLUSION

The presented system is based on direct converters so it does not require the dc link as in conventional DVRs. The absence of the dc link causes an enormous decrease in cost, weight, and volume and also avoids the maintenance of energy storage devices. Each phase direct converter is constructed using only two bidirectional switches. Control is very simple as no PWM technique is necessary for its control. The presented system is able to mitigate 100% of single phase voltage sag and voltage swell with 0% THD.

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