Mitigation of Voltage Sag, Swell and Outage without Converter

Abdul Rahman[1]

[1]*Department of Electrical and Computer Engineering,*
Institute of Technology, University of Gondar, Gondar, Ethiopia

Abstract- In this paper, a single phase dynamic voltage restorer (DVR) is realized to mitigate voltage sag and swell when the voltages in other two phases are in rated condition. The DVR does not require dc-link energy storage elements. As a result, they have less volume, weight, and cost. Each single phase compensator is constructed using one multi winding transformer, one bidirectional controlled switches and a series transformer. As each converter operates independently the DVR 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 at the point of common coupling. No modulation technique is required. So no controller and filters are needed. 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%.

Keywords – Dynamic Voltage Restorer (DVR), Multi winding Transformer, voltage sag, voltage swell, single phase outage

I. INTRODUCTION

Voltage disturbances are very important problem in industrial applications and could be classified as voltage sags, swells, harmonics, unbalances, and flickers [1]. These disturbances may cause malfunction of sensitive devices in factories, buildings, and hospitals [2] which leads to information and economic losses [3]. Voltage sag is a momentary decrease in the rms value of ac voltage from 10% to 90% of the nominal magnitude at the power frequency from 0.5 cycles to a few seconds [4]. The causes may be short-circuit faults, such as a single-line-to-ground fault in a power system and by the startup of induction motors of large ratings [4]–[6]. Voltage swell is defined as a short duration increase in the magnitude of rms voltage value from 1.1 p.u. to 1.8 p.u. of nominal supply [7]. The reasons for the occurrence of voltage swells are switching large capacitors or the removal of large loads [8]. The Dynamic Voltage Restorers (DVR) is able to compensate voltage harmonics, sags and swells thus maintaining a clean regulated voltage. 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. The cost of a DVR is chiefly determined by its power (kVA) rating and also by the control strategy used. Absence of energy storage systems, absence of series transformers and utilization of converters with reduced number of semiconductor devices and gate-driver circuits are the effective techniques to reduce the cost of the DVR.

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 [9, 10].

In the proposed DVR topology only two bi-directional switches are used. The DVR 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. DVR TOPOLOGY

Fig. 1 shows the schematic diagram of the proposed DVR topology. The DVR is composed of two bidirectional controlled switches, a multi winding transformer and a series transformer for each phase. The elimination of the dc link and energy-storage elements leads to a considerable reduction in cost, physical volume and very less maintenance. The compensating duration of the proposed DVR is unlimited since the required energy is taken from the grid. There are several configurations for bidirectional switches [11]. The switches are not controlled by any pulse width-modulation (PWM) technique. So filters are avoided. The switch will be either in on state when the voltage disturbance occurs or in off state when the voltage is in rated condition.

The following equation can be obtained from Fig. 1:

$$Vla = Vga + Vcon.a$$
$$Vlb = Vgb + Vcon.b$$
$$Vlc = Vgc + Vcon.c \tag{1}$$

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:

$$Vla = Vla\sin(wt)$$
$$Vga = Vga\sin(wt)$$
$$Vcon.a = Vcon.a\sin(wt + \phi) \tag{2}$$

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:

$$\phi = \begin{cases} 0^\circ \ \mathit{for\ sag} \\ 180^\circ \ \mathit{for\ swell} \end{cases} \tag{3}$$

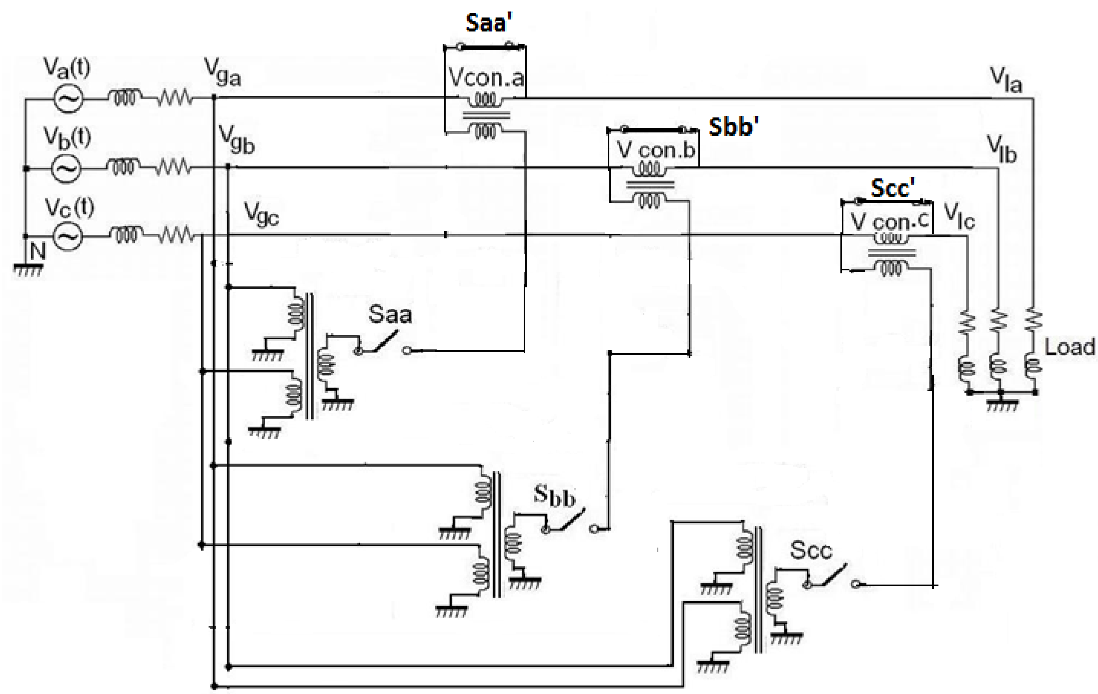

Fig 1. DVR Topology

The bypass switches connected across the series transformers are normally closed to short-circuit the DVR. In the case of voltage distortion, the bypass switches are opened and the DVR 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:

$$Vla = Vga + Vcon.a \tag{4}$$

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

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

When the phase “b” and phase “c” voltages are under rated condition

$$(Vgb + Vgc) = -Va \tag{6}$$

From (5) and (6) the injected voltage Vcon,a can be represented as

$$Vcon.a = Va - Vga \tag{7}$$

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.

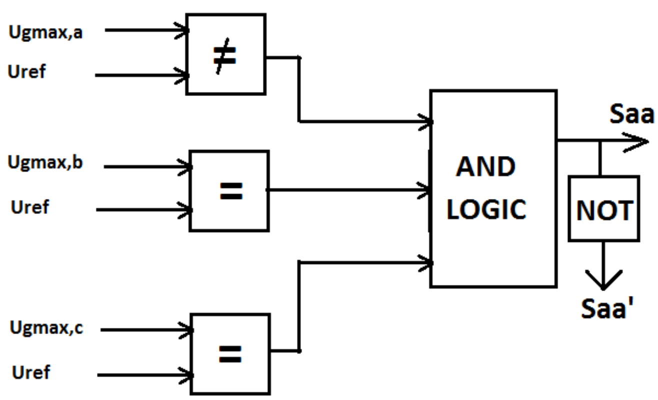

Fig. 2. Block diagram of switching pulse generation

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. 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, grid voltage is at 230V rms and 50-Hz frequency. The turns ratios of the injection transformers is 1:1. Choosing this turns ratio for the injection transformers, the DVR is able to compensate voltage sags of 100%, single phase outage and voltage swells of 100% magnitudes. The MATLAB/SIMULINK software has been used for simulation. Fig 3 shows the DVR’s ability to mitigate single phase voltage sag from 0% to 100%. It can be observed from the Fig 3(a) that up to 20ms the load voltage is maintained at 1 p.u and at 20ms the voltage sag occurs till 160ms. Fig 3(b) and Fig 3(c) shows the load voltage and the compensated voltage produced by the DVR. Fig 4 shows the single phase voltage swell mitigating capacity of the DVR. It can be observed from the Fig 4(a) that up to 20ms the load voltage is rated value and at 20ms the voltage swell occurs till 160ms. Fig 4(b) and Fig 4(c) shows the load voltage and the compensated voltage produced by the DVR.

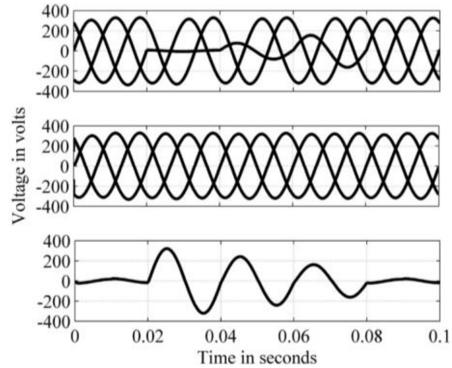

Fig 3. Mitigation of voltage sag (a) Grid voltage (b) Load voltage (c) Compensation voltage produced by the DVR
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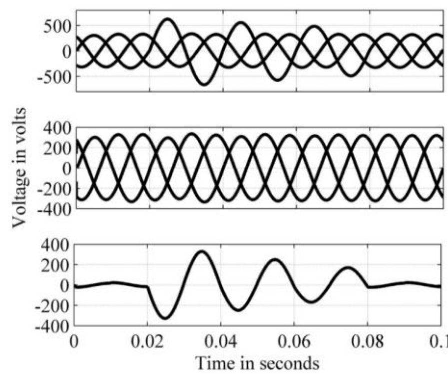

Fig 4. Mitigation of balanced voltage swell (a) Grid voltage (b) Load voltage (c) Compensation voltage produced by the DVR

V. EXPERIMENTAL RESULTS

A single phase DVR described in this paper has been fabricated in order to verify the design procedure. The PIC16F877A microcontroller has been used to control the switches. The rating of the multi winding transformer is 480VA, 48V with the transformation ratio of 1:1. IRFP460 power MOSFET switches of rating 500V, 20A were used to synthesize the DVR. The rating of the series transformer is 240VA, 24V with the transformation ratio of 1:1. The hardware prototype has been designed for a normal voltage of 24V, 50Hz.

The ability of the DVR to mitigate voltage sag of 75% at steady state is shown in Fig.5. The transient response of the DVR during compensation of voltage sag can be seen in Fig.6. Mitigation of a single phase outage is shown in Fig.7. Voltage swell mitigation in steady state and transient condition is shown in Fig.8 and Fig.9 respectively.

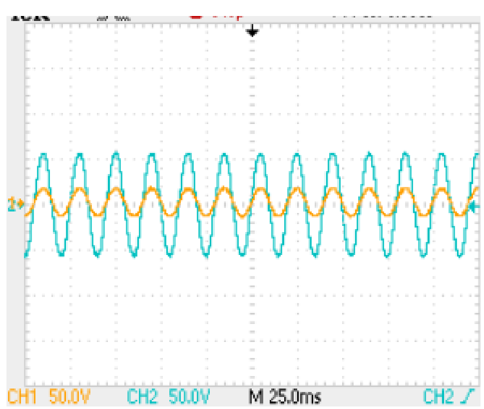

Fig. 5. Voltage sag mitigation at steady state, Grid voltage waveform (inner)

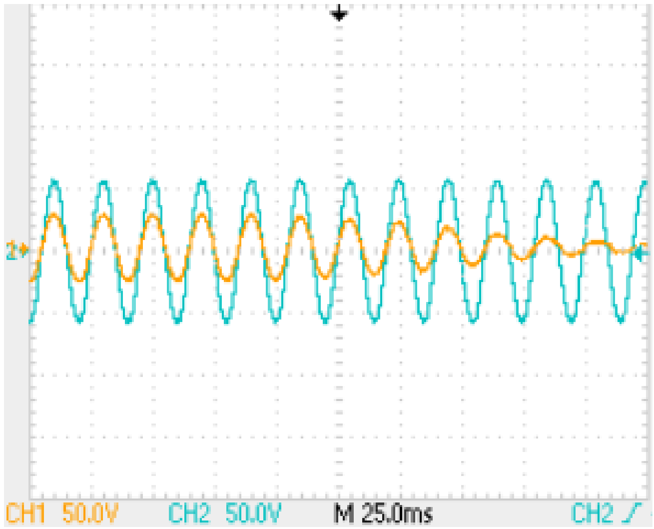

Fig. 6. Voltage sag mitigation at transient state, Grid voltage waveform (inner)

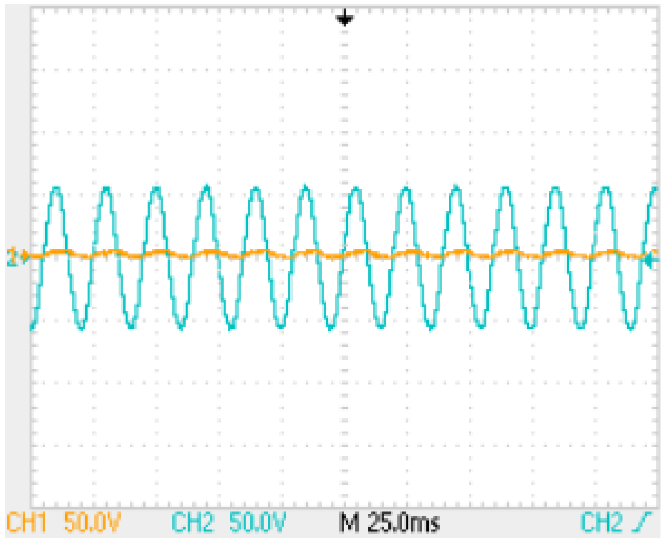

Fig. 7. Single phase outage mitigation, Grid voltage waveform (inner)

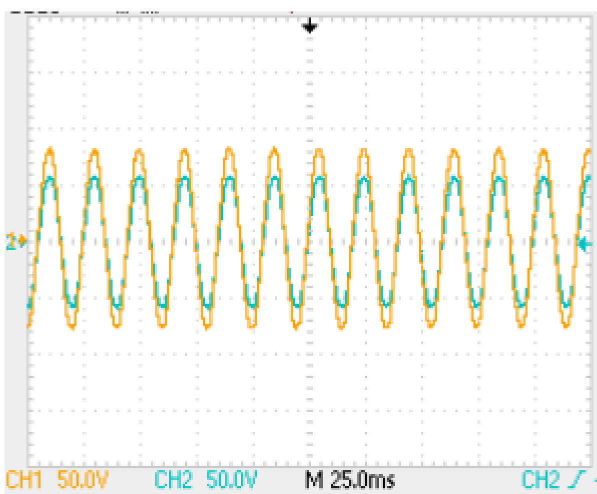

Fig. 8. Voltage swell mitigation at steady state, Grid voltage waveform (outer)

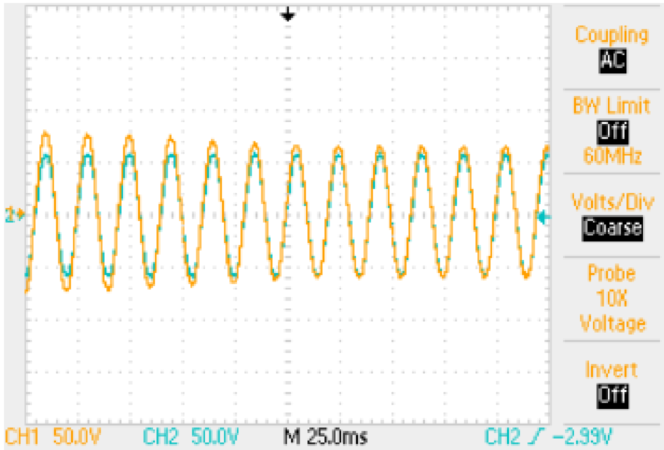

Fig. 9. Voltage sag mitigation at transient state, Grid voltage waveform (outer)

VI. CONCLUSION

The presented DVR 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 of the DVRs and also avoids the maintenance of energy storage devices. Each phase direct converter is constructed using only two bidirectional switches. Control of DVR is very simple as no PWM technique is necessary for its control. The presented DVR is able to mitigate 100% of single phase voltage sag and voltage swell with 0% THD.

VII. REFERENCES

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