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Maximum voltage sag compensation using direct converter by modulating the carrier signal

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ABSTRACT

The aim of this paper is to achieve maximum voltage sag compensation of 52% using direct converter based DVR. The DVR topology has only two switches. The DVR is designed to compensate the voltage sag in a phase by taking power from the same phase. A direct converter is connected between the series transformer and the line in which sag compensation is to be achieved. If the actual amplitude of the error signal is used and the amplitude of carrier signal is kept at 1 unit, it is possible to achieve only 22% of sag compensation. If the amplitude of the carrier signal is modulated according to the percentage of existing sag, 52% of the sag is compensated through ordinary PWM technique with the THD less than 5%. Matlab Simulation results are presented for the validating the analysis.

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1. INTRODUCTION

Though we have many power quality issues like sag, swell, flicker, harmonics, voltage sag is considered to be the severe issue as it affects the operation of sensitive loads like computer, micro controller, Digital Signal Processor, FPGA. As most of the industries are automated, the entire operation of the industries depends upon the operating condition of these sensitive loads. When sag or swell occurs in the industrial areas, these sensitive loads are getting affected, leading to immoral operation of the entire industry [1-8]. For the compensation of voltage sag, Dynamic Voltage Restorer (DVR) considered to be an effective device when compared to other devices like UPS, STATCOM [9-11]. Though many DVR topologies like DVR based on energy storage devices (like batteries, capacitors and super capacitors) have been proposed [12-17], in this paper DVR based on direct convert is presented [18-22]. The compensating range of the DVRs based on energy storage devices, depends upon the rating of the energy storage devices, but in the DVRs based on direct converters, it is based on the availability of voltage in the phase from which the power is taken for compensation and modulating techniques. In the DVR topologies based on direct converter, so far a maximum sag compensation of 33% had been done [23]. Even from the analysis done in this paper (direct converter based DVR, in which, to mitigate voltage sag in one phase the power will be taken from the same phase) by ordinary PWM technique, it is possible to achieve only 22% of sag compensation. If the carrier signal is modulated according to the percentage of existing sag, it is been shown in this paper that it is possible to achieve 52% of sag compensation.

2. PRINCIPLE OF OPERATION

The topology of the direct converter based DVR is been shown in the Figure 1. It has a direct converter, a LC filters at the input side of the direct converter and another LC filter at the output side of the converter, and a series transformer. The LC filters are to minimize the harmonics due to switching. The direct converter has two bidirectional switches S1 and S2 as shown in the Figure 1. The topology of the bidirectional switch is shown in the Figure 2.

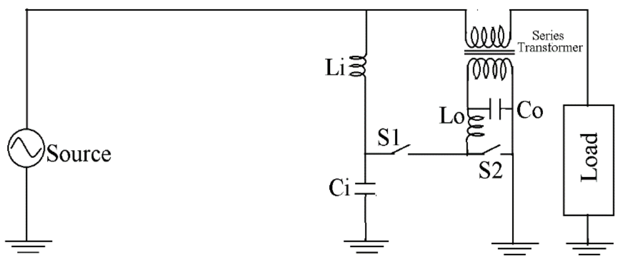

Figure 1. Topology of the DVR

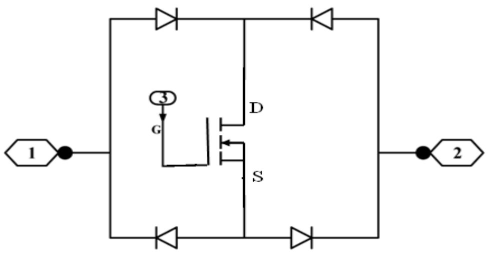

Figure 2. Topology of the bidirectional switch

When the supply voltage is at rated value, the switch S1 is open and switch S2 is closed. In this condition, the secondary of the series transformer is short circuited which results in zero voltage injection and the load voltage is maintained at its rated value. When the sag occurs, the DVR will synthesis the compensating voltage by taking power from the same phase and operating the switches S1 and S2 alternatively. The compensating voltage is added in phase with the supply voltage through the series transformer. The turns ratio of the series transformer is 1:1.

3. CONTROL ALGORITHM

The supply side voltage is measured and the peal value of the instantaneous voltage is calculated using single phase dq theory [24-26]. It is compared with the peak value of the rated voltage to generate the error signal. The error signal is compared with the carrier to generate PWM for controlling the switches as shown in the Figure 3.

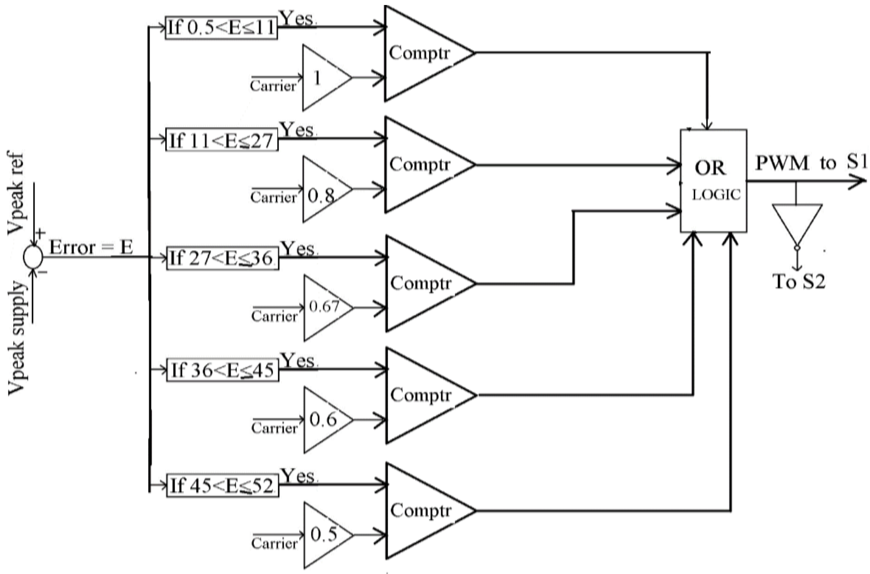

Figure 3. Block diagram for PWM generation with modulated error signal

In order to generate the PWM, the amplitude of the carrier is signal is kept at 1 unit. The actual error signal in per unit is compared with the carrier signal. It is been observed from the table 1that if the actual error signal is used to generate PWM, it is possible to achieve only 22% of sag compensation. Though there is a compensation by the DVR for more than 22% of sag, the load voltage is not met with the IEEE standard. But it is possible to improve the range of sag compensation, since sufficient voltage is available at the supply side to mitigate sag up to 52%. It could be observed from the Table 1 that, for a sag of 22%, the duty cycle of the PWM is only 22%. So by increasing the duty cycle of the PWM the compensating range also could be increased. The duty cycle could be increased by modulating the carrier signal amplitude according to the percentage of sag. The carrier signal is modulated in such a way that, if the sag is 0 to 11%, the carrier is not modulated and the actual error is compared with the carrier to generate the PWM to control the switches. For a sag of more than 11% and less than or equal to 27%, the error is amplitude of the carrier signal is kept at 0.8 unit. If the sag is more than 27% and less than or equal to 36%, the carrier is amplitude modulated by a gain of 0.67. For the sag of more than 36% and less than or equal to 45%, the carrier is amplitude modulated by a gain of 0.6. For the sag of more than 45% and less than or equal to 52%, the carrier is modulated by the gain of 0.5. It could be observed from the Table 2 that the compensated load voltage for the chosen modulation factor is maintained within the IEEE standard value.

Table 1. Possible compensation without modulating the carrier signal

Supply Voltage in Volts	% of Sag	Error	Duty Cycle of PWM	Compensating voltage generated by the DVR = Supply Voltage * Duty Cycle	LoadVoltage = Supply Voltage + Duty Cycle
100	0%	0	0	0	100
90	10%	10	10%	9	99
80	20%	20	20%	16	96
78	22%	22	22%	17.16	95.16
77	23%	23	23%	17.71	94.71
76	24%	24	24%	18.24	94.24
70	30%	30	30%	21	91
60	40%	40	40%	24	84
50	50%	50	50%	25	75

Table 2. Possible Compensation by modulating the carrier signal

Vsupply	Sag in %	Error in %	Load Voltage for Modulating Factor of				
			1	0.8	0.67	0.6	0.5
100	0	0	100.0	100.0	100.0	100.0	100.0
99	0.01	0.01	100.0	100.2	100.5	100.7	101.0
98	0.02	0.02	100.0	100.5	100.9	101.3	101.9
97	0.03	0.03	99.9	100.6	101.3	101.9	102.8
96	0.04	0.04	99.8	100.8	101.7	102.4	103.7
95	0.05	0.05	99.8	100.9	102.1	102.9	104.5
95	0.05	0.05	99.8	100.9	102.1	102.9	104.5
94	0.06	0.06	99.6	101.1	102.4	103.4	105.3
93	0.07	0.07	99.5	101.1	102.7	103.9	106.0
92	0.08	0.08	99.4	101.2	103.0	104.3	106.7
91	0.09	0.09	99.2	101.2	103.2	104.7	107.4
90	0.1	0.1	99.0	101.3	103.4	105.0	108.0
89	0.11	0.11	98.8	101.2	103.6	105.3	108.6
88	0.12	0.12	98.6	101.2	103.8	105.6	109.1
87	0.13	0.13	98.3	101.1	103.9	105.9	109.6
86	0.14	0.14	98.0	101.1	104.0	106.1	110.1
85	0.15	0.15	97.8	100.9	104.0	106.3	110.5
84	0.16	0.16	97.4	100.8	104.1	106.4	110.9
83	0.17	0.17	97.1	100.6	104.1	106.5	111.2
82	0.18	0.18	96.8	100.5	104.0	106.6	111.5
81	0.19	0.19	96.4	100.2	104.0	106.7	111.8
80	0.2	0.2	96.0	100.0	103.9	106.7	112.0
79	0.21	0.21	95.6	99.7	103.8	106.7	112.2
78	0.22	0.22	95.2	99.5	103.6	106.6	112.3
77	0.23	0.23	94.7	99.1	103.4	106.5	112.4
76	0.24	0.24	94.2	98.8	103.2	106.4	112.5
75	0.25	0.25	93.8	98.4	103.0	106.3	112.5
74	0.26	0.26	93.2	98.1	102.7	106.1	112.5
73	0.27	0.27	92.7	97.6	102.4	105.9	112.4
72	0.28	0.28	92.2	97.2	102.1	105.6	112.3
71	0.29	0.29	91.6	96.7	101.7	105.3	112.2
70	0.3	0.3	91.0	96.3	101.3	105.0	112.0
69	0.31	0.31	90.4	95.7	100.9	104.7	111.8
68	0.32	0.32	89.8	95.2	100.5	104.3	111.5
67	0.33	0.33	89.1	94.6	100.0	103.9	111.2
66	0.34	0.34	88.4	94.1	99.5	103.4	110.9
65	0.35	0.35	87.8	93.4	99.0	102.9	110.5
64	0.36	0.36	87.0	92.8	98.4	102.4	110.1
63	0.37	0.37	86.3	92.1	97.8	101.9	109.6

Table 2. Possible compensation by modulating the error signal (*continue*)

Vsupply	Sag in %	Error in %	Load Voltage for Modulating Factor of				
			1	0.8	0.67	0.6	0.5
62	0.38	0.38	85.6	91.5	97.2	101.3	109.1
61	0.39	0.39	84.8	90.7	96.5	100.7	108.6
60	0.4	0.4	84.0	90.0	95.8	100.0	108.0
59	0.41	0.41	83.2	89.2	95.1	99.3	107.4
58	0.42	0.42	82.4	88.5	94.4	98.6	106.7
57	0.43	0.43	81.5	87.6	93.6	97.9	106.0
56	0.44	0.44	80.6	86.8	92.8	97.1	105.3
55	0.45	0.45	79.8	85.9	91.9	96.3	104.5
54	0.46	0.46	78.8	85.1	91.1	95.4	103.7
53	0.47	0.47	77.9	84.1	90.2	94.5	102.8
52	0.48	0.48	77.0	83.2	89.3	93.6	101.9
51	0.49	0.49	76.0	82.2	88.3	92.7	101.0
50	0.5	0.5	75.0	81.3	87.3	91.7	100.0
49	0.51	0.51	74.0	80.2	86.3	90.7	99.0
48	0.52	0.52	73.0	79.2	85.3	89.6	97.9

4. SIMULATION RESULTS

For easy understanding, the rated value of supply voltage is set with the amplitude of 100V, 50Hz. The DVR operates with the filter inductance of 1mH and filter capacitance of 15uF at the carrier frequency of 4 KHz. The following Figures 4-8 shows the ability of the control algorithm to mitigate sag from 0 to 52%.

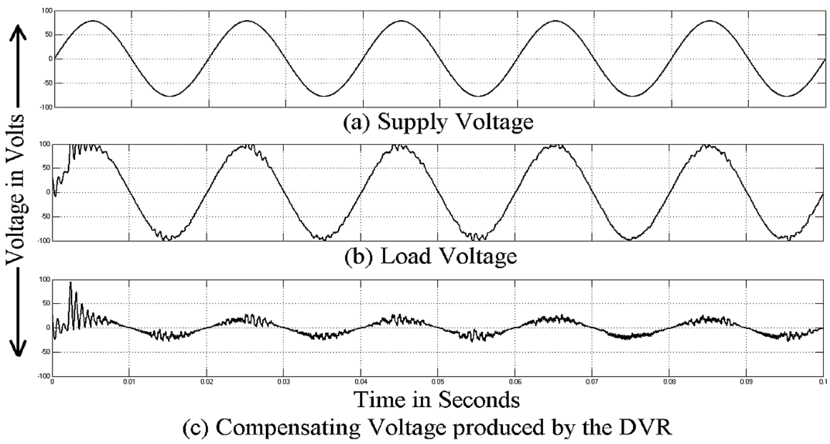

Figure 4. Sag compensation of 22%

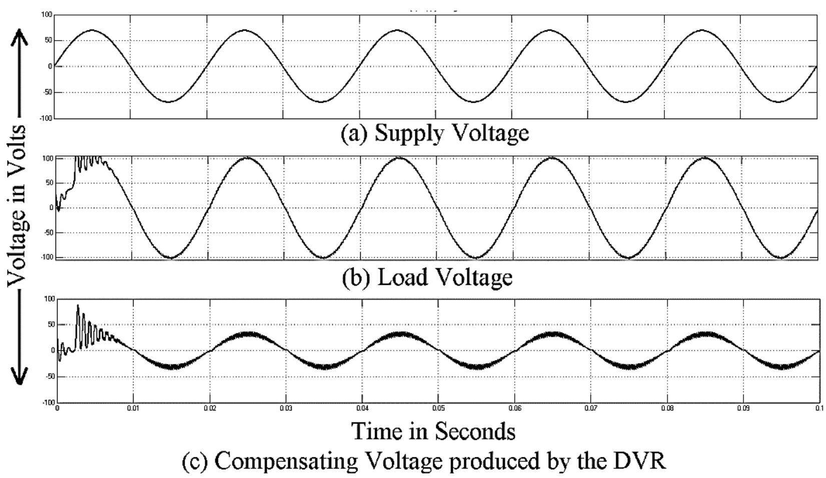

Figure 5. Sag compensation of 30%

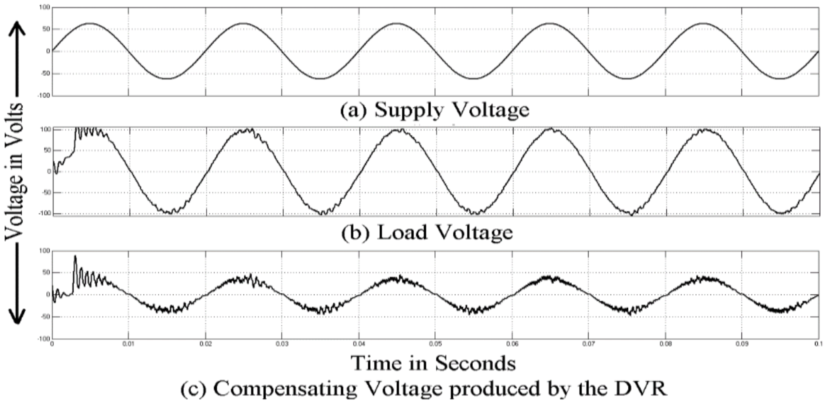

Figure 6. Sag compensation of 37%

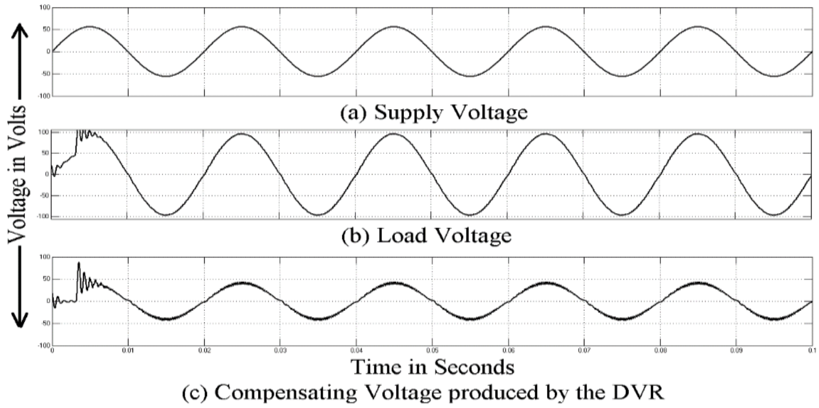

Figure 7. Sag compensation of 45%

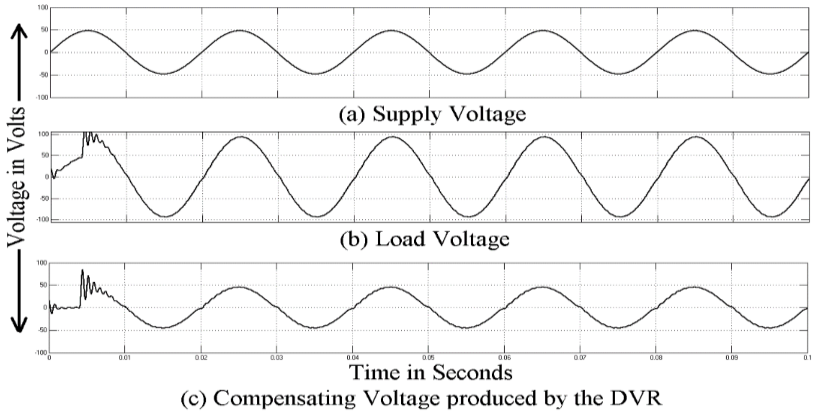

Figure 8. Sag Compensation of 52%

5. CONCLUSION

As the DVR is constructed using direct converter, energy storage devices are avoided which leads to saving of cost, space, weight and maintenance. During compensation only two switches are alternatively modulated. Thus switching losses are minimized and switching pulse generation is easier. With all these advantages, it is been demonstrated in this paper that it is possible to achieve 52% of sag compensation by modulating the carrier signal according to the percentage of voltage sag, using a DVR based on direct converter with THD less than 5%.

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