VOLTAGE SAG MITIGATION USING PV CONNECTED DYNAMIC VOLTAGE RESTORER

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Abstract: Voltage sag is a major and common power quality problem in power system network. To mitigate voltage sag, a custom power device-dynamic voltage restorer (DVR) is used in this paper. Proportional-Integral controller with pulse width modulation is used as control scheme. Photovoltaic system has been used as a DC source of DVR. Faults are created for voltage sag. Performance of the system has been investigated under different fault conditions.

Keywords- Dynamic Voltage Restorer, Faults, Photovoltaic, Voltage Sag.

I. INTRODUCTION

Power electronics and microprocessor based devices are increasing in industry. These devices are very sensitive to any variation in supply. Problems in the quality of power (sag, swell, flicker, harmonics etc.) can affect the performance of sensitive load and can cause data as well as financial loss to the consumer [1, 2]. Therefore attention toward power quality (PQ) has been increased in recent fast few years. One of the most common PQ problem is voltage sag [1-4].

Voltage sag is defined as the reduction in RMS voltage between 0.1 and 0.9 p.u. for the time duration of 0.5 cycle to 1 min. [5-6]. Sources of voltage sag are generally, faults in network, sudden energizing of transformers or starting of large loads [7]. Sags can cause complete shutdown in the industry and cost of interruption may be very large. Therefore to protect sensitive loads, mitigation devices have been developed which maintain the supply to acceptable range. Earlier un-interruptible power supply (UPS) was developed but UPS is not the optimum solution in industry, where load are generally in the range of MW [8]. Dynamic voltage restorer (DVR) is accepted as the most economic device to mitigate sag of large loads [9-11].

DVR is a series connected custom power device which injects AC voltage is series with line to improvement the voltage quality. Energy injection in the distribution line depends on the capacity of energy storage device. If voltage is injected in-phase with line voltage then magnitude of injected voltage is minimum [1].

In this paper, configuration of DVR is explained in section II. Section III presents the proposed system with control technique of DVR. Results of the system is analysed in section IV. From the simulation results conclusion is drawn in section V.

II. DVR CONFIGURATION

DVR circuit mainly consists of a) Inverter, b) Energy storage device, c) Injection transformer and d) Filter [2, 12]. Voltage source inverter is connected to the low voltage side of series transformer with filter. Input DC voltage of inverter is supplied by energy storage device. A briefly explanation of DVR components are following:

A. *Inverter:* This is power electronics based device which converters DC voltage, supplied by the energy storage device, into AC voltage. Voltage source inverter is used in DVR. Since step up transformer is connected in the system therefore high voltage rating inverter is not required [12, 13].
B. *Energy Storage Device:* Energy storage device supplies power to the load during sag. Some of the energy storage devices are, lead acid battery, flywheel, super capacitor, super conducting magnetic energy storage (SMES) etc. For flywheel AC-AC converter is used

while for batteries, SMES and super capacitor, inverters are used [2].

C. *Injection Transformer:* To inject the voltage in series with distribution line, three single phase step-up transformers are used. To avoid the saturation, size of the transformer is chosen such that it can handle double value of flux requirement [2].

D. *Filter:* Since DVR is a power electronics based device, hence filter is needed for harmonics mitigation. Filter can be placed either side of transformer but it is generally used at low voltage side because at this side, it is closer to harmonic source [2].

Advance inverter like, multi-level inverter can also be used to reduce harmonics in the system and to avoid bulky sized filter.
Basic configuration of DVR is shown in fig. 1.

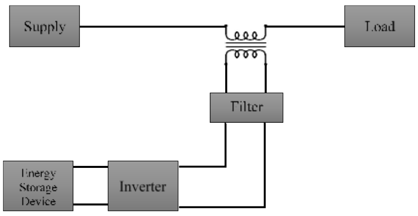


Fig. 1 Basic Configuration of DVR

III. PV CONNECTED DVR

Due to clean and green power source, photovoltaic (PV) is very good alternative of conventional energy resources. The output of PV system is DC, therefore it can be used as DC energy source. In the proposed system, PV is used as DC energy source of DVR. The proposed system is shown in fig. 2. In the practical life, output of PV depends on weather conditions therefore another energy storage device (like super capacitor or fuel cell) can also be used with switch.

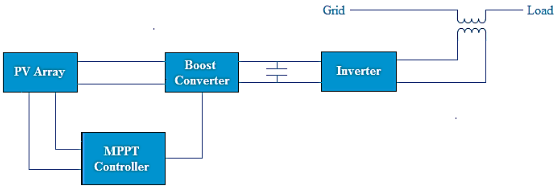


Fig 2 Block Diagram Representation of PV Connected DVR

Proportional-Integral (PI) controller is used in this system. The main objective of control scheme is to detect sag, measure required voltage to load and inject missing voltage to the load by generating triggering pulse to the inverter. The PI control scheme is shown in fig. 3.

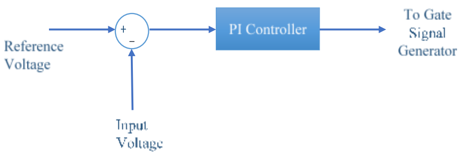


Fig. 3 Control Strategy of DVR

Fault is created for voltage sag event. Load voltage magnitude is compared with reference voltage (1p.u.) and difference signal is fed to the PI controller. Pulse width modulation technique is used for switching of inverter. Parameters of test model is shown in following table:

Parameters	Values
3-Φ Source	13 kV, 50 Hz
Step-up Transformer	Yg/Δ, 13 kV/220 kV
Transmission Line	100 km long, π section line, R_1 = 0.01273 Ω/km, R_0 = 0.3864 Ω/km, L_1 = 0.9337 mH/km, L_0 = 4.1264 mH/km, C_1 = 12.74 nF/km, C_0 = 7.751 nF/km
Step-down Transformer	Y/Δ, 220 kV/11 kV
Series Injected Transformer	11 kV/9 kV
Load	R = 0.1 Ω, L = 0.20 H
Inverter	IGBT based, 3 arms, 6 Pulse Bridge
PI Controller	K_P = 0.5, K_i = 50, Sampling Time=50 µs

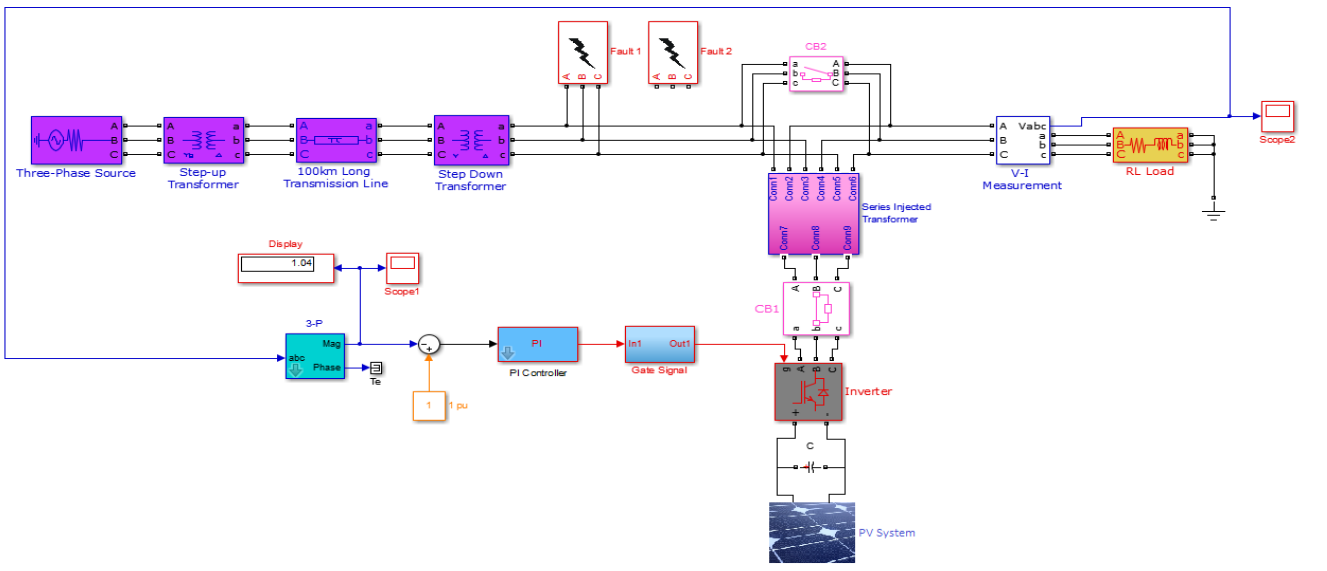
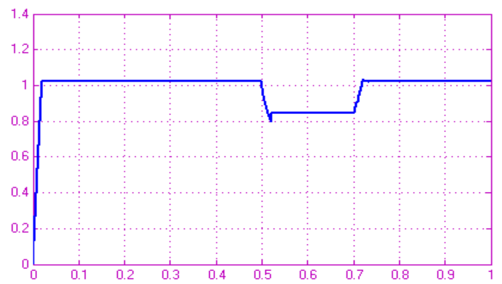


Fig. Simulink Model of PV Connected Dynamic Voltage Restorer

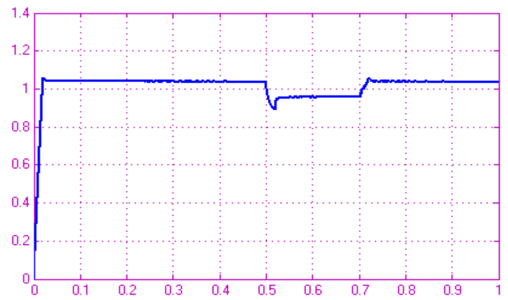
IV. SIMULATION RESULTS

To investigate the performance of system, simulation is carried out under different fault conditions. In each condition, line voltage is compared with and without DVR. System performance under different cases are following:

Case 1. A 3-Φ fault is created at point A for voltage sag. Fault resistance is taken as 0.70 Ω for the transition time of 0.5s to 0.7s. When system is operated without DVR, then voltage sag of 15% occur in the load voltage. When system is operated with DVR then voltage sag is reduced from 15% to 4%. Output voltage of PV system is considered as 4kV. Voltage magnitude in p.u. is shown in fig. 4.



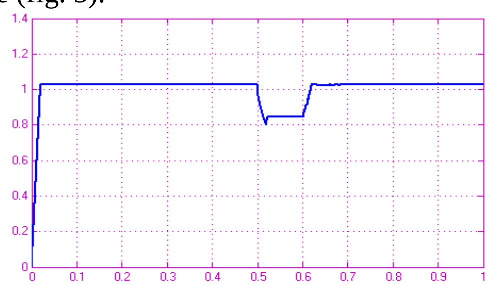
(a)



(b)

Fig. 4 (a) Line voltage without DVR, (b) Line voltage with DVR

When transition time of fault is considered as 0.5s to 0.6s then also compensation value of system is same (fig. 5).



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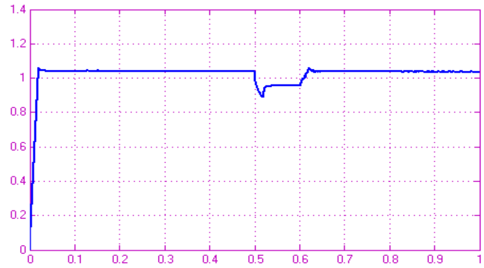
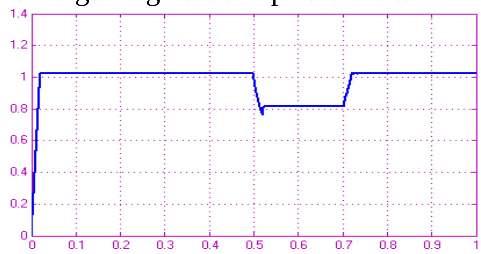


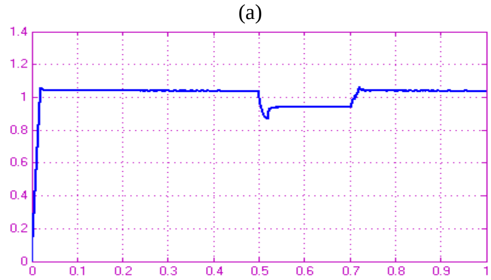
(b)

Fig. 5 Line Voltage without DVR (a) and with DVR (b)

Case 2. A 3-Φ fault is created at point A for voltage sag. Fault resistance is taken as 0.60 Ω for the transition time of 0.5s to 0.7s. When system is operated without DVR, then voltage sag of 19% occur in the load voltage. When system is operated with DVR then voltage sag is reduced from 19% to 6%. Output voltage of PV system is considered as 4kV. Voltage magnitude in p.u. is shown in fig. 6.



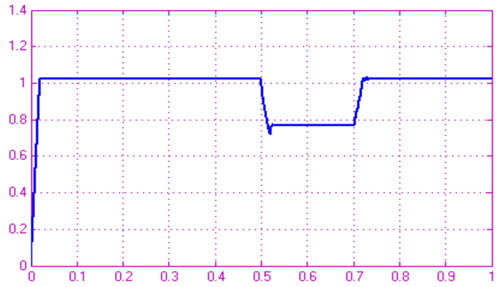
(a)



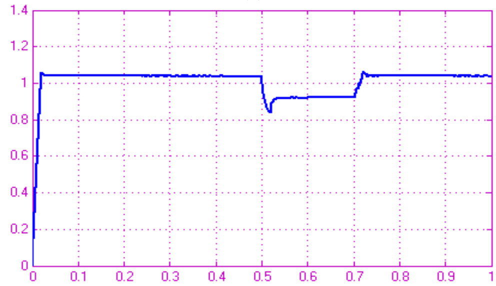
(b)

Fig. 6(a) Line voltage without DVR, (b) Line Voltage with DVR

Case 3. A 3-Φ fault is created at point A for voltage sag. Fault resistance is taken as 0.50 Ω for the transition time of 0.5s to 0.7s. When system is operated without DVR, then voltage sag of 23% occur in the load voltage. When system is operated with DVR then voltage sag is reduced from 23% to 8%. Output voltage of PV system is considered as 4kV. Voltage magnitude in p.u. is shown in fig. 7.



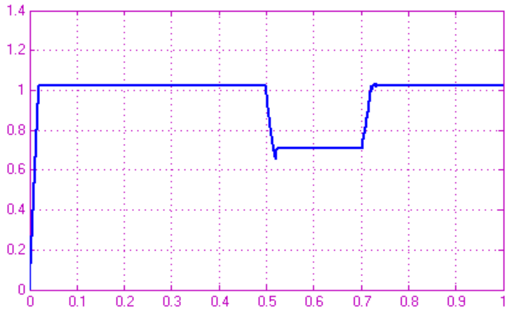
(a)



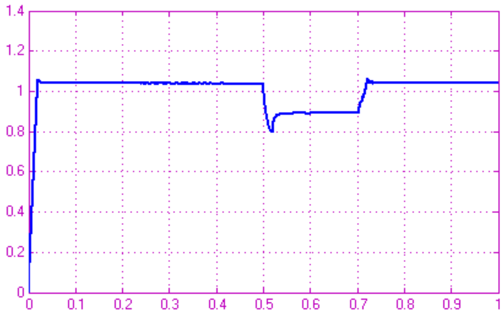
(b)

Fig. 7 (a) Line voltage without DVR (b) voltage with DVR

Case 4. A 3-Φ fault is created at point A for voltage sag. Fault resistance is taken as 0.40 Ω for the transition time of 0.5s to 0.7s. When system is operated without DVR, then voltage sag of 29% occur in the load voltage. When system is operated with DVR then voltage sag is reduced from 29% to 10%. Output voltage of PV system is considered as 4kV. Voltage magnitude in p.u. is shown in fig. 8.



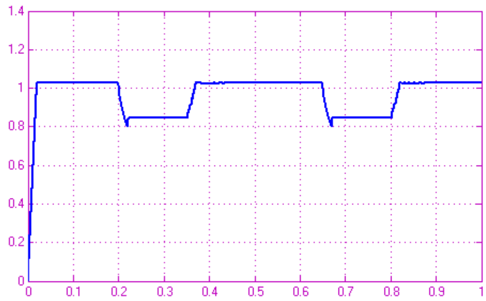
(a)



(b)

Fig. 8 (a) Line voltage without DVR, (b) Voltage with DVR

Case 5. Two 3-Φ fault is created at point A and B for multi-sag. Fault resistance for both cases is taken as 0.70 Ω for the transition time of 0.2s to 0.35s and 0.65s to 0.8s. When system is operated without DVR, then voltage sags of 15% for both transition times occur in the load voltage. When system is operated with DVR then voltage sag is reduced from 15% to 4%. Output voltage of PV system is considered as 4kV. Voltage magnitude in p.u. is shown in fig. 9.



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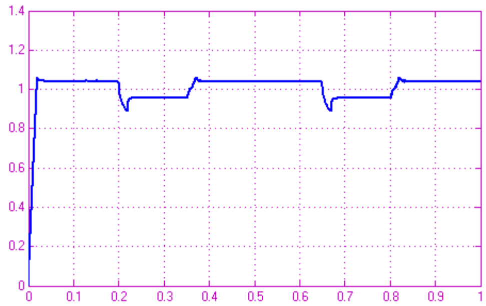
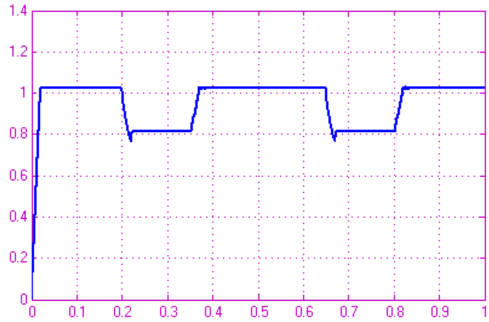


(b)

Fig. 9 (a) Line Voltage without DVR, (b) Voltage with DVR

Case 6. Two 3-Φ fault is created at point A and B for multi-sag. Fault resistance for both cases is taken as 0.60 Ω for the transition time of 0.2s to 0.35s and 0.65s to 0.8s. When system is operated without DVR, then voltage sags of 19% for both transition times occur in the load voltage. When system is operated with DVR then voltage sag is reduced from 19% to 6%. Output voltage of PV system is considered as 4kV. Voltage magnitude in p.u. is shown in fig. 10.



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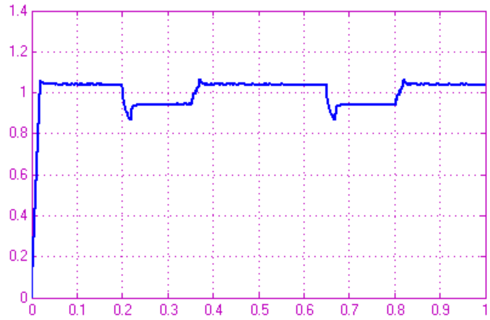
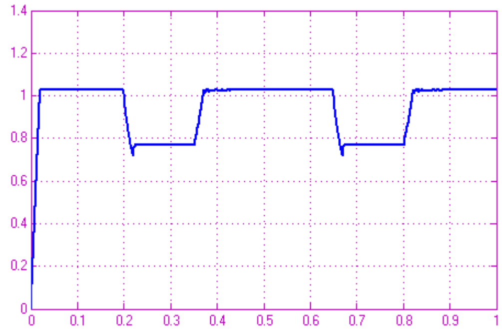


(b)

Fig. 10 (a) Line voltage without DVR, (b) Voltage with DVR

Case 7. Two 3-Φ fault is created at point A and B for multi-sag. Fault resistance for both cases is taken as 0.50 Ω for the transition time of 0.2s to 0.35s and 0.65s to 0.8s. When system is operated without DVR, then voltage sags of 23% for both transition times occur in the load voltage. When system is operated with DVR then voltage sag is reduced from 23% to 8%. Output voltage of PV system is considered as 4kV. Voltage magnitude in p.u. is shown in fig. 11.



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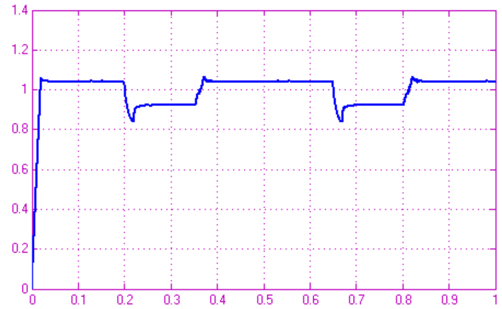
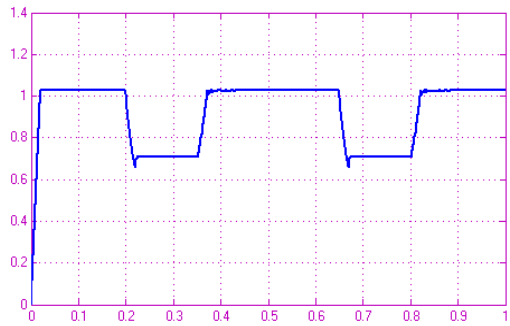


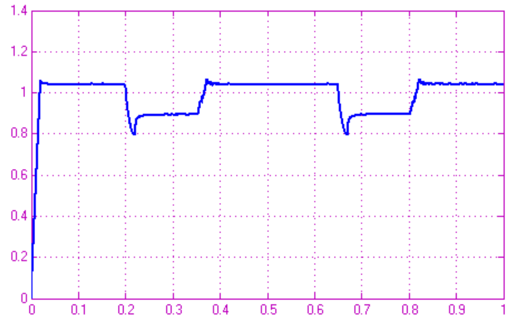
(b)

Fig. 11 (a) Line voltage without DVR, (b) Voltage with DVR

Case 8. Two 3-Φ fault is created at point A and B for multi-sag. Fault resistance for both cases is taken as 0.40 Ω for the transition time of 0.2s to 0.35s and 0.65s to 0.8s. When system is operated without DVR, then voltage sags of 29% for both transition times occur in the load voltage. When system is operated with DVR then voltage sag is reduced from 29% to 10%. Output voltage of PV system is considered as 4kV. Voltage magnitude in p.u. is shown in fig. 12.



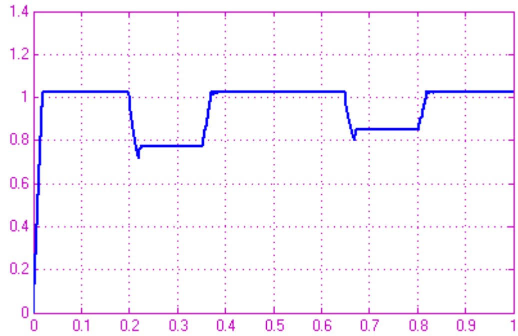
(a)



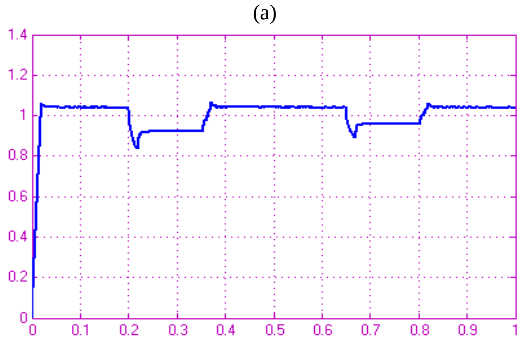
(b)

Fig. 12 (a) Line voltage without DVR, (b) Voltage with DVR

Case 9. Two 3-Φ fault is created at point A and B for multi-sag. Fault resistances are is taken as 0.50 Ω and 0.70Ω for the transition time of 0.2s to 0.35s and 0.65s to 0.8s respectively. When system is operated without DVR, then voltage sags of 23% for first transition time and 15% for second transition time, occur in the load voltage. When system is operated with DVR then voltage sag is reduced from 23% to 8% and 15% to 4%. Output voltage of PV system is considered as 4kV. Voltage magnitude in p.u. is shown in fig. 13.



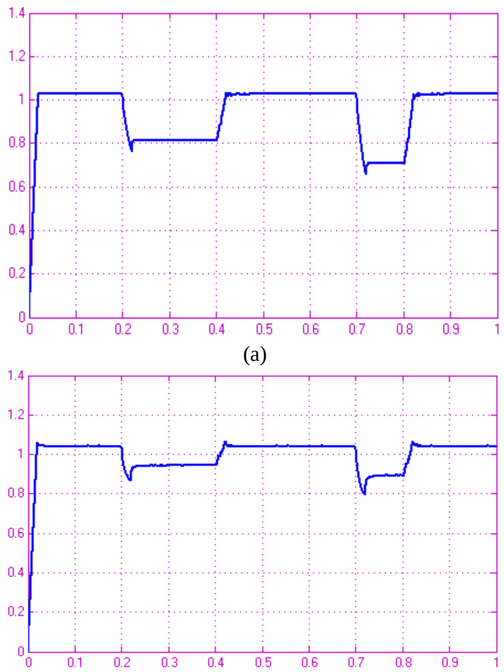
(a)



(b)

Fig. 13 (a) Line voltage without DVR, (b) Voltage with DVR

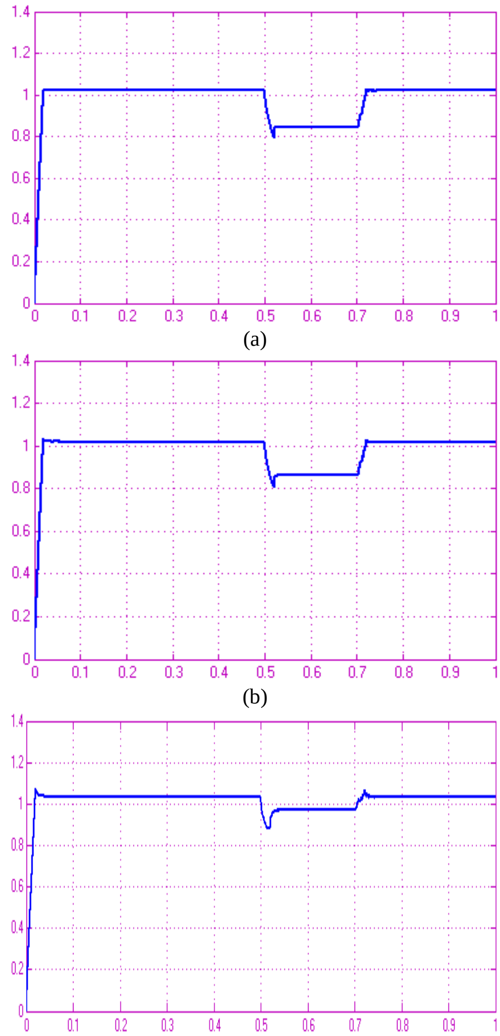
Case 10. Two 3-Φ fault is created at point A and B for multi-sag. Fault resistances are is taken as 0.60Ω and 0.40Ω for the transition time of 0.2s to 0.4s and 0.7s to 0.8s respectively. When system is operated without DVR, then voltage sags of 19% for first transition time and 29% for second transition time, occur in the load voltage. When system is operated with DVR then voltage sag is reduced from 19% to 6% and 29% to 11%. Output voltage of PV system is considered as 4kV. Voltage magnitude in p.u. is shown in fig. 14.



(a) (b)

Fig. 14 (a) Line voltage without DVR, (b) voltage with DVR

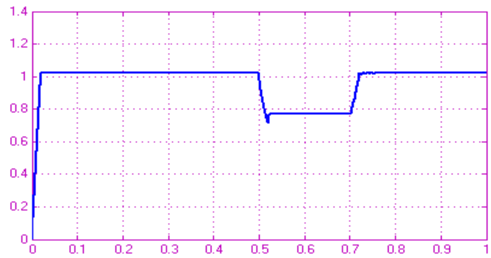
Case 11. In above all the cases load of R=0.1ohm and L=0.2H is taken. If the load parameters for the system is considered as R=0.2ohm and L=0.1H and a 3-Φ fault is created at point A sag with fault resistances is taken as 0.70Ω, for the transition time of 0.5s to 0.7s then system is operated without DVR, then voltage sags of 16% occurs in the load voltage. When system is operated with DVR with output voltage of PV is considered as 4kV then desired compensation is not achieved therefore with increased value of output voltage (6kV) has to be considered. With this condition voltage sag is reduced from 16% to 3%. Therefore the required capacity of energy storage in DVR depends on load parameters. Voltage magnitude in p.u. is shown in fig. 15.



(a) (b) (c)

Fig. 15 (a) Line voltage without DVR, (b) voltage with DVR (4kV), (c) voltage with DVR (6kV)

Case 12. Load parameters for the system is considered as R=0.2ohm and L=0.1H and a 3-Φ fault is created at point A sag with fault resistances is taken as 0.50Ω, for the transition time of 0.5s to 0.7s. When system is operated without DVR, then voltage sags of 23% occurs in the load voltage. When system is operated with DVR with output voltage of PV is considered as 4kV, with 6kV output, voltage sag is reduced from 23% to 4%. Voltage magnitude in p.u. is shown in fig. 16.



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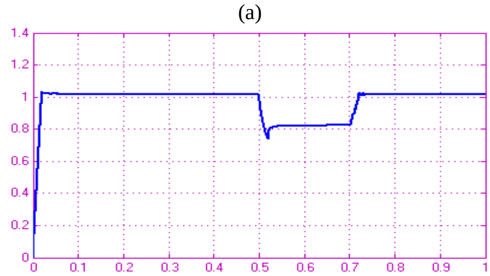

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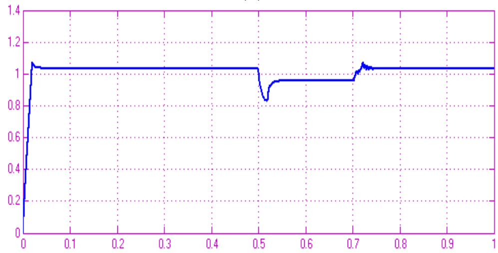

(c)

Fig. 16 (a) Line voltage without DVR, (b) voltage with DVR (4kV), (c) voltage with DVR (6kV)

V. CONCLUSIONS

Voltage sag is a common power quality problem which affects consumer loads. To mitigate sag in distribution system, DVR is presented in this paper. PI based control scheme has been used to control the gate triggering pulse of inverter. PV system is used as a DC source of DVR. Simulation results reveal that, the presented system reduces the voltage sag to acceptable range which doesn’t affect system performance, also the required capacity of energy storage depends on the load parameters.

VI. REFERENCES

1. Choi, S.S., Li, B.H. and Vilathgamuwa, D.M.: *Dynamic Voltage Restoration with Minimum Energy Injection*. In: IEEE Transactions on Power Systbms, 15 (2000), 2000, Pebicuary.
2. Zhan, C., Ramachandaramurthy, V.K., Arulampalam, A., Fitzer, C., Kromlidis, S., Barnes, M. and Jenkins, N. *Dynamic Voltage Restorer Based on Voltage-Space-Vector PWM Control*. In: IEEE Transactions on Industry Application, 37 (2001), No. 6, November/December 2001.
3. Ajaei, F.B., Afsharnia, S., Kahrobaeian, A. and Farhroh, S. *A Fast and Effective Control Scheme for the Dynamic Voltage Restorer*. In: IEEE Transactions on Power Delivery, 26 (2011), 2001, p. 2398-2406.
4. Jothibasu, S. and Mishra, M.K. *A Control Scheme for Storageless DVR Based on Characterization of Voltage Sag*. IEEE Transactions on Power Delivery, 29 (2014), 2014, p. 2261-2269.
5. Dugan, R.C., McGranaghan, M.F., Santoso, S. and Beaty H.W.: *Electrical Power System Quality*. McGraw-Hill Professional Engineering, 2004.
6. Moreno-Munoz, A., Oterino, D., González, M. and Olivencia, F.A. *Study of Sag Compensation with DVR*. In: Proceedings of the IEEE Mediterranean Electrotechnical Conference, 2006, p. 990-993.
7. Huang, C., Huang, S. and Pai, F. *Design of Dynamic Voltage Restorer with Disturbance-Filtering Enhancement*. In: IEEE Transactions on Power Electronics, 18(2003), No. 5, September 2003.
8. Fitzer, C., Arulampalam, A., Barnes, M. and Zurowski, R. *Mitigation of Saturation in Dynamic Voltage Restorer Connection Transformers*. In: IEEE Transactions on Power Electronics, 17 (2002), No. 6, November 2002.
9. Hingorani, N.G. *Introducing Custom Power*. In: IEEE Spectrum 32(1995), 1995, p. 41-48.
10. Bhumkittipich, K. and Mithulananthan, N. *Performance Enhancement of DVR for Mitigating Voltage Sag/Swell using Vector Control Strategy*. In: Energy Procedia (Elsevier) 9(2011), 2011, pp. 366-379.
11. Rauf, A.M. and Khadkikar, V. *Integrated Photovoltaic and Dynamic Voltage Restorer System Configuration*. In: IEEE Transactions on Sustainable Energy 6(2015), 2015, p. 400-410.
12. Rauf, A.M. and Khadkikar, V. *An Enhanced Voltage Sag Compensation Scheme for Dynamic Voltage Restorer*. In: IEEE Transactions on Industrial Electronics 62(2015), 2015, p. 2683-2692.
13. Perera, K., Son, D.S., Arulampaiam, Atputharajah, Alahakoon, S. *Automated Control Technique for A Single Phase Dynamic Voltage Restorer*, In: Proceeding of the IEEE International Conference on Information and Automation, 2006, p. 63-68.
14. Nielsen, J.G., Newman, M., Blaabjerg, *Control and Testing of a Dynamic Voltage Restorer (DVR) at Medium Voltage Level*. In: Proceeding of the IEEE 34th Annual Power Electronics Specialist Conference, 3, p. 1248-1253.