

PV System Connected High Step-Up Boost DC-DC Converter Based Voltage Compensator

K.Tamilselvan¹, R.Anita²

^{1,2}Department of Electrical and Electronics Engineering, Institute of Road and Transport Technology, Erode-638316, Tamilnadu, India

Abstract— In this paper, a Photovoltaic (PV) system interfaced high step up DC-DC converter based voltage compensator such as Dynamic Voltage Restorer (DVR) is presented to alleviate the voltage sag and swell in low voltage single-phase power distribution system. The PV system supports the DC-link of the DVR. The PV array output voltage stepped up with the use of high step up DC-DC boost converter. The converter attains high step-up voltage gain by means of low voltage stress on the power semiconductor switch. Similarly, the stored energy in the coupled inductor may be reprocessed to the load. The usage of high step up DC-DC converter decreases the size and necessary power rating of the series injection transformer. It as well increases the stability and safety of the system. A feedback loop is engaged to attain a faster response in sag/swell detection. A single phase full bridge inverter is added to convert DC bus voltage into a 230V, 50Hz single phase AC source by means of Sinusoidal Pulse Width Modulation (SPWM) technique. Simulation results have ascertained the proficiency of the presented PV supported DVR in alleviating voltage sag and swell in low voltage single-phase power distribution system.

Index Terms— Dynamic Voltage Restorer , DC-DC Boost Converter, Photovoltaic System, Sag, Swell.

1. INTRODUCTION

DVR offers the most cost effective solution to alleviate voltage sag and swell in the low and medium electric power distribution system. The disturbances such as voltage sag, swell and voltage distortion have become an accumulative concern in both domestic and industrial customers. Voltage sag is a sudden reduction of source voltage from 90% to 10% of its nominal value with duration from 0.5 cycles to 1 min [1].

Voltage swell is a sudden rise of supply voltage from 110% to 190% with duration from 0.5 cycles to 1 min [2,3]. This may occur in the distribution system where the grid quality is unacceptable.

The above stated voltage variation measures happen owing to single line to ground fault, phase to phase fault, energization of large capacitor banks, switching of heavy loads, starting of large motors and pressing process in steel plants. The voltage variations events and its effects are shown in Table 1.

Table 1

Voltage Variation Events and its Effects

Disturbances	Effects
Unbalance voltage	Produce excessive heat in motor and control equipment.
Interruption	Complete shutdown.
Voltage sag	Trip out the adjustable speed drive & computer.
Voltage swell	Overstress to insulation.
Fluctuations in voltage	Light Flicker.
Harmonics	Produce more noise and overheating.

To alleviate the above stated power quality issues, the DVR has been projected as effective sag/swell alleviation equipment [4,5]. The injections of voltage from DVR compensate the voltage sag/swell during sag and swell events [6,7].

In this paper a simulation of high step up DC-DC converter with the PV power generating system is integrated to function as a high capacity DC voltage source. It reduces the size and capacity of series injection transformer. The converter practices the coupled inductor and capacitors to attain high step up voltage gain. This converter can offer higher voltage gain than the conventional DC-DC boost converter [8,9].

2. PV SYSTEM INTERFACED HIGH STEP UP DC-DC CONVERTER BASED DVR

The schematic diagram of the PV supported DVR is shown in Figure 1. The projected system includes of a battery, high step up DC-DC converter with coupled inductor, Voltage Source Inverter (VSI), series injection transformer (1:1) and semiconductor bypass switch S.

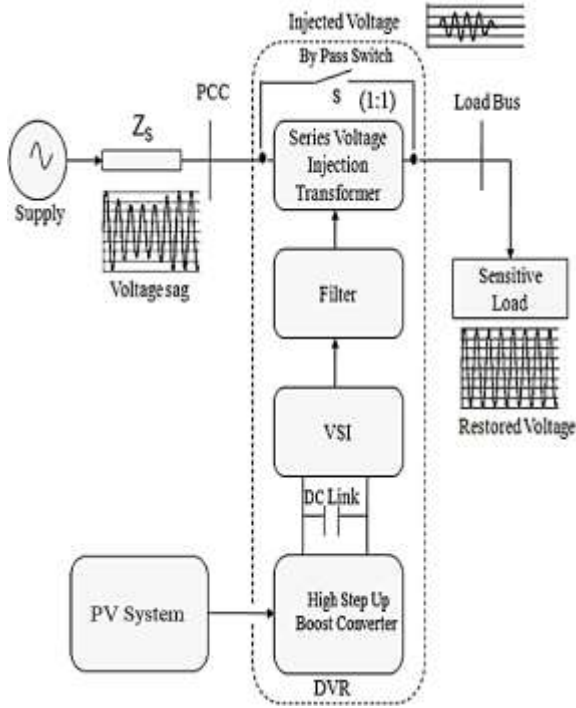


Figure 1 Block diagram of the PV-DVR

Table 2 displays the control signal of semiconductor switch S , which is connected in parallel with the secondary of series injection transformer. The power semiconductor switch S is controlled by voltage sensor and the simple logical circuits.

Table 2

Control Signal of Semiconductor Switch S

Supply voltage in %	Control signal	Mode of Operation
100%	1	Ideal
<100%	0	DVR
>100%	0	DVR

A DVR is connected in series with the power distribution system to inject a compensating voltage in series with the AC source. The main components of a DVR are the high capacity DC source, bridge inverter, injection transformer and control system. A DVR can compensate the voltage drop across a sensitive load by injecting a voltage through a series injection transformer[10,11,12].

The inverter is a foremost component of DVR. Its control will directly distress the transient and dynamic performance of the DVR. The voltage injection of the DVR is mainly being subject to on the capacity of DC source, which is connected in the DC-link of the DVR. A high step up DC-DC converter with coupled inductor offers a high power DC source to voltage source inverter of the DVR.

3. HIGH STEP UP DC-DC CONVERTER

A high step up DC-DC converter can boost the voltage from low level to high level. It decreases the number of batteries, essential to attain the mandatory DC voltage level in that way saving the cost and space as an alternative of using numerous batteries. In general, the DC-DC boost converter can offer high step up voltage gain with exceedingly high duty cycle. The step-up voltage gain is inadequate by the effect on power semiconductor switches, inductors and capacitors. To develop the conversion efficiency and to achieve high step up voltage gain the coupled inductor with switched capacitor technique is used[9]. This converter is connected in between the low power DC source such as renewable energy power generation system or conventional battery storage units and voltage source inverter. The high step up DC-DC converter with coupled inductor is shown in Figure 2.

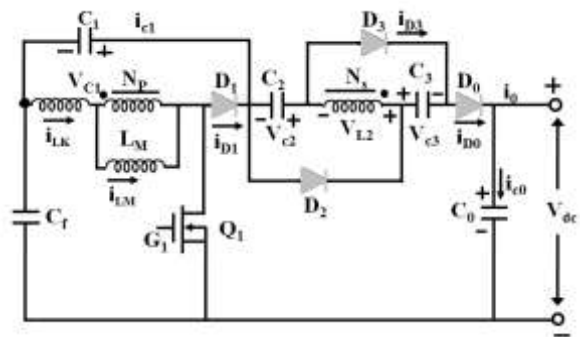


Figure 2 Circuit configuration of high step up DC-DC boost converter

The secondary side (N_s) of the coupled inductor is used as a flyback converter. It can increase the voltage gain. The energy stored in the leakage inductor (L_k) is recycled to the load directly. The advantages of this DC-DC converters is as follows

- It confines voltage spike on the main switch.
- Delivers high step up gain.
- High conversion efficiency.
- Low conduction loss.
- High step up ratio.

The secondary of the coupled inductor can charge capacitors in parallel and discharge them in series with the load. This converter combines the concept of coupled inductor and switched capacitor techniques. The secondary of the coupled inductor charge the capacitors C_2 and C_3 when the switch is switched OFF and are discharged in series by the secondary side of coupled inductor when the switch is switched ON. It operates in two mode of operation.

1) Mode 1: When the switch is switched ON, the secondary of the coupled inductor induces voltage and magnetizing inductance (L_m) is charged by V_{in} . The induced voltage in the secondary of the coupled inductor makes V_{in} , V_{C1} , V_{C2} and V_{C3} released in series with the load.

$$V_o = V_{in} + V_{C1} + V_{C2} + V_{L2} + V_{C3} \quad (1)$$

$$V_{L2} = kV_{in} \quad (2)$$

Where,

N_p, N_s – Number of turns in primary and secondary of the coupled inductor.

S – Main switch.

C_1, D_1 – Clamp capacitor and diode.

L_m – Magnetizing inductance.

L_k – Leakage inductor.

C_1, C_2 – Storage capacitors.

V_{in} – Input DC voltage.

V_{C1} – Voltage across the capacitor C_1 .

V_{C2} – Voltage across the capacitor C_2 .

V_{L2} – Voltage across the secondary of the coupled inductor.

n – Turns ratio ($N_p : N_s$)

2) Mode 2: When the switch is switched OFF, the energy stored in the magnetic inductor (L_m) is released through the secondary side of coupled inductor to charge the capacitor C_2 and C_3 in parallel.

$$V_{C1} = \frac{D}{1-D} V_{in} \frac{(1+k)+(1-k)n}{2} \quad (3)$$

$$V_{C2} = V_{C3} = \frac{nDk}{1-D} V_{in} \quad (4)$$

where,

K – Coupling coefficient ($k = \frac{L_m}{L_m + L_k}$).

n – Coupled inductor turns ratio ($\frac{N_s}{N_p}$).

D – Duty Cycle ($D = \frac{T_{on}}{T_{on} + T_{off}}$).

The voltage gain is obtained by

$$M_{CCM} = \frac{V_o}{V_{in}} = \frac{1 + nk}{1 - D} + \frac{D}{1 - D} \frac{(k - 1) + n(1 + k)}{2}$$

4. SIMULATION RESULTS OF PV-DVR

To demonstrate the usefulness of PV interfaced high step up DC-DC converter based DVR for voltage sag and voltage swell mitigation on low voltage single phase distribution system is shown in figure 3. A 2 kVA, 230/230V (1:1) series injection transformer is used for connecting the DVR to the network. The proposed DVR model is simulated by MATLAB simulink to compensate voltage sag and voltage swell at the source side.

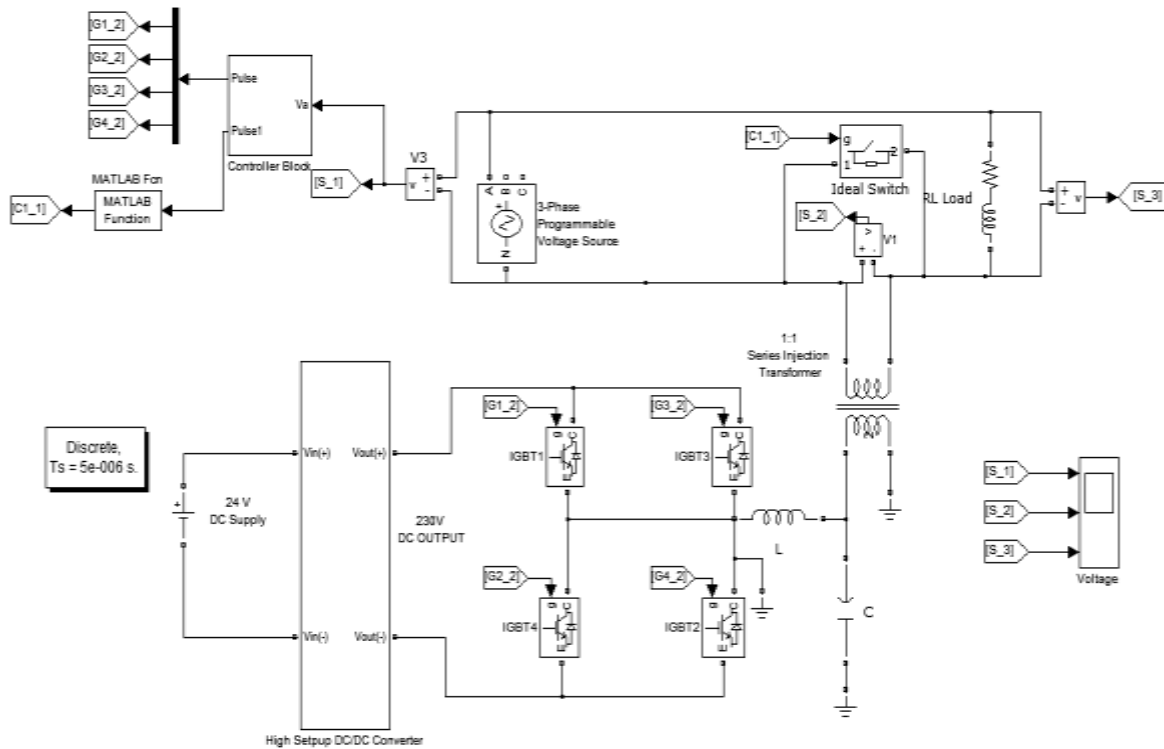


Figure 3 Simulation model of the proposed DVR

The simulation parameters of the DVR are shown in Table 3.

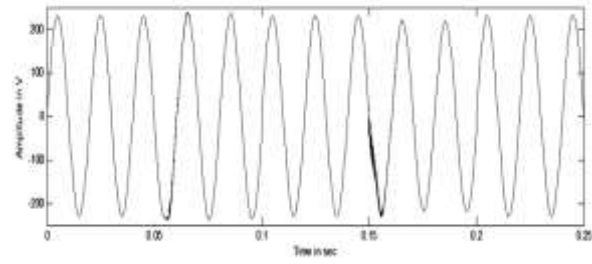
Table 3

Simulation Parameters

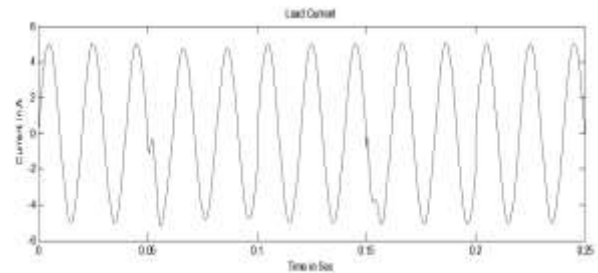
Parameters	Values
Load Resistance (R_L)	43 Ω
Load Inductance	10 mH
Source Voltage	230 V
Load Voltage	230V
Rated Load Current	5 A

The total simulation period is 0.25 sec. In MATLAB the DVR is simulated to be in operation only when the supply voltage differs from its nominal value. Then, the DVR will be in standby mode .

A programmable three-phase voltage source is used to provide the variable single phase voltage at the source end. The first simulation contains no DVR, a reduced voltage (0.5 pu) is applied, during the period 0.05 sec to 0.1 sec and a raised voltage (1.5 pu) is applied, during the period 0.15 sec to 0.2 sec, as presented in figure 4 (a). The voltage sag and swell at the source point is 50% and 50% with respect to the reference p.u. voltage. The injected voltage, load voltage and load current of the DVR are shown in figure 4 (b)- 4 (d).



(b) Load Voltage



(d) Load Current

Figure 4 a) Supply voltage, b) Injected voltage, c) Load voltage and d) Load Current

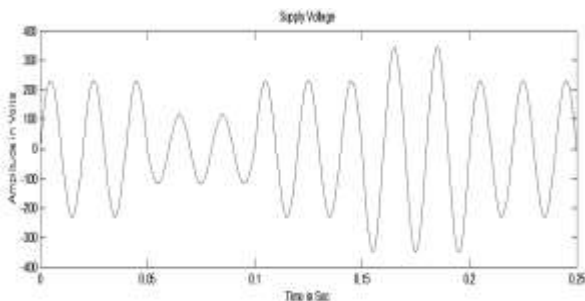
The simulation parameter of high step up DC-DC converter is shown in Table 4.

Table 4

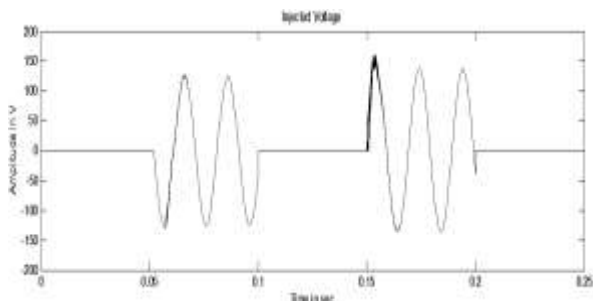
Simulation Parameters of DC-DC Boost Converter

Parameters	Values
Input DC voltage	24 V
Output DC voltage	230 V
Maximum output power	4000 W
Switching Frequency	25 KHz
Inductors	$L_m = 48\mu\text{H}$
	$L_k = 0.25\mu\text{H}$
Capacitors	$C_1 = 3.151\mu\text{F}$
	$C_2 = 1.062\mu\text{F}$
	$C_3 = 1.062\mu\text{F}$
	$C_0 = 500\mu\text{F}$

The output voltage and output power of high step up DC-DC converter with coupled inductor is shown in Figure 5. The converter is operated in continuous conduction mode. A control circuit is amalgamated with the proposed DC-DC boost converter to regulate the output voltage at 230V. The PV output voltage is shown in Figure.6.



(a) Supply Voltage



(b) Injected Voltage

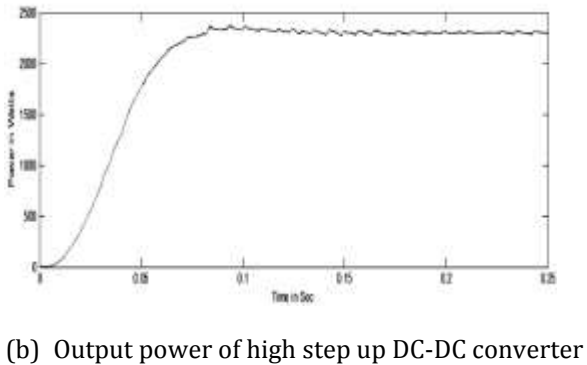
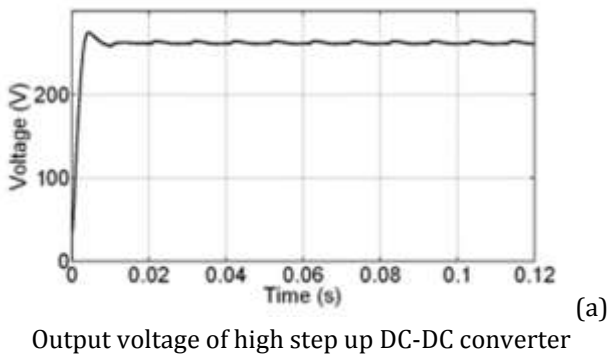


Figure 5 output of High step up DC-DC converter

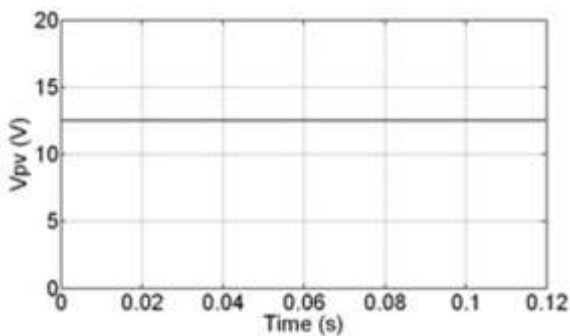


Figure 6 PV array output voltage

5. CONCLUSION

The PV-DVR which integrates a PV interfaced high step up DC-DC converter as a DC voltage source to alleviate the voltage sag and swell in a single phase low voltage electric power distribution system has been presented. The PV system supports the DC link of the DVR to offer long lasting compensation against voltage based disturbances in the power distribution system. The simulation of the proposed system has been presented. By using the capacitor charged in parallel and discharged in series by coupled inductor, high step up voltage gain and high efficiency are achieved. Furthermore, the mandatory power rating of series injection transformer is reduced to low rating by selecting 1:1 transformer for series injection.

6. REFERENCES

[1]Amrita Rai, A.K. Nadir, "Modeling and Simulation of Dynamic Voltage Restorer (DVR) for Enhancing Voltage Sag," in sensor and transducer journals, Vol. 87, issue 1, pp: 85-93, Jan 2008.

[2]F.A.L.Jowder, "Modeling and simulation of different system topologies for dynamic voltage restorer using simulink," in proc. EPECS '09, p. 1-6, Nov 2009.

[3]H.Ezaji, A.Sheikholeslami, M.Tabasi, and M.M.Saeednia, "Simulation of dynamic voltage restorer using hysteresis voltage control," European journal of scientific research, vol. 27, pp. 152-166, Feb 2009.

[4]Hyun Lark Do, "Zero voltage switching boost converter using a coupled inductor," Vol. 11, No. 1, pp. 16-20, Jan 2011.

[5]P.Boonchiam, and N.Mithulananthan, "Understanding of dynamic voltage restorers through MATLAB simulation," Thammasat Int. J. Sc. Tech., Vol. 11, No.3, pp. 1-6, Sep 2006.

[6]R.J.Wai and R.Y.Duan, "High-efficiency DC/DC converter with high voltage gain," IEE Proc. Electric Power Applications, Vol.152, No.4, pp.793-802, Jul. 2005.

[7]R.Omar, and N. Abd Rahim, "Mitigation of voltage sags/swells using Dynamic voltage restorer (DVR)," ARPN Journal of Engineering and Applied Sciences, Vol. 4, No. 4, June 2009.

[8]S.K.Changchien, T.J.Liang, J.F.Chen and L.S.Yang, "Novel high step-up DC-DC converter for fuel cell energy conversion system," IEEE Trans. Ind. Electronics, Vol. 57, No.6, pp.2007-2017, June 2010.

[9]Y.P.Hsieh, J.F.Chen, T.J.Liang and L.S.Yang, "Novel high set-up DC-DC converter for distributed generation system," IEEE transaction on Industrial Electronics, pp. 1-7, Jan 2011.

[10]Meyer, C., De-Doncker, R.W., Li, Y.W. and Blaabjerg, F. "Optimized control strategy for a medium-voltage DVR-Theoretical Investigations and experimental results", IEEE Transactions on Power Electronics, Vol.23, No.6, pp.2746-2754, 2008.

[11]Mahdianpoor, F.M., Hooshmand, R.A. and Mohammad, A. "A new approach to multifunctional dynamic voltage restorer implementation for emergency control in distribution systems", IEEE Transactions on Power Delivery, Vol.26, No.2, pp.882-890, 2011.

[12]Mohan, N., Undeland, T.M. and Robbins, W.P. "Power Electronics Converters: Applications and Design", Third Edition, Jhon Wiley & Sons Asia Pte. Ltd., Singapore, pp.172-178, 2006.