전압 강하 및 전력 전달 유연성을 위한 직렬 및 분로 통합형 인버터

Desmon Petrus Simatupang [1], 배성진[1], 최재호[1]
충북대학교[1]

Integrated Series and Shunt Inverter for Voltage Sag and Power Transfer Flexibility

Desmon Petrus Simatupang[1], Sungjin Bae[1], Jaeho Choi[1]
[1] School of Electrical Engineering, Chungbuk National University, Chungbuk, Korea

ABSTRACT

In this paper, integrated series and shunt inverter is presented to solve power quality problems in distribution line system. In this configuration consists of series inverter and shunt inverter. Series inverter acts as DVR to compensate voltage during sagging occurred and shunt inverter optimize to inject balance active power from distributed power source like PV system with Maximum Power Point Tracing (MPPT). Finally, the proposed configuration is verified through the PSiM simulation.

1. Introduction

In the distribution network, power quality is the major issue because of the radial system. Voltage sags is probably the most common and important problems affecting low voltage customers. That is challenge for us how to maintain the power quality within acceptance limit based on standard [1] – [2].

Dynamic Voltage Restorer (DVR) mitigates voltage sag on the utility side. However, since voltage sag generally occurs below 60 second and few times each year, a DVR spend more time for standby mode only.

In principle, it will give benefit if inverter can inject active power to the grid from shunt connection during DVR in standby mode. Therefore, the shunt connection is based on active and reactive power control. Shunt connection inverter will inject flexibility balance active power to the grid even when DVR is in standby.

2. Configuration and Operation

Both of inverters will be connected with the same PV source with PnO MPPT scheme as per fig.1.

The DVR operate as in-phase compensation, which is DVR injects the smallest possibility voltage magnitude in phase with sagged grid voltage [3-4]. The phasor diagram for the in phase voltage compensation is shown in fig. 2. When V'G is sagged, V'DVR will inject amount of voltage to compensate load voltage.

The voltage calculation for DVR is as follows:

$$V'_{dvr} = \sqrt{2}.\left[V_{load} - V'_{grid,a,b,c}\right] \quad (1)$$

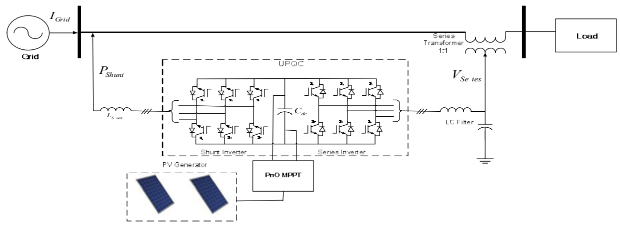

Fig.1. Proposed integrated PV and UPQC

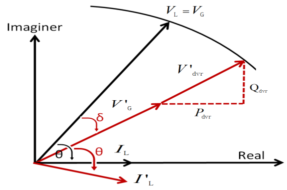

Fig.2. In-phase injection phasor for DVR

There are two modes for this scheme. When DVR is in off mode, PQ control will inject maximum active power and zero reactive power. When DVR is in on mode, PV generation will transfer power to DVR and the PV generator remaining power will be injected by shunt connection.

$$P_{dvr} = \frac{3}{2}\left[V_{d,dvr}\, I_{d,dvr} + V_{q,dvr}\, I_{q,dvr}\right] \quad Q_{dvr} = \frac{3}{2}\left[V_{d,dvr}\, I_{q,dvr} - V_{q,dvr}\, I_{d,dvr}\right] \quad (2)$$

$$S_{dvr} = \sqrt{P_{dvr}^{\ 2} + Q_{dvr}^{\ 2}} \quad (3)$$

3. System Control

3.1 Series Inverter

As per fig. 3, V_{load} and V_{DVR} are transformed to DQ. $V*_{d}$ is subtracted from $V_{load,d}$ and the result is the voltage compensation needed to load. The result as a input for PI-1 and subtracted with $V_{DVR,d}$. This result is to be an input for PI-2. The output PI-2 is as d reference signal. $V*_{DVR,q}$ reference is subtracted from $V_{DVR,q}$ frame and to be a q frame reference signal. Both of dq frame reference signal is transformed to abc domain.

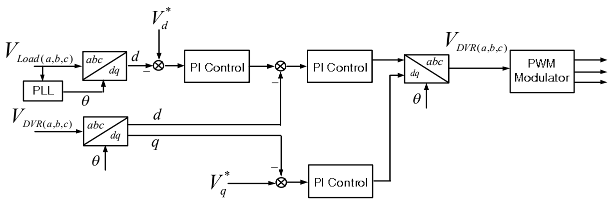

Fig.3. Series Connection Inverter In-phase control scheme

3.2 Shunt Inverter

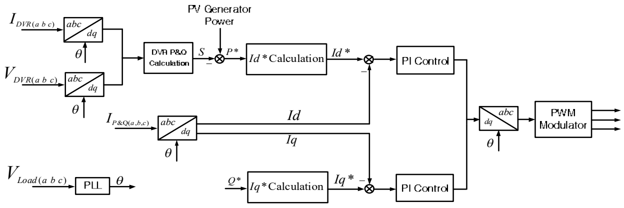

Fig.4. Shunt Connection Inverter control scheme

In this control, shunt inverter will inject the maximum power from PV MPPT using PnO[5]. In fig.4, PQ control scheme which is active power from PV generator will be subtracted from apparent power from DVR by using equation (2–3). If series connection inverter is in off mode, shunt inverter will inject the maximum active power without any reduction by series inverter. The balance of the power is set to be a reference active power value for PQ control. Reference reactive power is set to be zero (0) value. Reference active and reactive power is converted to reference Id and Iq values from equation (4–5). Hereinafter, reference Id and Iq values are subtracted from the real values of Id and Iq and PI control will control Id and Iq to follow Id and Iq reference value.

$$I^*_{d,PQ} = \frac{\frac{2}{3}P^*_{PQ} - V_{q,PQ} I_{q,PQ}}{V_{d,PQ}} \quad (4)$$

$$I^*_{q,PQ} = \frac{\frac{2}{3}Q_{PQ} + V_{q,PQ} I_{d,PQ}}{V_{d,PQ}} \quad (5)$$

4. Simulation Result

Part	Descriptions	Value	Part	Descriptions	Value
Grid	Voltage & Freq.	380V(L–L) & 50Hz	Series Inverter	Transformer	1:1
Load	Active	160kW		Filter	100μF 1mH
	Reactive	120kVar		PI–1 PI–2 & PI–3	20
Cdc	Capacity	10mF	Shunt Inverter	Lshunt	4.5mH
PV	Max Power	113kW		PI–1 & PI–2	100
	Vmpp	675V	PWM	Sampling Frequency	5kHz
	Immp	168A			

In this section, parameters are shown in Table I. Fig.5 shows the voltage grid, DVR voltage and load voltage. During $t<1$ grid voltage is in normal condition. Series inverter is in off mode. Once voltage sag occurs ($1<t<2$), series inverter will inject voltage to load. After clearing fault, voltage grid is back in normal magnitude voltage and no action from series inverter.

In fig. 6, during t<1, shunt inverter is in mode 1, will inject active power without any reduction from DVR. Between 1<t<2, series inverter injects voltage required at load. During this time, active power injected by shunt inverter will be reduced since small amount of power used by series inverter. After grid voltage back to normal ($t>2$), series connection is back to off mode and shunt inverter increase its power injection to the grid.

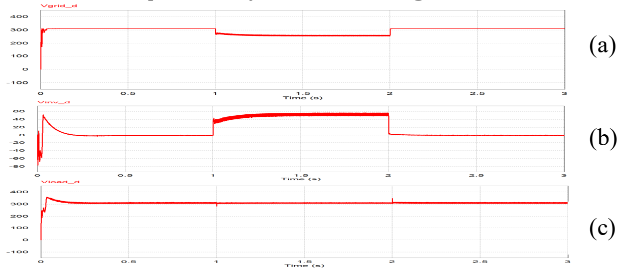

Fig.5. Simulation result: (a) voltage grid; (b) voltage series inverter; (c) voltage load.

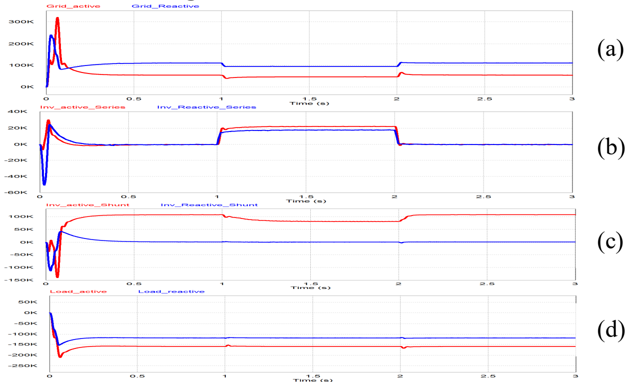

Fig.6. Simulation result: (a) P & Q power grid; (b) P & Q series inverter; (c) P & Q shunt inverter; (d) P & Q load.

5. Conclusion

This paper reviews two operating modes. First, when PQ inverter is in operating mode without DVR Second, when series and shunt inverters work simultaneously. The proposed strategy for this scheme is power calculated result from DVR is subtracted from PQ inverter power. The balance power from this calculation is to be an active power reference for shunt connection inverter. The proposed strategy for shunt connection inverter can accurately compensate voltage sag and series connection can control active and reactive power injected to the distribution line grid. The performance of the proposed controlled system is verified by simulations.

References

[1] R. C. Dugan, M. F. McGranaghan, and H. W. Beaty, Electrical Power Systems Quality. *New York: McGraw-Hill*, 1996.

[2] A. Ghosh and G. Ledwich, Power Quality Enhancement Using Custom Power Devices. Boston, *MA: Kluwer*, 2002

[3] A. Sadigh and K. Smedley, “Review of voltage compensation methods in dynamic voltage restorer DVR,” in *IEEE Power and Energy Society General Meeting*, July 2012, pp. 1–8.

[4] A. Rauf and V. Khadkikar, “An enhanced voltage sag compensation scheme for dynamic voltage restorer,” *IEEE Trans. Ind. Electron.*, vol. 62, no. 5, pp. 2683–2692, May 2015.

[5] PSIM User Manual, http://www.powersimtech.com/manual/psim-manual.pdf, Powersim Inc., 2006.