Indian Journal of Science and Technology, *Vol 9(3), DOI: 10.17485/ijst/2016/v9i3/71368, January 2016*

ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Voltage Compensation of Smart Grid using Bidirectional Intelligent Semiconductor Transformer and PV Cell

K. Bharathi[1*] and M. Sasikumar[2]

[1*]Sathyabama University, Chennai – 600019, Tamil Nadu, India; bharathihve@gmail.com
[2]Department of Electrical and Electronics Engineering, Jeppiaar Engineering College, Chennai – 600019, Tamil Nadu, India; pmsasi77@gmail.com

Abstract:

Conventional grids are being replaced by smart grids nowadays to improve the transmission efficiency and to incorporate the recent power electronics based compensation devices. The proposed system deals with the voltage compensation using BIST, battery and PV cell for smart grid applications, which has three stages high voltage high frequency bidirectional AC/DC rectifier, bidirectional DC/DC dual active bridge converter and bidirectional DC/AC inverter. This paper mainly focuses on the voltage balancing of DC link which lies between DC/DC converter and DC/AC inverter by connecting two DC sources viz. PV and battery across the capacitor. In order to maintain a constant voltage across the DC link, a droop control with droop curve is proposed for battery and BIST. With this power management system, typical case studies have been analyzed using MATLAB simulation and it was verified with the prototype hardware.

Keywords: Bidirectional Semiconductor Transformer, DAB Converter, Droop Control Technique

1. Introduction

With the rapid growing of the power electronic technology, solar based grid connected system is possible without any interruption of power dispatch. Moreover these devices can also be acted as the compensating device to reduce the voltage sag and swell. BIST is used to interface the DC micro grid with the high voltage AC grid and low voltage loads. The droop control technique for BIST, Battery and PV are used with their respective power ratings. The system can automatically change its control algorithm based on the SOC of battery and DC link voltage. Full bridged DC-AC converter is used making use of hybrid switches[1] to attain the desired voltage.

Intelligent semiconductor transformer[2] was not suitable for DC distribution and micro grid[3]. SST[4] with bidirectional power flow without any control[5] over power factor was discussed. In SST[6] can compensate voltage sag and swell but it has bulky transformers for isolation[7]. BIST[8] with complex control for voltage balancing[9] was used. A Photovoltaic (PV) system used as a major role and set to grow fast among all potential solar power generation systems. In grid connected PV energy systems[10] PV inverter[11] is a key element. So the main objectives of this paper are:

- To provide uninterrupted power to consumer.
- Better utilization of generated power.
- To provide better power quality.
- To improve efficiency of transmission system.
- To eliminate voltage sag and swell.
- To provide power factor correction.
- To have an efficient power management, this in turn depends upon demand response.

2. DC Micro Grid Enabled by BIST

The Distributed Generation (DG) system shown in Figure 1 consist of the AC grid and DC grid in addition

**Author for correspondence*

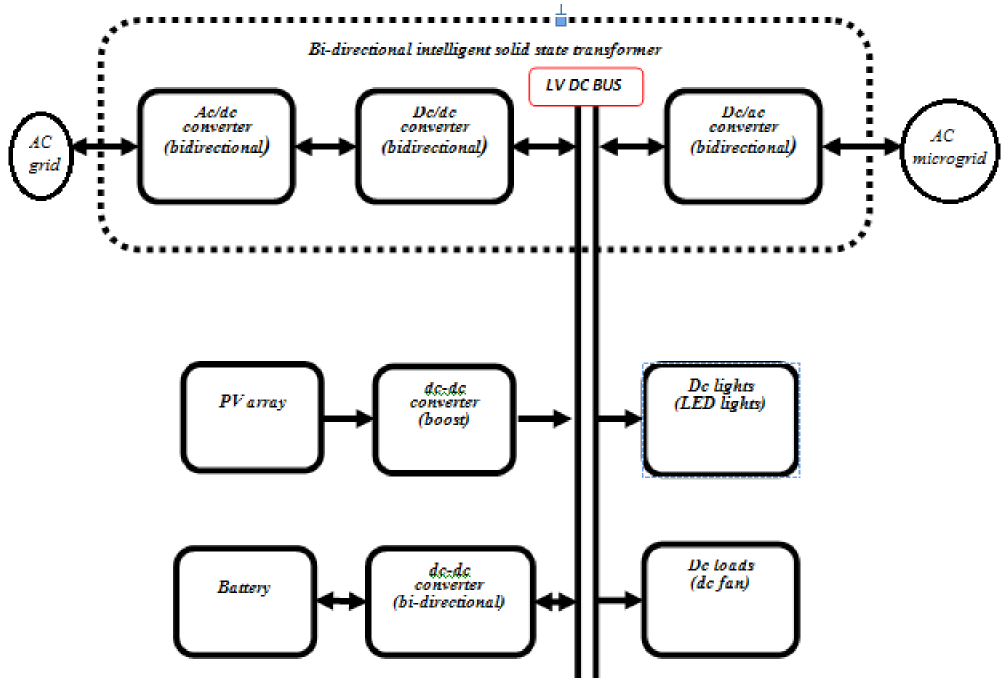

Figure 1. BIST enabled DC micro grid.

to renewable generation sources such as solar and battery energy storage systems. The BIST performs the process of converting high voltage high power AC into a low voltage and nominal frequency AC through an intelligent solid-state transformer. PV and battery are used to construct DC micro grid as shown in Figure 2. DC link is connected to BIST DC output terminal. BIST can be used as an interface between low voltage AC and DC system. PV and battery are also interconnected through the DC link. The current harmonics reduction using Hysteresis Current Controller (HCC) is described and discussed[12].

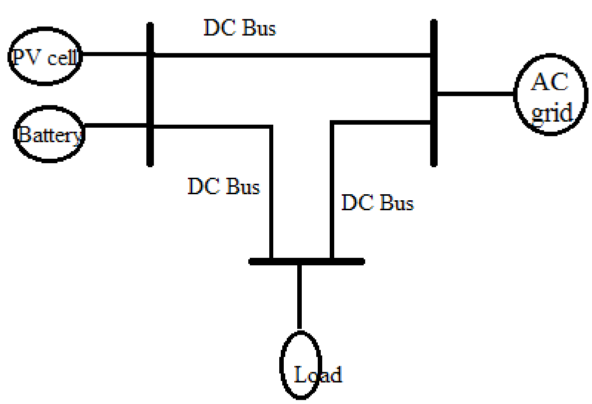

Figure 2. Single line diagram of the proposed system.

Battery with super capacitor based hybrid energy storage system is used for power management that depends upon demand response. This micro grid supplies both the load and AC source. The process of converting high voltage nominal frequency into a low voltage nominal frequency is done using BIST which has three intermediate stages. The first intermediate stage is an AC-DC rectifier with high voltage AC input and high voltage DC output. The second intermediate stage is a DC/DC converter with a high frequency transformer. Then the converter DC voltage is converted into AC source for the end user through the DC-AC inverter.

3. Proposed BIST with System Power Management using PV Cell and Battery

In the proposed BIST system, 3.3 KV input voltage is divided into three 1.9 KV voltage through three converters which are connected in series to form the total voltage of 3.3 KV. This input is given to the high voltage side of bidirectional AC-DC converter through high frequency transformer. This output is given to the bidirectional DC-DC converter to convert the voltage into 400 V. Then bidirectional full bridged DC-AC converter is used to get the 400 V AC output. The output of solar cell and battery are connected to the secondary side DC link of 400 V. Because of the changes in irradiation, the PV output power will also change. So the information given to the micro grid system is very complicated. Due to the changes in the load, the grid faces many problems. Therefore in order to supply sustainable, reliable and quality power the system power management should deals these conditions. According to that, whenever the system has more power the Dc bus voltage will increase and when the system requires more power the voltage will decrease. So the droop control is used for BIST and battery which is explained through Figure 3. But this DC voltage variation should lie within certain range of 360 V to 400 V by regulating through BIST and battery. While executing this droop control, it is very important to check that the voltage should not exceed too high and too low voltage. So the constant bus voltage control technique is also implemented along with droop control method. This method was explained earlier in detail. In this paper the voltage limit is taken as 380 V.

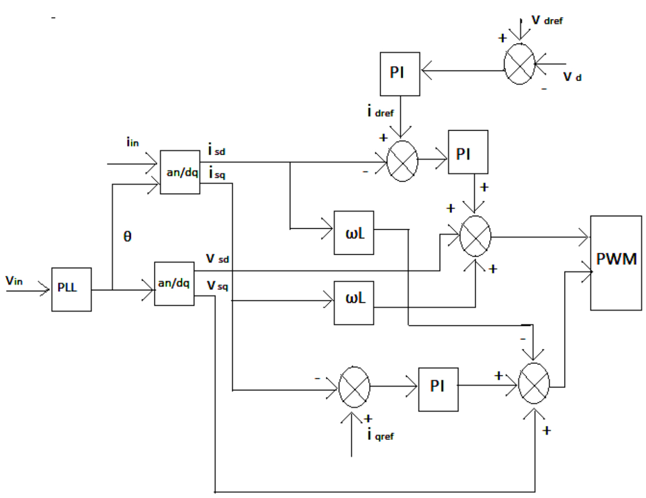

Figure 3. Control loop for rectifier.

4. Control Algorithm

4.1 SST Control

The output from the BIST is in the range of (360-400) V. The control logic for BIST is given in Figure 4. The single phase d-q decoupled control scheme is used for rectifier. The high voltage DC bus is controlled by dual loop controller that controls inner current loop and outer voltage control loop. The DC-DC converter in BIST uses the phase shift control to transfer power between high voltage DC side and low voltage DC side:

$$V_{SST\_dc} = V_{SST\_dc\ max} - R_{SST}\ I_{SST.}$$

V_{SST_dc} is the reference point of low DC voltage side and is equal to 380 V. R_{SST} is the slope value and I_{SST} is the output current. The control loop for DAB (Dual Active Bridge) is given in Figure 5.

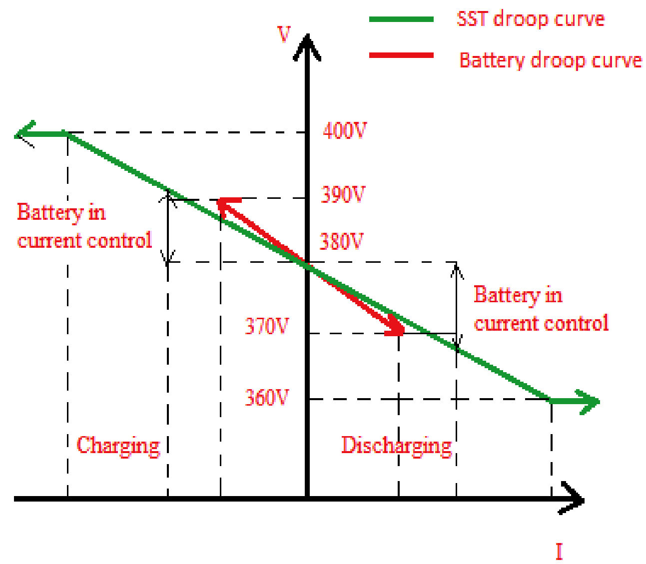

Figure 4. Droop curves for battery and BIST.

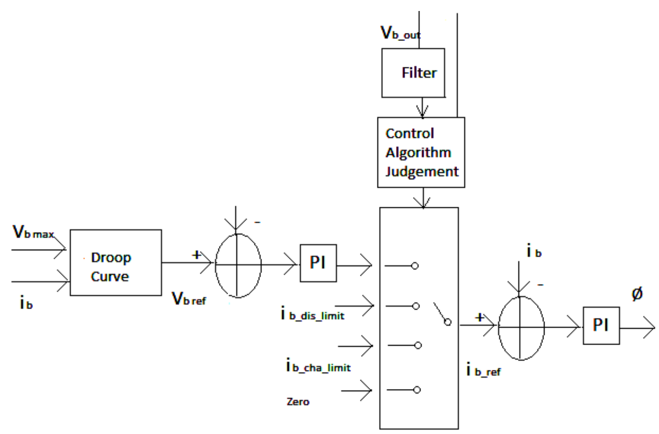

Figure 5. Control loop for DAB stage.

4.2 Battery Control

The battery control algorithm is explained in Figure 6. The battery droop control equation is:

$$V_b = V_{b\ max} - R_b\ I_{b.}$$

Where V_b is the output reference voltage for battery, $V_{b\ max}$ is the no load output voltage and is equal to 380 V.

$$R_b\, S_b = R_{SST}\, S_{SST.}$$

S_b is the power rating of battery.

S_{SST} is the power rating of SST. The control loop for inverter is given in Figure 7 which uses pulse width modulation technique.

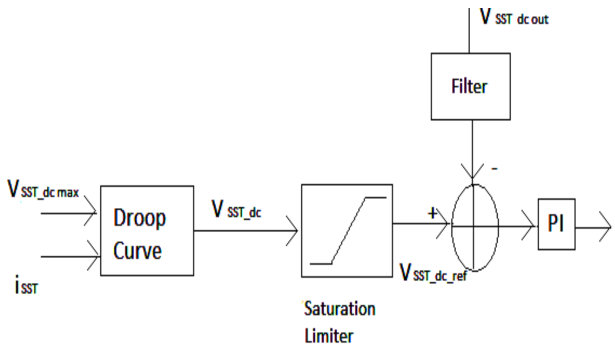

Figure 6. Control loop for battery.

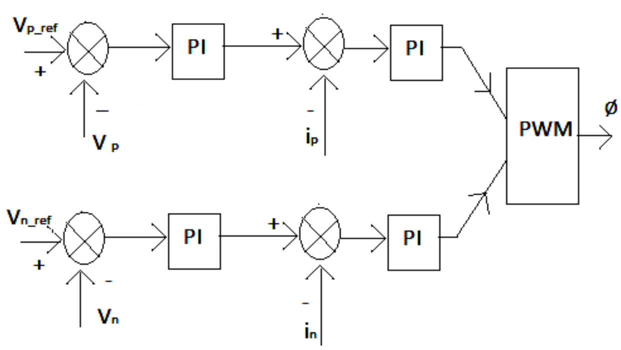

Figure 7. Control loop for inverter.

5. Case Study

The four modes of operation are explained with Figures 8-11. The outputs of the following case studies were analyzed using MATLAB simulation as shown in Figure 12. In the load side three different rating loads are connected. Load 1 consumes low voltage when compared to the PV output voltage. Load-1 (0-1 sec) and load-2 (0.3-0.5sec) together will consume supply from PV and battery. According to that, ratings of the loads are selected. And if we add load-3 (0.4-0.7 sec) to the system, PV and battery are not sufficient to supply the load. Hence we need the supply from the AC grid to satisfy the load and to charge the battery. With these arrangements the following cases are analyzed using the hardware prototype.

Load-1 is in ON condition throughout the simulation time of 1 second. From 0–0.2 sec the battery is in charging mode and gets charge from the PV cell till SOC reaches 80%. During this starting period the load doesn't get any supply from PV cell. Once the battery's SOC reaches 80%, it doesn't get charge from PV cell. So the output voltage from the PV cell starts increasing, thus the DC bus voltage also increases to 400 V. During the period 0.2–0.3 sec there is no change in load and solar irradiation. Therefore the DC bus voltage remains the same. The load voltage also remains the same. At the same time the battery is in idle mode and the load is supplied only by PV cell.

Case 2: (0.3-0.4 sec)

Load–2 is turned ON at the time of 0.3 sec and it will exist in the system till 0.5 sec.

From 0.3 sec to 0.4 sec, because of the increased load the DC bus voltage may decrease beyond 380 V. But this decrease in voltage will be compensated by the battery through the discharging mode. At the same time the SOC level should also be maintained at 80%. So the total load (Load-1 +Load-2) is supplied by PV cell and battery. Finally the DC bus voltage is again maintained as a constant of 380 V. The voltage across the load is increased, so the remaining voltage at the low voltage side of BIST is lowered when compared to case 1.

Case 3: (0.4-0.5 sec)

Time period is 0.4sec–0.5 sec. During this period, Load-3 is added to the circuit in order to make the DC source (PV cell and battery) unable to supply the load. If BIST is not introduced then the load voltage will automatically drop because of the insufficient DC source. But due to the introduction of BIST this situation won't occur. When the load is increased beyond the DC source limit the AC grid comes into picture through the BIST to compensate the reduction in output voltage. At the same time the battery also gets charge from the BIST.

Case 4: (0.5-0.7 sec)

Load-2 is removed in this case. Load-1 and Load-2 are connected to the circuit. Even though Load-2 is out of circuit to make the output from the load still lower, the irradiation of the PV cell is decreased during 0.5-1 sec.

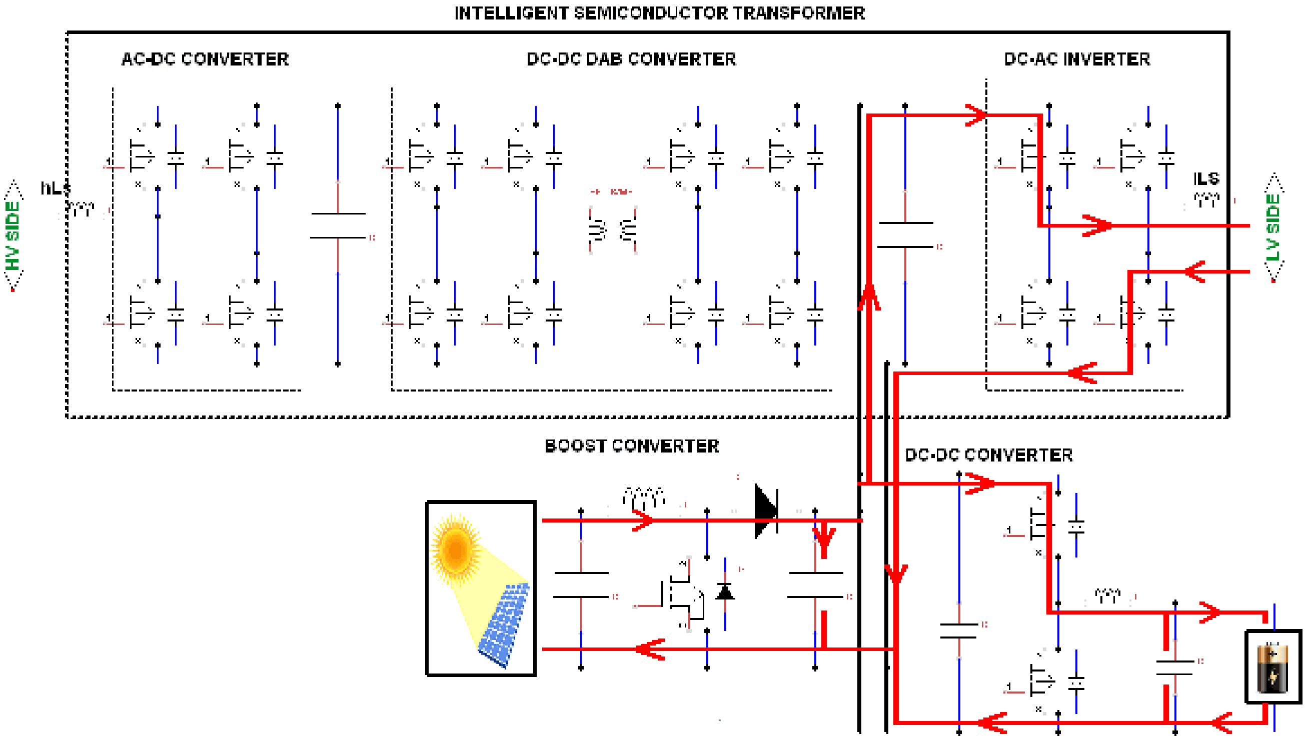

Figure 8. HV AC side to LV AC side and battery charging.

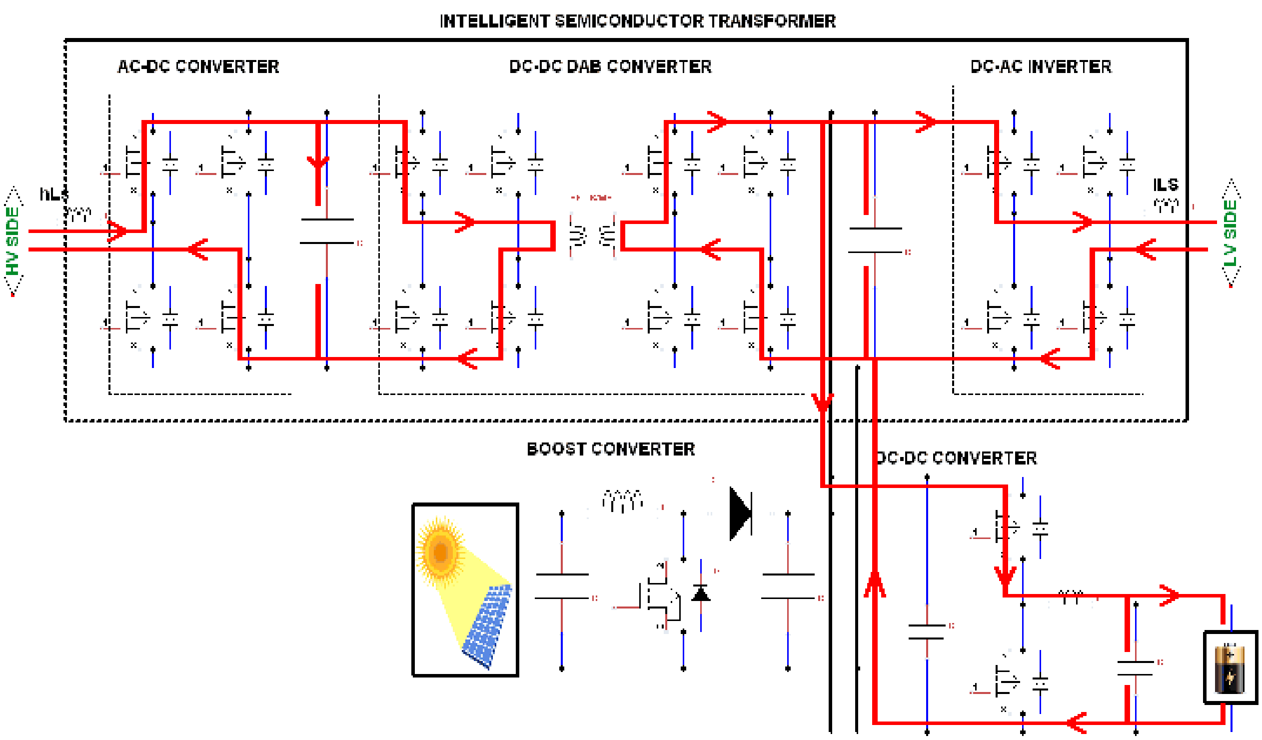

Figure 9. Solar to LV AC side and battery charging.

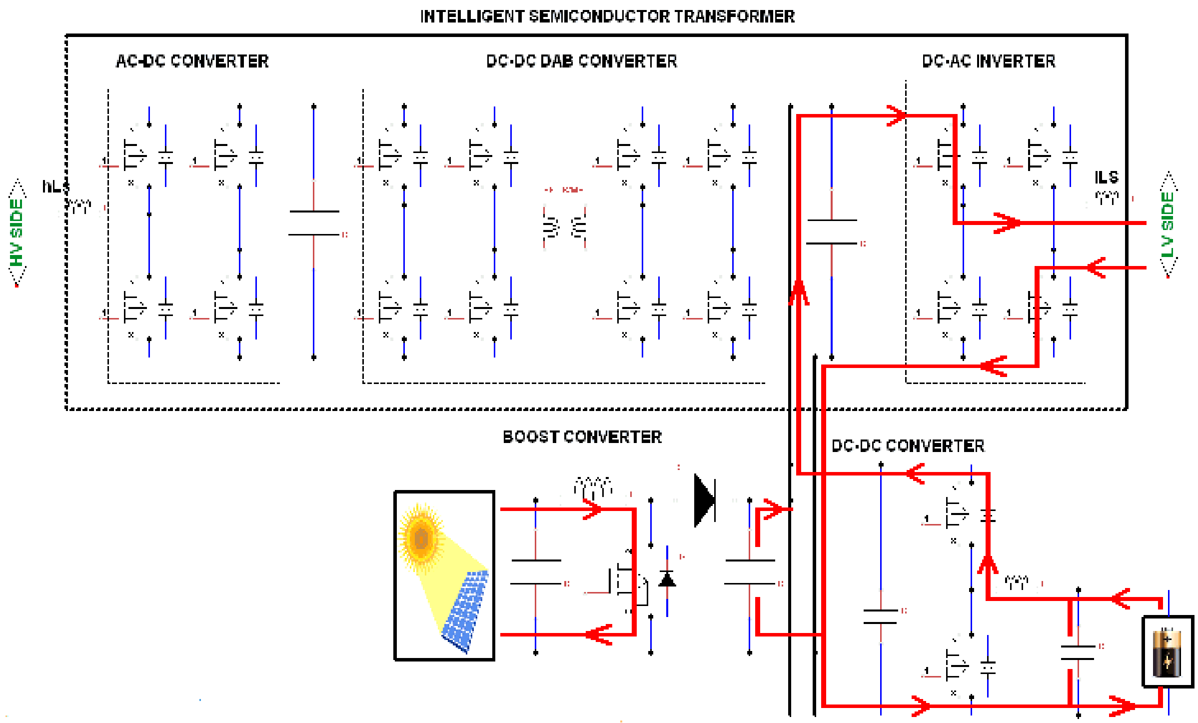

Figure 10. Solar with battery charging to LV AC side.

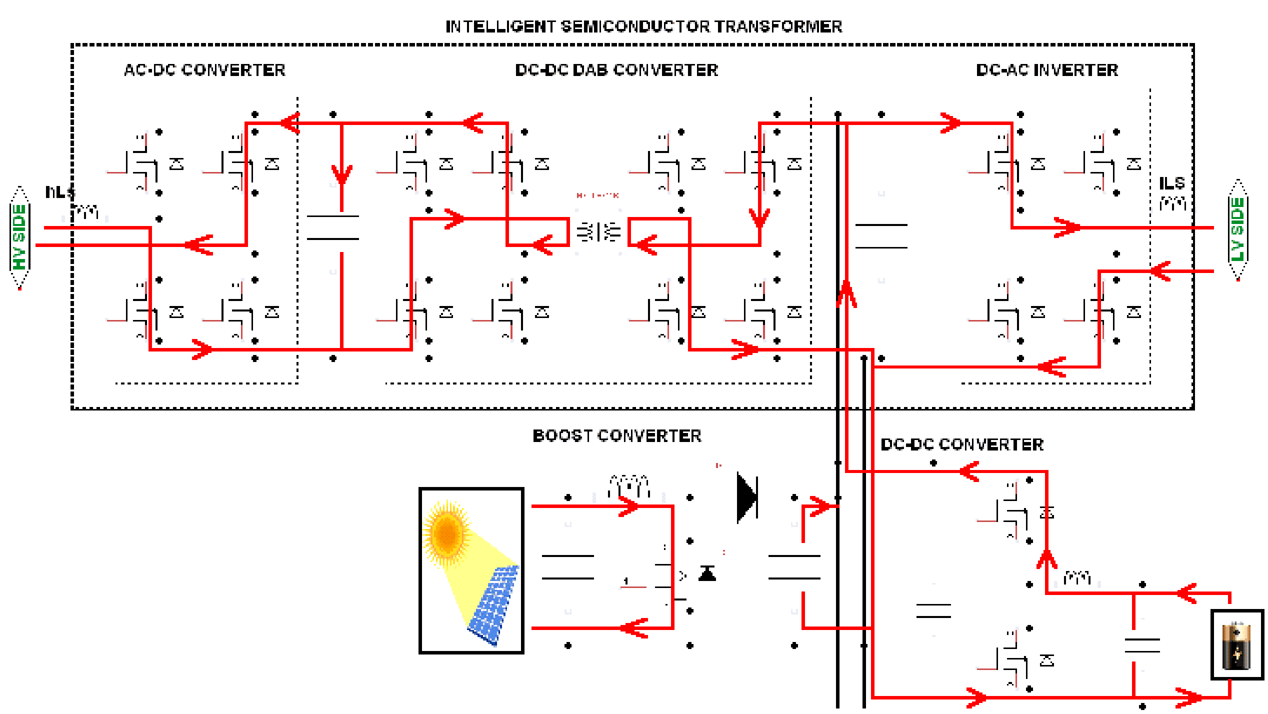

Figure 11. Solar and battery charging to both HV AC side and LV AC side.

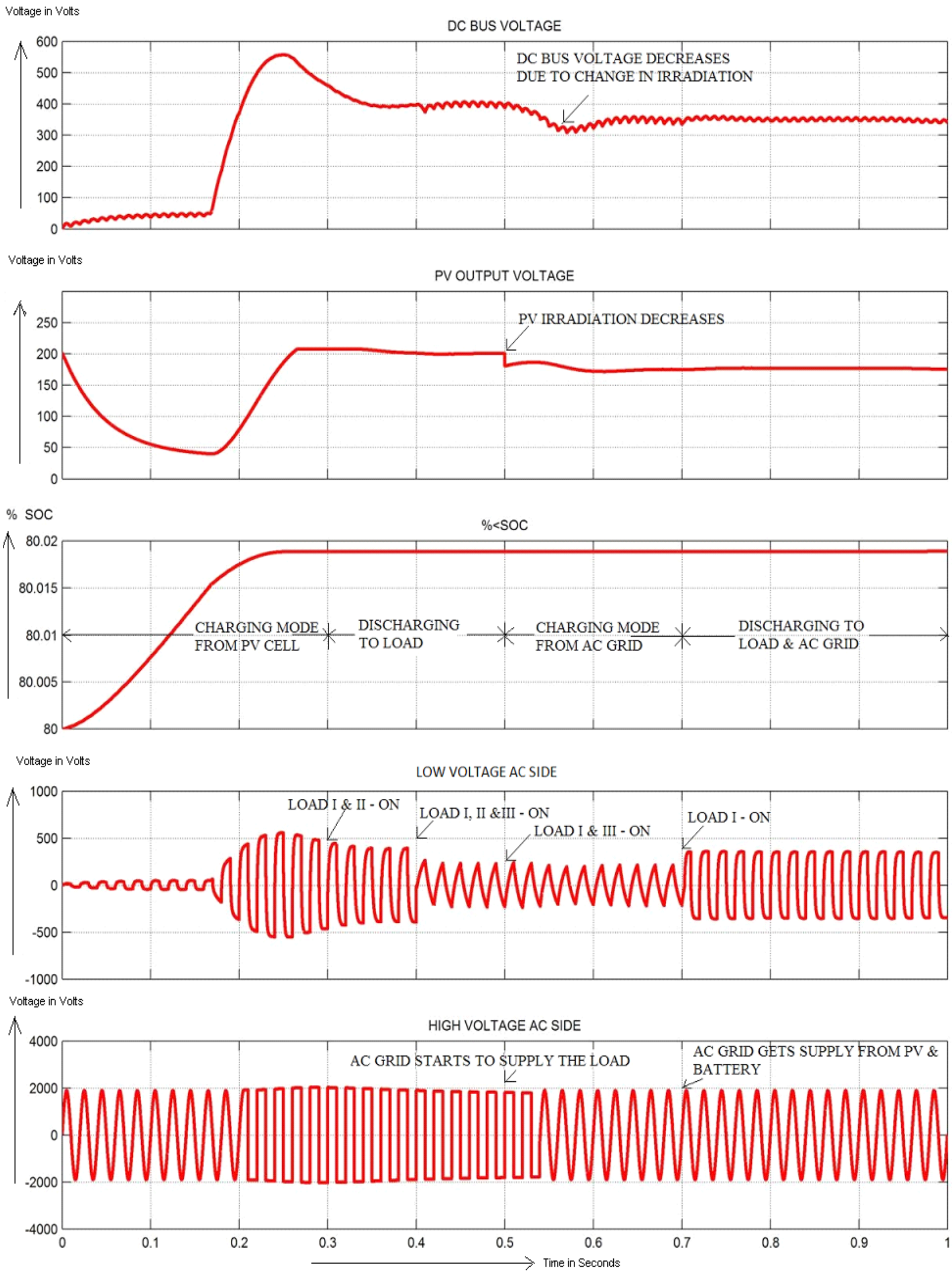

Figure 12. Simulation output of the proposed system.

This lowering in voltage is again compensated through the BIST as in case 4.

Case 5: (0.7-1 sec)

Load-3 is also removed at 0.7 sec. Only Load-1 is connected that too it consumes low voltage. The output from the PV cell alone is enough to supply the required load if the irradiation is good. But we are simulating PV cell for low irradiation which cannot supply even a small load. Again in this case also the required output is supplied by the BIST. And the battery is also getting charge from the BIST. During this mode if the PV irradiation is normal, load demand will be very low and there exists a surplus power at DC micro grids. The excessive power is transferred to the high voltage conventional AC grid through the semiconductor transformer. During this mode the SST act as a step up transformer.

6. Conclusion

The system power management control is explained in this paper for DC micro grid, which consists of battery and PV cell. BIST is used to interface the DC micro grid with the high voltage AC grid and low voltage loads. The droop control technique for BIST, battery and PV are also explained with their respective power ratings. The system can automatically change its control algorithm based on the SOC of battery and DC link voltage. With the proposed system uninterruptable power at consumer end is possible at low size and cost. The power losses are also reduced thus increasing the system efficiency.

7. Reference

1. Yu X, She X, Zhou X. Power management for DC micro grid enabled by solid-state transformer. IEEE Transactions on Smart Grid. 2014 Mar; 5(2):954–65.
2. Xie Y, Sun J, Freudenberg JS. Power flow characterization of a bidirectional galvanically isolated high-power DC/DC converter over a wide operating range. IEEE Transactions on Power Electronics. 2010 Jan; 25(1):54–66.
3. Lasseter H, Akhil A, Marnay C, Stevens J. White paper on integration of distributed energy resources, the CERTS micro grid concept. Proceedings of Consortium for Electric Reliability Technology Solutions, Gray, Davis, Governor; 2002 Apr. p. 1–27.
4. Bryan J, Duke R, Round S. Decentralized generator scheduling in a nanogrid using DC bus signalling. Proceedings of IEEE Power Engineering Society General Meeting; 2004 Jun 6-10. p. 977–82.
5. Schonberger J, Duke R, Round SD. DC-bus signalling: A distributed control strategy for a hybrid renewable nanogrid. IEEE Transactions on Industrial Electronics. 2006 Oct; 53(5):1453–60.
6. Sun K, Zhang L, Xing Y, Guerrero JM. A distributed control strategy based on DC bus signalling for modular Photovoltaic generation systems with battery energy storage. IEEE Transactions on Power Electronics. 2011 Oct; 26(10):3032–45.
7. Guerrero JM, Vasquez JC, Matas J, Sosa JL, de Vicuna LG. Parallel operation of uninterruptible power supply systems in micro grids. Proceedings of 2007 European Conference on Power Electronics Application; Aalborg. 2007 Sep 2-5. p. 1–9.
8. Ronan ER, Sudhoff SD, Glover SF, Galloway DL. A power electronic-based distribution transformer. IEEE Transactions on Power Delivery. 2002 Apr; 17(2):537–43.
9. Lai JS, Mitra A, Mansoor A, Goodman F. Multi-level intelligent universal transformer for medium voltage applications. IEEE 14th IAS Annual Meeting Conference Record of the 2005 Industry Applications Conference; 2005 Oct 2-6.3. p. 1893–9.
10. Divya S, Abarna K, Sasikumar M. PV Micro inverter topology using soft switching half-wave cycloconverter. ARPN Journal of Engineering and Applied Sciences. 2015 May; 10(9):3873–7.
11. Savio M, Murugesan S. A high efficient Fuzzy Logic Controlled Maximum Power Point Tracking (FLMPPT) in solar PV for brushless DC motor drives. ARPN Journal of Engineering and Applied Sciences. 2015 Jan; 10(4):1756–61.
12. Manjula HS, Sasikumar M. Current harmonics reduction using Hysteresis Current Controller (HCC) for a wind driven self-excited induction generator drives. Indian Journal of Science and Technology. 2015 Jul; 8(13):1–6.