International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Design and Implementation of Non-Isolated Three-Port DC/DC Converter for Stand-Alone Renewable Power System Applications

Archana[1], Nalina Kumari[2]

[1]PG Student (power Electronics), Department of EEE, The Oxford College of Engineering, Bangalore, India

[2]Assistant Professor, Department of EEE, The Oxford College of Engineering, Bangalore, India

Abstract: ***DC-DC Converters are those devices which have the ability to change one level of direct voltage/ direct current to that of another level. Non-Isolated DC/DC three-port converters intermeddling the input source that is photovoltaic array, storage device like battery and the load is proposed in Stand-Alone Renewable system applications. In This application PV panel is not being connected to the grid but instead are used for charging the batteries. Each port is used for specific input or output, and its functions depend on the port; they are the renewable source, the battery set, and the output port. Three-Port Converters are bring into existence by introducing a bidirectional converter into Boost converter. Power flow path either from PV array to the load or from battery to the load is achieved in this project. Using four regulators accomplishing Maximum Power Point Tracking (MPPT) control of PV array, governs the charging battery and voltage control of the load. PWM scheme applied to the Three-Port Converter based on power relations among three ports. DC/DC Converter works in every operation mode and switch between dissimilar mode easily. Three-Port Converter has advantages of high efficiency, higher flexibility, reliability and lower cost. A proposed system is simulated using MATLAB/SIMULINK environment.***

Keywords: PV array, DC/DC converter, Bidirectional converter, MPPT controller.

1. Introduction

Now a day's world population is increasing rapidly, the power demand is also increasing frequently. Conventional energy sources like oil, coal and so on (fossil fuels) are continuously depleting in the recent years in the universe, it is necessary to known various choice of energy sources in order to meet power demands. Hence renewable sources play an important role in generating power and achieve the load requirements. Advantages like low maintenance, almost nil harmful emissions, and renewable energy sources hold virtual role in satisfying the future load demand.

Applications of renewable energy sources may be different depending upon whether they are connected to the grid or not, also known as standalone system. Standalone system is also known as remote area power supply (RAPS), it is an off-the-grid electricity system for the locations that are not connected with an electricity distribution system. Standalone system includes electricity generation, energy storage and generation.

The renewable source like solar energy utilization has been looked upon by many researchers all around the world. It has been known that solar cell operates at very low efficiency approximately around 20% and thus a better control mechanism is required to increase the overall efficiency of the solar cell. In this field researchers have developed that are nothing Maximum Power Point Tracking (MPPT) algorithms [1].

PV array should be the main energy source in standalone application. Renewable sources like solar, wind are not regular in nature. Hence storage device like battery is required for stand-alone power system to improve overall dynamics of the system. Renewable energy sources have few disadvantages like fluctuation in output due to weather conditions, temperature irradiance. To overcome from these drawbacks battery is used as a storage element to improve dynamic characteristics.

The power management of power converter is required in order to meet output power. Three-Port DC/DC converter is best for standalone PV system applications. TPC has advantages of less component count, lower cost higher reliability and fewer conversion stages [2]-[4]. Due to considerable advantages of the TPC, a variety of topologies have been proposed in different fields, like hybrid electric vehicles [5]-[8]. PV system with battery backup [9]-[12].

2. Photovoltaic system

2.1 PV cell

PV cell is made of semiconductor material absorb light that is reflected on them and convert it directly into electricity. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current - that is, electricity.

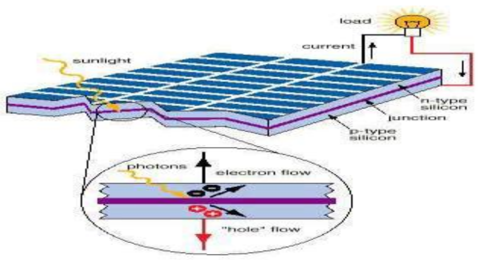


Figure2.1: Working of PV cell

2.1 PV module

Due to the low voltage generated in a PV cell (around 0.5V), several PV cells are connected in series (for high voltage) and in parallel (for high current) to form a PV module for desired output. Separate diodes may be needed to avoid reverse currents, in case of partial or total shading, and at night.

2.3 PV Array

The power produced by one module is not sufficient to achieve the load requirements; initially modules in a PV array are connected in series to obtain the desired voltages, and then individual modules are connected in parallel to produce current.

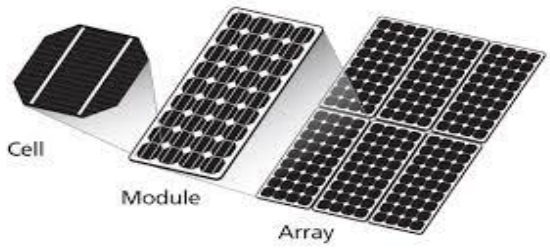


Figure 2.2: PV cell, module and array.

3. DC-DC Converter

Three-port DC/DC converter has the advantages of less component count, less conversion stages, lower cost and higher reliability. TPC has two categories: Non-isolated and isolated topologies. Non-isolated is better one compared to isolated one because in Non-isolated converter isolation is not required and non-isolated converter has advantages of compact design and higher power density.

Different types of non-isolated DC/DC converters are as follows:
3.1) Buck (Step down) converter.
3.2) Boost (Step up) converter.

3.1 Buck (Step down) converter

Buck converter is also known as step down converter because output voltage is less than that of input voltage. When switch is open, current through inductor is zero. When switch is closed, current through inductor is increases linearly and the inductor will produce an opposing voltage across its terminals in response to the changing current. This voltage drop counteracts the voltage of the source and therefore reduces the net voltage across the load.

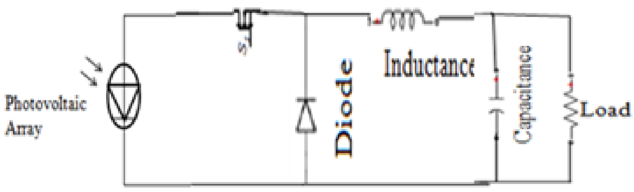


Figure 3.1: Buck converter

$$\frac{Vo}{Vin} = k$$

V_o is output voltage.
V_{in} is input voltage.
K is duty cycle.

3.2 Boost (Step up) converter

Boost converter is also known as step up converter because output voltage is greater than that of input voltage.

- When the switch is closed, current flows through the inductor is increases in clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive.
- When the switch is opened, inductor current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current flow towards the load. Thus the polarity will be reversed (means left side of inductor will be negative now). As a result two sources will be in series causing a higher voltage to charge the capacitor through the diode D.

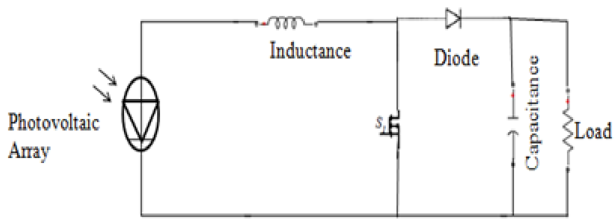


Figure 3.2: Boost converter

$$\frac{Vo}{Vin} = \frac{1}{1-k}$$

V_o is output voltage.
V_{in} is input voltage.
K is duty cycle.

4. Block diagram

Non-isolated Three-Port (DC/DC) converters that is NI-TPC intermeddling PV array, the battery and the load. Non-isolated converters contain an inductor instead of a transformer (isolated). Power efficiency of all three ports power flow paths in the Boost (DC/DC) TPCs is higher.

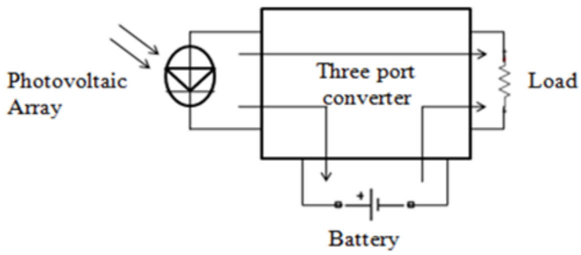


Figure 4.1: Three-Port Converter

As long as the Sun irradiation is high that is power produced by PV panel is greater than that of load demand. PV array feeds the load at the same time battery charges. When sun irradiation is low, battery discharges to the load because PV panel doesn't have sufficient power to meet load demand.

MPPT controller is not mechanical tracking of the system. MPPT is electronic tracking of the system. The controller looks at the output of the Photovoltaic array and compares PV voltage to the battery voltage. It then figures out what is the best power that PV can put out to charge the battery.

Bidirectional converter is used to achieve power transfer between two dc power sources in either of direction. If battery connected with bidirectional converter results in improved system efficiency. Bidirectional converter increases battery life with proper control of charging and discharging of the battery.

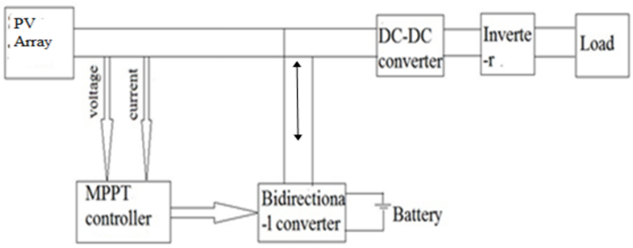


Figure 4.2: Block diagram of TPC with MPPT controller.

5. Topology of TPC

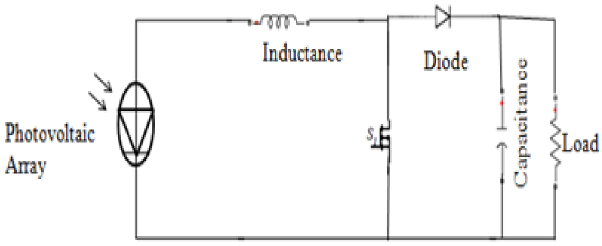


Figure 5.1: Boost converter

Figure 5.1 shows the basic property of the Boost TPC. Power flow from PV array to the load is defined. Battery is used as storage mechanism for smoothing output power in a stand-alone system. Boost converter is a single input, single output converter which use one inductor and one power switch.

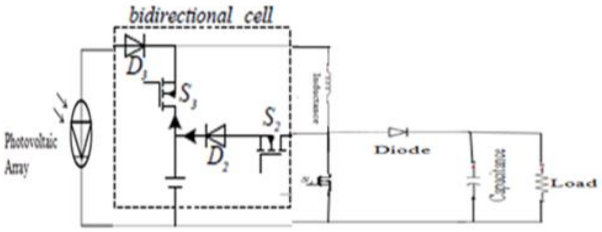


Figure 5.2: Boost TPC with bidirectional converter

Figure 5.2 shows Bidirectional converter obtained by introducing additional two power paths in the basic topology of the Boost TPC. In the basic step up converter inductor L and switch s_1 connected in series with PV array.

When input power is greater than the load demand, battery will charges. Charging is controlled by power switch s_2 which is introduced in the boost converter and diode D_2 is provided to prevent the reverse current flow. The power flow path is PV array to the battery. The final circuit is remains the boost converter that is output voltage is more than input voltage.

When input power is lower than the load demand, battery should discharges to the resistive load, discharging of battery is controlled by switch s_3 which is introduced in the boost converter. Input source that is PV array and battery should not be connected in parallel hence diode D_3 is required. Here also the final circuit is Boost converter.

6. Operation mode analysis

Power in the input source is P_{in}, power in the battery is P_b and power in the load is $P_{o.}$ Consider that P_b is negative when the battery charges and P_b is positive when the battery discharges, neglecting the power loss. Input power and battery power is equal to battery power. That is:

$$Pin + Pb = Po$$

Three different modes of operations are:
6.1 Dual Output (DO) mode.
6.2 Dual Input (DI) mode.
6.3 Single Input Single Output (SISO) mode.

6.1 DO mode

The TPC operates in DO mode when input power is more than that of the output power is shown in figure8. In this mode input source and battery both works as outputs. Hence, named as dual-output mode. PV array supply the power to load and at the same time charge the battery. Power switch s_3 is off, input power is controlled by duty cycle k_1 and output power is controlled by k_2 .

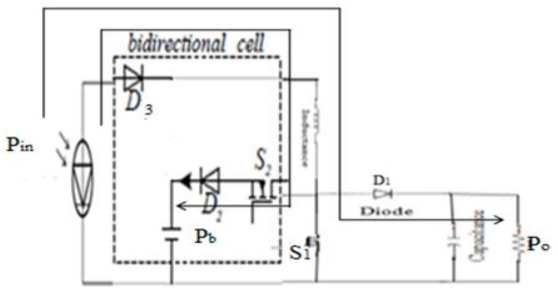


Figure 6.1: DO mode

Net change in the inductor current over one complete cycle is zero in steady state. Therefore we have Output voltage is:

$$Vo = \frac{V_{in} - k_2 V_b}{1 - k_1 - k_2}$$

6.2 DI mode

The TPC operates in DI mode when input power is less than that of output power that is when sun irradiation is low. In this mode battery discharges to the load and PV array should not have sufficient power to meet load demand. Power S_2 is off in dual input mode. Input source and battery both works as inputs. Output power is controlled by k_3 instead of k_2 .

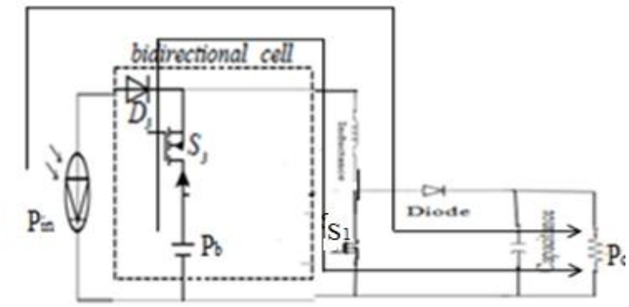


Figure 6.2: DI mode

Net change in the inductor current over one complete cycle is zero in steady state. Therefore we have Output voltage is:

$$Vo = \frac{(1-k_3)\,V_{in} + k_3\,V_b}{1-k_1}$$

6.3 SISO mode

TPC operates in SISO mode when input power is zero that is during night time. In SISO mode battery power is supply to the load. Power switch S_2 is off. Here battery is serve as input and load as output.

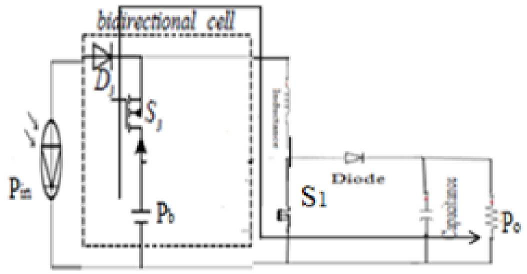


Figure 6.3: SISO mode

$$Vo = \frac{V_b}{1-k_1}$$

7. Simulation

Design: The boost converter design is as follows

Parameters	*values*
Input voltage	120v
Output voltage	230v
Battery voltage	0v
Switching frequency	100kHz
Output power	500w

Conventional circuit for Dual-Output mode: (From figure 6.1)

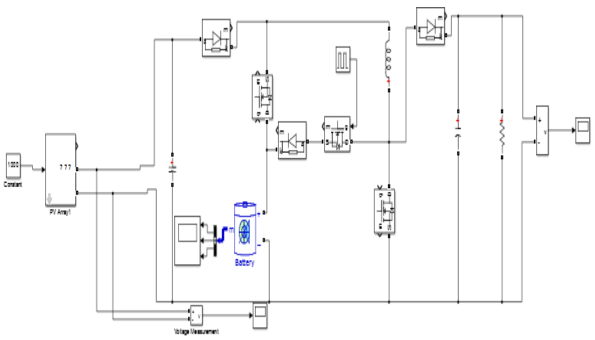
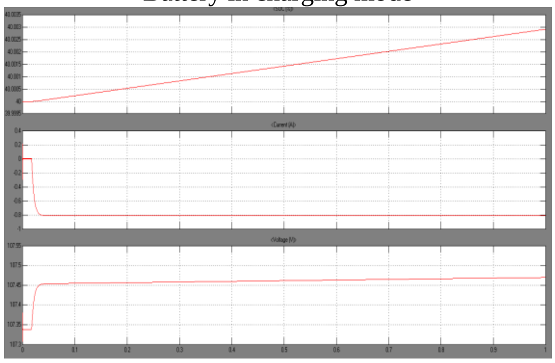


Figure 7.1: Simulation circuit of DO mode.
Battery in charging mode



Time (second)
Figure 7.1.1: Testing Battery State Of Charge (Charging)-Time (sec)

Conventional circuit for Dual-Input mode: (From figure 6.2)

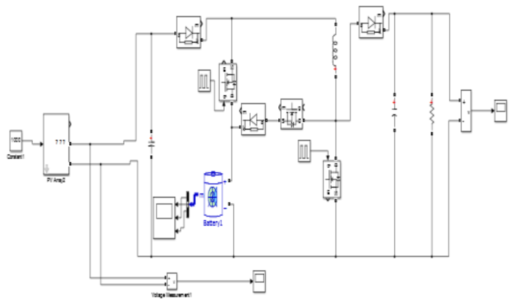
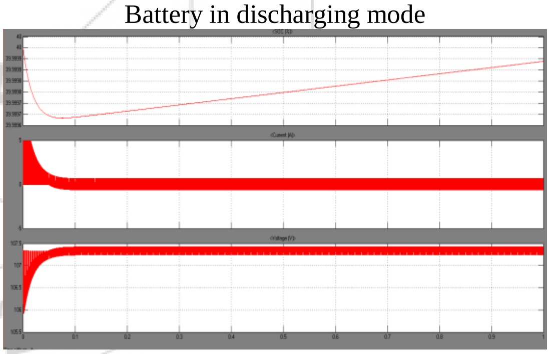


Figure 7.2: Simulation circuit of DI mode

Battery in discharging mode



Time (second)
Figure 7.1.2: Testing Battery State Of Charge (Discharging)-Time (sec)

Conventional circuit for Single-Input Single Output mode: (From figure 6.3)

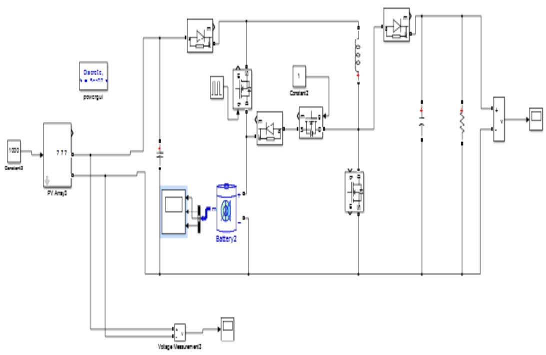
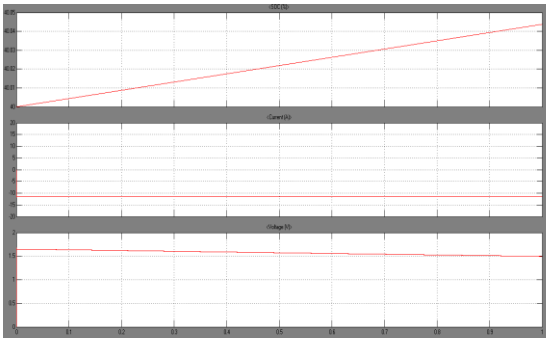


Figure 7.2: Simulation circuit of SISO mode.
Battery in charging mode



Time (second)

Figure 7.1.3: Testing Battery State Of Charge (Charging)-Time (sec)

- **Closed loop TPC**

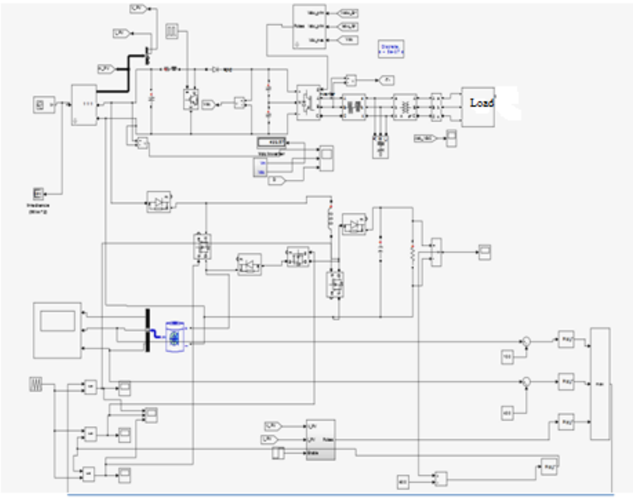


Figure 7.4: Simulation circuit for TPC (From figure 4.2)

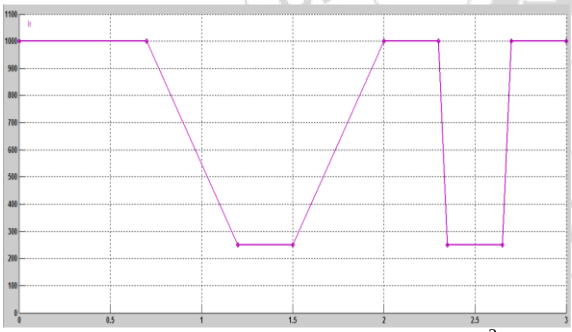


Figure 7.4.1: Solar irradiance initially 1000w/m^2 varies on weather conditions.

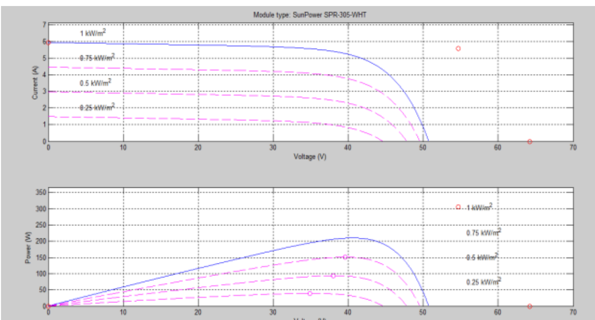
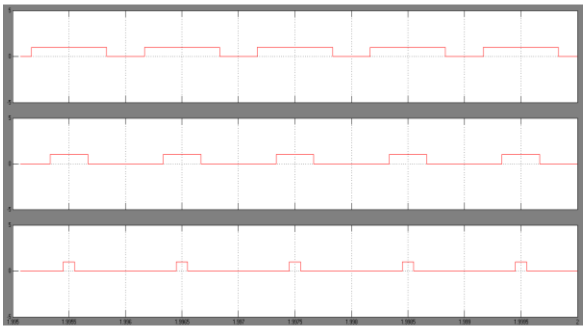


Figure 7.4.2: I-V and P-V charactristics for different irradiance at fixed 25^{0}c temperature.



Figire 7.4.3: The required PWM signal used as the gate pulse for the MOSFET is shown above in the figure.

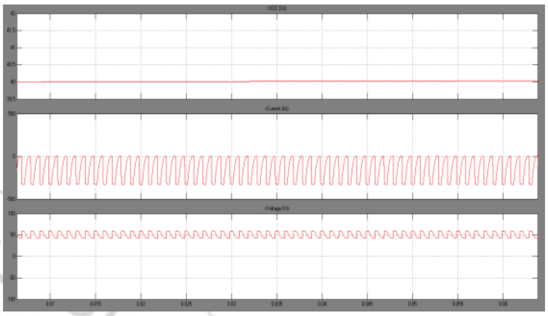


Figure 7.4.4: Battery charging voltage 40v

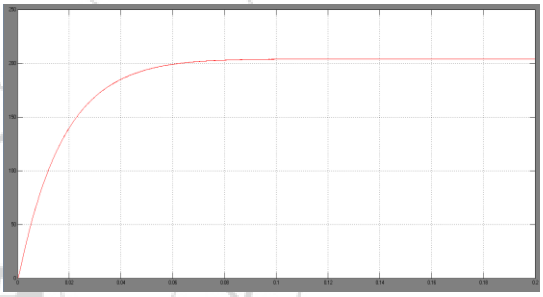


Figure 7.4.5: Output 230v DC voltage

8. Conclusion

Three- port DC/DC converter in renewable applications should be able to handle both the renewable source that is PV array and battery port; the renewable sources are not regular in nature it depends on climatic conditions, temperature and irradiance. Hence battery port is used; its utility period of life should be taken into consideration. Three-port DC/DC converters in this report are, one port is for PV array, the second port is for battery and finally the output port. Power may be obtained from both input voltages simultaneously or each one independently that is single stage power conversion between any two of the three ports can be accomplished. Battery port is used whenever it is required; this results in an increase the lifetime of battery. Also when the solar power is not available for example during night, the system automatically takes energy from battery port without any change, only when the MPPT optimize the renewable source.

Using four regulators MPPT control of input source, charging control of the battery and voltage control of the load is accomplished. Three-Port DC/DC converter operates in all DO, DI and SISO modes freely. PWM scheme is proposed based on power relations among three-ports. All three modes are simulated using MATLAB/SIMULINK environment.

References

[1] Mummadi Veerachary, "Control of TI-SEPIC Converter for Optimal Utilization of PV Power", IICPE, 2010 New Delhi.

[2] W. Jiang and B. Fahimi, “Multi-port power electric interface for renewable energy sources,” in Proc. IEEE 2009 Appl. Power Electron. Conf., pp. 347-352.

[3] H. Tao. J. L. Duarte, Hendrix, M.A.M., “Multiport converters for hybrid power sources,” in IEEE Proc. PESC, USA, 2008.

[4] G. Su and L. Tang, “A reduced-part, triple-voltage DC-DC converter for EV-HEV power management,” IEEE Trans. Power Electron., vol. 24, no. 10, pp. 2406-3410, Oct. 2009.

[5] Gui-Jia Su, Lixin Tang, “A multiphase, modular, bidirectional, triple voltage DC-DC converter for hybrid and fuel cell vehicle power system, ” IEEE Trans. on Power Electronics, vol. 23, no. 6, pp. 3035- 3046, 2008.

[6] G. Gamboa, C. Hamilton, R. Kerley, “Control strategy of a multi- port, grid connected direct DC PV charging station for plug-in electric vehicles ,” in proc. IEEE Energy Conversion Congress & Expo, Atlanta, USA, 2010, pp. 1173-1177.

[7] Chuanhong Zhao, Simon D. Round, Johann W., “An isolated three-port bidirectional DC-DC converter with decoupled power flow management,” IEEE Trans. on Power Electronics, vol. 23, no. 5, pp. 2443 -2453, 2008.

[8] Haimin Tao, J. L. Duarte, Marcel A. M., “Three-port triple-half-bridge bidirectional converter with zero-voltage switching,” IEEE Trans. On power Electronics, vol. 23, no. 2, pp. 782-792, 2008.

[9] H. Tao, A. Kotsopoulos, J. Duarte, and M. Hendrix, “Transformer coupled multiport ZVS bidirectional dc-dc converter with wide input range,” IEEE Trans. Power Electron., vol. 23, no. 2, pp. 771-781, Mar. 2008

[10] Zhan Wang, Hui Li, “Integrated MPPT and bidirectional battery charger for PV application using one multiphase interleaved three-port DC-DC converter,” in Proc. IEEE APEC 2011, USA, pp. 295-300.

[11] Hongfei Wu, Kai Sun, Zihu Zhou, Yan Xing, “An integrated four-port full-bridge converter with DMPPT for renewable power system,” in PEDG, 2012 3rd IEEE International Symposium on, 2012, pp. 895- 900.

[12] Hongfei Wu, Runruo Chen, Junjun Zhang, Yan Xing, “A family of three-port half-bridge converters for a stand-alone renewable power system,” IEEE Trans. on Power Electronics, vol. 26, no.9, pp. 2697-2706, 2011.

Author Profile

Rachana received the B.E degree in Electrical and Electronics Engineering from Guru Nanak Dev Engineering College Bidar in 2011 affiliated to VTU Belgum, and pursuing M.Tech in Power Electronics from The Oxford College of Engineering, Bangalore from 2013 to 2015 affiliated to VTU Belgum.