Indian Journal of Science and Technology, *Vol 8(24), DOI: 10.17485/ijst/2015/v8i24/80880, September 2015*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Survey on Nanogrid Converters

I. S. Sree Devi and D. M. Mary Synthia Regis Prabha

EEE, Noorul Islam University, Kumarakovil - 629180, Tamil Nadu, India

Abstract

Nanogrids are renewable energy based distribution system suitable for low power household applications. This paper focuses on DC nanogrid which is supplied by Solar photovoltaic. Nanogrids are considered building cells of a Microgrid. A survey of different types of DC to DC Boost converters used in Nanogrid is presented in this paper. The topologies of some of the configurations of Boost converter are reviewed. This paper also highlights the advantages and disadvantages of all the reviewed converters.

Keywords: BHDC, CFSI, DC to DC Boost Converter, IBC, Nanogrid, QBC, SBI, SEPIC, Solar Photovoltaic, ZSI

I. Introduction

Recently distributed renewable energy sources are gaining more attraction due to environmental related problems caused by conventional power generation, free trade of the power and advancement in power electronics and renewable energy sources technology. Green energy sources like solar, wind etc can be connected directly to the grid by means of a grid-tied inverter or they can be form a standalone power system which supplies the domestic loads.

Nanogrid is meant for supplying domestic load of the order of few hundred watts to 5 kW generated from renewable sources like roof-top solar photovoltaic, fuel cell, wind farm, etc. The generators are primarily based on clean forms of energy such as fuel cells, solar arrays and wind turbines. A nanogrid consists of power electronic converters which interface the generators and the loads to the nanogrid. These converters also link the nanogrid to the power system grid. Each nanogrid should be efficient, reliable, self-sufficient and fault tolerant[2–6].

The nanogrid distribution system can be based on AC or DC depending on design. DC nanogrid possesses the following advantages over AC nanogrid

- DC based distribution provides higher system efficiency than AC based distribution as losses due to skin effect, no-load equipment losses are absent.
- Unlike AC distribution systems, frequency stability is not a concern for DC distribution systems.
- DC distribution systems do not have any reactive power issues[11–14].

2. Components of Nanogrid

The nanogrid envisioned in this paper consists of a solar PV system as the source of energy, energy storage, nanogrid controller and residential or commercial loads.

The converter for the PV system typically consists of a two stage converter with the first stage being a unidirectional DC to DC step-up (boost) converter and second stage being a unidirectional DC to AC converter (inverter). Single stage PV inverters are also common in the industry.

The loads in a residential building consist of consumer electronics products such as computers, TVs, phones and appliances such as washers, dryers. These loads utilize various power electronics converters to operate. The energy storage component of a nanogrid can be battery based such as Lead Acid or Li-Ion which are widely available[6].

**Author for correspondence*

3. Nanogrid Converter Review

3.1 Conventional Boost Converter

The conventional converter consists of two stages where step up operation is done by a classic Boost converter and inversion is done by Voltage Source Inverter (VSI). In the boost topology, there is switch S, inductor L, and D_b is the freewheeling diode which help to avoid reverse current. C is the filter capacitor. The Boost converter output is fed as the input to VSI. The qualities of boost converter are continuous input current flows into the input port and step up operation is done without transformer[1].

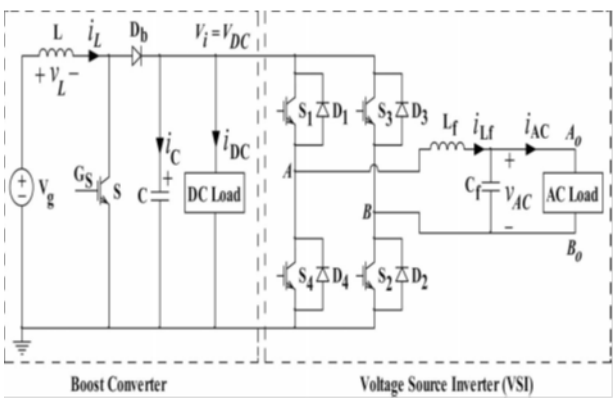

Figure 1. Conventional boost converter.

The detriments of classical boost converter are the output voltage is very sensitive to changes in the duty cycle and high current flows through the single switch. Since it is a two stage converter it consists of more number of power electronic switches and has high EMI problems. Inspite of all these detriments, boost topology is used in PV systems to extract as much power as possible from the photovoltaic cells because of its high efficiency and transformer less boost operation.

3.2 Interleaved Boost Converter (IBC)

The topology explained in[7,8] is known as Interleaved Boost Converter (IBC). It consists of interleaved and intercoupled boost converter. By interleaving method the converters are modulated such that each switch operates at same switching frequency with a phase shift of 180°. Interleaving also requires additional inductors, diode and switching devices.

This will increase the cost of the converter. The efficiency, size and transient response are improved. IBC is more economical method for EMI. Interleaved Boost converter has only small unbalance in current even the duty cycle mismatch is large. Also the two boost converter cells share the same magnetic core which makes it less costly.

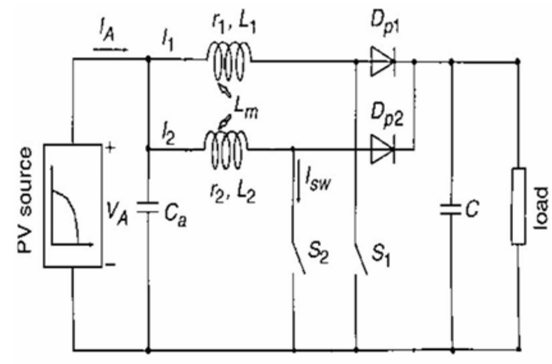

Figure 2. Interleaved boost converter.

It is more capable for photovoltaic system because the ripple contents both in the input and output waveforms are cancelled.

Interleaved boost converter can also be operated at an optional power level to improve the conversion efficiency and is suitable for high power application[7].

3.3 Quadratic Boost Converter

Quadratic Boost Converter (QBC)[9] consist of a single ideal switch SW, diodes D_1 and D_2, capacitor C_1 and two inductors L_1 and L_2 in the source side. C_1 and C_2 are large enough so that the capacitor voltages V_{C1} and V_{C2} are constant over a switching period.

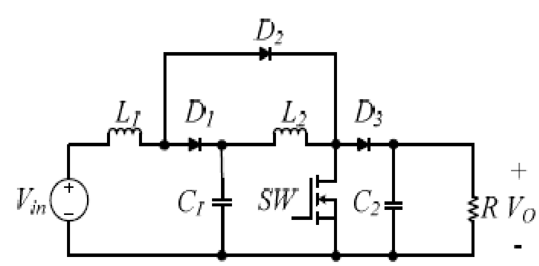

Figure 3. Quadratic boost converter.

The merits of this topology[9] are it has high gain and reduced voltage stress and current stress. More number of components is present which leads to decrease in efficiency. It is mainly used in high power application. These converters are best suited for solar PV applications.

3.4 Z-Source Inverter (ZSI)

In the Z-Source Inverter (ZSI)[10], there is a LC network which is X-shaped, in between the power source and voltage source converter.

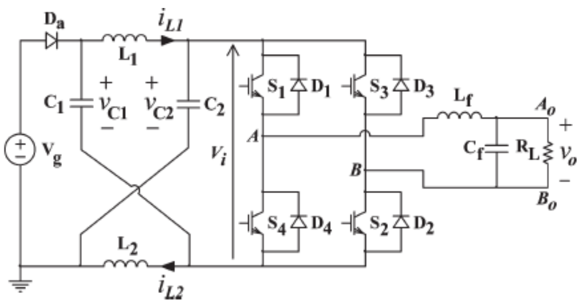

Figure 4. Schematic of ZSI.

The advantages of ZSI are input voltage can be stepped up or stepped down as per the output requirement and it possess good immunity to EMI. But there are two inductors and two capacitors in the LC network which will increases the size and cost of power converters.

3.5 Switched Boost Inverter (SBI)

SBI[11–14] is a buck boost type converter and it converts dc to ac. It consists of a switched boost network in between the power source and power converter. Boost operation is invoked by utilizing the shoot through state of Inverter Bridge.

Switched boost network has one active switch S, two diodes (D_a and D_b), inductor L and capacitor C. To boost the input voltage both the switches in the same leg are turned ON simultaneously.

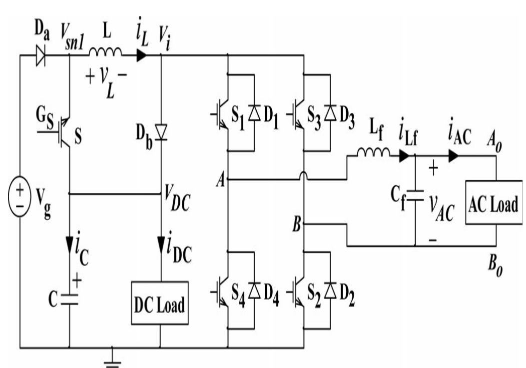

Figure 5. Schematic diagram of SBI.

SBI has two passive device and three semiconductor switches. This will reduce the size and weight of the power converter which in turn reduce the cost. The other advantages of SBI are

- SBI is a single stage converter. It can simultaneously supply both ac and dc loads. This will make the converter compact.
- The AC output voltage of the SBI can be either higher or lower than the input voltage.
- The DC output is due to the shoot through in the inverter legs. A dead time circuit is not required as it allows shoot through operation. So it doesn't require any complex dead time compensation technique.

The disadvantage is that it requires a better protection circuit due to the increase in number of semiconductor switches even though SBI is immune to electromagnetic noise. From the merits of SBI it is clear that it is best suited for low power application like PV system.

3.6 Current-fed Switched Inverter (CFSI)

This topology[15] is derived from current fed DC/DC converter topology. From the Figure 6 the DC bus is realized across the nodes V_{s2} and V_{s3} across capacitor C_0 which is held at voltage V_{DC} and the AC bus is realized across the capacitor C_f which is held at the voltage V_{AC}.

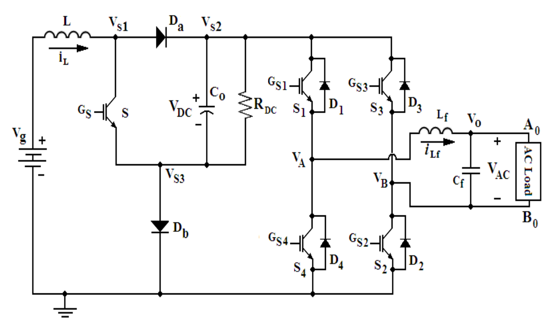

Figure 6. Schematic diagram of Current-Fed Switched.

CFSI is a single stage converter and has following advantages. It can supply both ac and dc loads simultaneously.

As it is a single stage converter it does the tasks of both DC to DC converter and DC to AC converter in a single stage. This will reduce the size and weight of the converter which in turn reduces the cost.

The wide range of ac output voltage can be obtained. The AC bus voltage of CFSI can be higher and lower than the input voltage. The DC output is obtained from the shoot through operation.

CFSI is more immune to EMI noise and it does not require any dead time to avoid shoot through state. CFSI has an input inductor in its structure so continuous input current operation is possible. Except the EMI problem, CFSI is best suited for low power PV applications.

3.7 Single Ended Primary Inductor Converter (SEPIC)

Single Ended Primary inductor converter (SEPIC)[16,17] is a type of dc to dc buck boost converter. The output can be greater than or lesser than the input voltage. Duty cycle of the control switch is controlled to control the output of the SEPIC converter.

SEPIC consist of input filter inductance L_1 and controllable switch S. It also consists of diode D and filter capacitor C_f in the output side. The main feature of the SEPIC is the presence of series capacitor C and inductor L_2. It is essentially a boost converter followed by buck boost converter. The input DC voltage is chopped to get desired output voltage. The output is similar to buck boost converter but has the output polarity same as the input voltage[23].

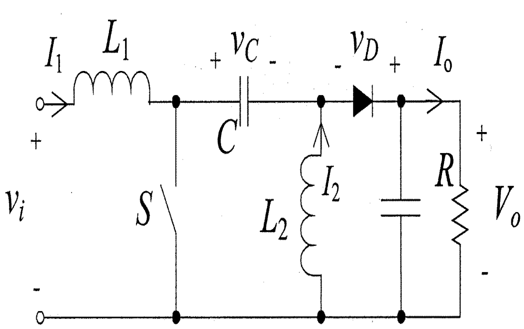

Figure 7. Schematic diagram of SEPIC boost converter.

The advantages of SEPIC converter are it has output gain flexibility. It also gives non inverted output.

The disadvantages of SEPIC are it has a pulsating output current. SEPIC converter transfers all the energy through the series capacitor. So this capacitor must have high capacitance and high current handling capacity. It is a fourth order converter and it is difficult to control. It can supply only DC loads. It is suitable for very slow varying applications[23].

3.8 Push-pull Boost Converter

The converter presented in[18,19] is known as push-pull boost converter. It is based on push pull architecture associated with magnetically coupled transformer. From Figure 8, it consists of diodes D_1, D_{11} and capacitor C_1 which acts as a regenerative snubber. This will recycle the energy stored in a leakage inductance of the push pull transformer. The voltage gain is improved by the series connection of all capacitors. It is also called as boost converter with a voltage multiplier and three state switching cells. Push pull converter operates with duty cycle above 50% in continuous current mode

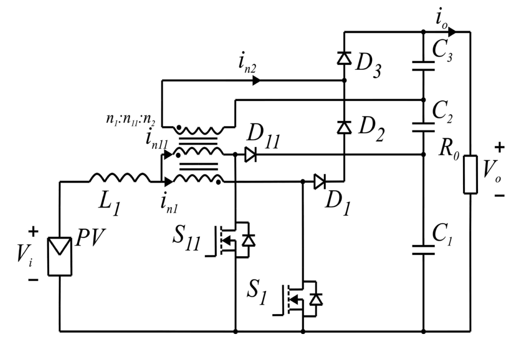

Figure 8. Schematic diagram of push-pull boost converter.

The major advantages of push-pull converter[18] are,

- It has less input current ripple and has very low voltage stress.
- The weight and volume of the converter is reduced because the input inductor operates with twice the switching frequency.
- The output voltage is increased by incrementing the transformer turns ratio for a given duty cycle. This will reduce the voltage stress across the switches.
- Presence of an inductance in the output stage will avoid fast transient currents in all parts of the converter.
- It has high conversion ratio.

The detriments of the converter are as follows. Push pull converter has more number of components which makes the control process complicated. It can supply only DC loads. The output voltage produced by the converter is constant and it depends on the transformation ratio of transformer. In spite of all these drawbacks, push pull boost converter seems to be a best solution for boost operation in photovoltaic systems.

3.9 High Step-up DC–DC Converter with Hybrid Transformer

The converter shown in Figure 9 consists of a active switch S_1, input capacitor C_{in} and clamping diode D_1. The main feature of this converter is that it has a hybrid transformer with turns ratio 1: n. When S_1 is off, the current path for the leakage inductance of hybrid transformer[20] is provided by D_1.

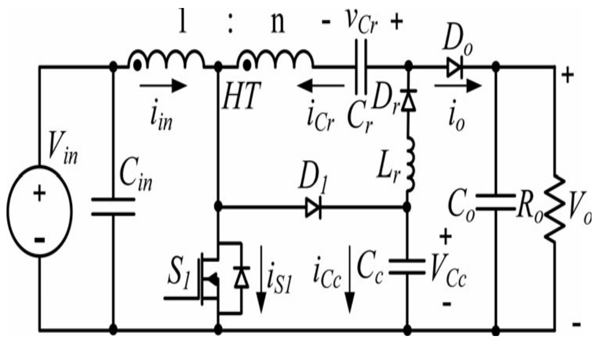

Figure 9. Schematic diagram of high step-up DC–DC converter with hybrid transformer.

There is a resonant circuit which consists of two capacitor C_c and C_r, one inductor L_r and diode D_r. The leakage energy from the hybrid transformer is captured by C_c and transferred to resonant capacitor C_r. D_r provides a current flow path for the operation of resonant circuit[20].

C_r will operate in hybrid mode by having a resonant charge and linear discharge. S_1 determines the turn on state of D_r. D_o is the output diode similar to diode in classic boost converter. C_o is the output capacitor for filtering purpose.

The advantage of this converter is that it has high conversion ratio. The output depends on hybrid transformer. It requires additional components including the transformer and the control is difficult.

3.10 Boost Derived Hybrid Converter (BDHC)

BDHC[21,22] topology can be synthesized by replacing the controlled switch with an inverter bridge network. It can be single-phase or three-phase.

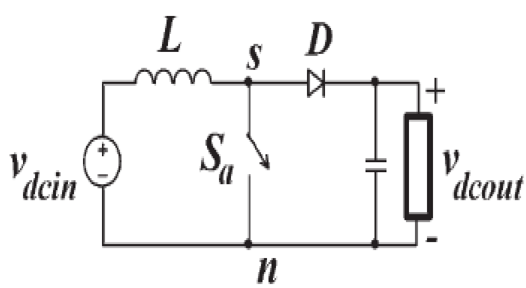

Figure 10. Circuit diagram of BDH converter.

The BDHC has the following advantages[21],

- EMI and spurious noise causes the misgating of the two complementary switches of the same leg. This problem is eliminated in BDHC topology.
- The shoot through condition does not cause problems in the operation but this condition is used to supply AC load and also improves the reliability of the system.
- The dead time compensation is not requires as it uses the shoot through condition.
- Compared to the two stage converter which requires classical boost and VSI, BDHC has less number of controllable switches. This will also reduce the control circuit.
- From a single input DC supply, the converter can simultaneously supply both AC and DC loads.

The limitation of BDHC is the peak value of ac output voltage is less than the input voltage. BDHC is well suited for low power photovoltaic application[21].

4. Conclusion

Some of the Boost converter topologies used in Nanogrids have been reviewed in this paper. Detailed analysis of different topologies of Boost converter with advantages and disadvantages are done. The upcoming work may be extended for the design of some of these boost converter topologies for efficient, reliable, self-sufficient and fault tolerant nanogrid and will be compared for their operation and performance for the wide varying input.

5. References

1. Appelbaum J. Advantage of boost vs. buck topology for MPPT in photovoltaic systems. Proceedings of 19th Convention of Electrical and Electronics Engineers in Israel; 1996.
2. Ahmed M, Ami U, Qureshi SA, Ahmed Z. Implementation of nanogrids for future power system. Sci Int. 2014; 27(1):133–9. ISSN: 1013-5316.
3. Schonberger J, Duke R, Round SD. DC-bus signalling: A distributed control strategy for a hybrid renewable Nanogrid. IEEE Trans Ind Electron. 2006 Oct; 53(5):1451–9.
4. Nordman B. Nanogrids: Evolving our electricity systems from the bottom up. Darnell Green Building Power Forum; 2010 May.
5. Bryan J, R. Duke R, Round S. Decentralised Control of a Nanogrid. Canterbury: Department of Electrical and Computer Engineering; 2002.
6. Teleke S, Oehlerking L, Hong M. Nanogrids with energy storage for future electricity grids. IEEE PES T&D Conference and Exposition; 2014 Apr 14-17; Chicago, IL, USA; p. 1–5.

7. Lee P, Lee Y, Cheng KW, Liu X-C. Steady state analysis of interleaved boost converter with coupled inductors. IEEE Trans on Industrial Electronics. 2000 Aug; 47(4):787–95.
8. Veerachary M, Senjyu T, Uezato K. Maximum power point tracking of coupled inductor interleaved boost converter supplied PV system. IEEE Proceedings-Electric Power Applications. 2003;150(1):71–80.
9. Tattiwong K, Bunlaksananusorn C. Analysis design and experimental verification of quadratic boost converter. IEEE Region 10 Conference; 2014 Oct 22-25; Bangkok. p. 1–6.
10. Peng FZ. Z-Source Inverter. IEEE Trans on Industry Applications. 2003 Mar/Apr; 39(2):504–11.
11. Adda R, Ray O, Mishra S, Joshi A. Implementation and control of switched boost inverter for DC nanogrid applications. IEEE Energy Conversion Congress and Exposition (ECCE); 2012 Sep 15-20; Raleigh, NC. p. 3811–8.
12. Adda R, Mishra S, Joshi A. A PWM control strategy for switched boost inverter. Proceedings IEEE ECCE; 2011 Sep; Phoenix, AZ, USA; p. 991–6.
13. Adda, R, Ray O, Mishra S, Joshi A. Synchronous reference frame based control of switched boost inverter for standalone DC nanogrid applications. IEEE Trans on Power Electronics. 2012; 28(3):1219–33.
14. Adda R, Ray O, Mishra S, Joshi A. DSP based PWM control of switched boost inverter for DC nanogrid applications. 38th Annual Conference on IEEE Industrial Electronics Society; 2012 Oct 25-28; Montreal, QC; p. 5285–90.
15. Nag SS, Adda R, Ray O, Mishra S. Current fed switched inverter based hybrid topology for DC nanogrid application. 39th Annual Conference of the IEEE; 2013 Nov 10-13; Vienna; P. 7146–51.
16. El Khateb AH, Abd Rahim N, Selvaraj J. Fuzzy logic control approach of a maximum power point employing SEPIC converter for standalone photovoltaic system. Procedia Environmental Sciences. 2013; 17:529–36.
17. Venkatanarayanan S, Saravanan M. Design and implementation of SEPIC integrated KY converter for SLIT-LAMP. International Journal of Applied Engineering Research. 2015.
18. Dawidziuk J. Review and comparison of high efficiency high power boost DC/DC converters for photovoltaic applications. Bulletin of the Polish Academy of Sciences Technical Sciences. 2011; 59(4).
19. Petit P, Aillerie M, Sawicki JP, Charles JP. Push-pull converter for high efficiency photovoltaic Conversion. Energy Procedia. 2012; 18:1583–92
20. Gu B, Dominic J, Lai JS, Zhao Z, Liu C. High boost ratio hybrid transformer DC-DC converter for photovoltaic module applications. IEEE Transactions on Power Electronics; Orlando, FL; 2012 Feb 5-9. p. 598–606.
21. Ray O, Mishra S. Boost-Derived hybrid converter with simultaneous DC and AC outputs. IEEE Transactions on Industry Applications. 2014 Mar/Apr; 50(2).
22. Ray O, Mishra S. A modified boost topology with simultaneous AC and DC load. 2012 IEEE Energy Conversion Congress and Exposition (ECCE); 2012 Sep 15-20; Raleigh, NC. p. 2454–9.
23. Available from: www.en.wikipedia.org