Low-Voltage DC Microgrid Network: A Case Study for Standalone System

Abhimanyu Kumar Yadav*‡, Abhijit Ray **, Makarand M. Lokhande ***

* Department of Electronics and Telecommunication, SITRC, Nashik, India

**Department of Solar Energy, PDPU, Gandhinagar, India

***Department of Electrical Engineering, VNIT, Nagpur, India

(abhimanyu.yadav@sitrc.org, abhijit.ray@sse.pdpu.ac.in, mml@eed.vnit.ac.in)

‡ Corresponding Author; Abhimanyu kumar yadav, abhimanyu.yadav@sitrc.org

Received: 18.01.2017 Accepted:20.03.2017

Abstract- In this paper a novel technique is used to aggregate power of the distributed renewable energy sources, especially the photovoltaic energy. The DC/DC converter is the main instrument for extracting the energy from these direct current (DC) renewable energy sources like solar photovoltaic module (PV), wind turbine, and fuel cell, etc. The reason for using DC/DC boost converter in this case of PV energy is for two reasons. Firstly, the maximum output voltages of PV modules at standard test condition (STC) are low in range of 30 to 45 volts. Secondly, DC voltages are being considered as standard by corporates like Emerge-alliance for lighting systems in green energy building. The paralleling of DC/DC converter boost converters helps in aggregation of varying power from these converters connected to different power rating PV modules under varying irradiation and in regulation of 48 volts DC at load terminal. To obtain the aggregate power from the parallel DC converters, this paper proposes a systematic approach for power sharing between converters under varying irradiance. The integrated circuit (IC) UC3843 is based on current mode control and it is the heart of the DC converters used in this proposed work. The cable resistance is another disturbing factor in regulation of the set standard DC voltage. With above mentioned factors, PV module of low power with current mode boost controlled DC converters is implemented and the simulation and experimental results are discussed.

Keywords- Current Mode Control, Pulse Width Modulation, Power Sharing, Voltage Regulation, Direct Current, Linear Voltage Regulator..

1. Introduction

The DC distributed generation power can be directly used in DC appliances via the DC microgrid. The reason behind the gaining popularity of DC microgrid is the distributed renewable energy sources [1]. The different existing distributed energy sources that are contributing to the conventional grid are photovoltaic, micro turbine, fuel cell and wind power turbine etc. The demand of DC power for DC appliances in the years to come will be huge, merely based on the fact that the inherently DC nature of the renewable source and less conversion losses. Currently, world's energy demand of 17-20% is being fulfilled by renewable energy [2]. In Nigeria, a detailed study suggested on design of energy efficient buildings for energy sustainability [3]. The domestic DC industry is currently in a nascent stage of its development when compared with its counterparts. In a case study at Virginia Tech's Center for Power Electronics systems, it is found that 80% of all electricity goes through AC-DC conversions and losses occurred at each conversion stage are not additive, but multiplicative [4]. The priority of using DC power in residential appliances use and elimination of AC-DC conversions in the restructured DC distribution network is favored in [5-7,18]. The selection of 380 VDC for power distribution is approved by several organizations such as Emerge Alliance, European Telecommunications Standards Institute (ETSI), International Electrotechnical Commission (IEC) and EPRI [8]. A feasibility study of the DC electrical distribution system in Korean houses for various DC voltage supply is reported in [19]. Several research groups have studied the low voltage DC microgrid and concluded that 48 V DC distribution systems for residential area located near the DC power resources with optimized cable area could be a more economical system [20-22]. A low-voltage DC microgrid with various safety measures such as grounding methods and fault-detection are discussed [23]. The modular strategy on power conditioning systems comprising of forward DC\DC converters in input series output parallel (ISOP) configuration, paralleled SEPIC DC\DC converters are developed to achieve equal sharing of input voltage between them and about the improvement in transient response of the system is discussed in [24], [26] and [25] respectively. Improvement in efficiency along with reduction in size and cost of the DC distribution network can be attributed to the advancement in short circuit protection, transformer-less voltage levels in DC microgrids and the absence of the skin effect phenomenon in DC power lines [27-30]. Several current sharing (CS) techniques based on both active and passive methods are presented in literature [31, 32]. However, in active CS method, the current mode controller is employed to match the individual phase current with the reference phase current. DC\DC Converter can efficiently convert unregulated DC voltage to a regulated DC voltage with better efficiency along with high power density. A DC\DC converter of high power is used nowadays in the field of renewable energy and also in Telecom applications. Paralleled DC converter topology has several advantages over single DC converter, such as high design standardization, modularity, thermal stress control of the components and ease of maintenance and repair. The large network of such paralleled topology of DC converters is the key technology for large power system and DC micro-grids. The optimal voltage level in DC network for distribution system and commercial use is discussed in [9-17] and the same is tabulated in table 1.

Table 1. DC Microgrid systems for commercial applications

DC Grid Standards for Data center	Operational Voltage	Capacity(MW)
Sweden UPN AB IBM [11]	24–350/380 LVDC	≥5MW
Japan, NTT Group [11]	380/400 LVDC	≥5MW
New Zealand Telecom NZ [11]	220 LVDC	0.5–5MW
US Intel Corp.[11]	400 LVDC	≥5MW
For general case [12]	187.8V—450 LVDC	600–2100W
Two Steam turbines-Testing prototype [13]	800V—1200LVDC	4.8–18 kW
PV arrays, BESS & AC utility system [14]	180–210 VLVDC	150–945W
PMSG WTs, BESS & AC utility system [15]	360 V—420 LVDC (for experiment prototype)	
Gas engine cogeneration, EDLC,BESS, PV arrays & AC system [16]	1200 LVDC	0.9–3.5 MW
For general case testing prototype [17]	±170V, 340V LVDC	0.7–2.7kW

Note:- BESS; Battery energy storage system, PMSG WTs; permanent magnet synchronous generators Wind turbines, EDLC; Electrical double-layer capacitors, LVDC; Low voltage direct current.

The figure 1 depicts a sort of DC microgrid of low voltage for remote areas where utility lines have not reached. Renewable resources can contribute much in developing a sustainable DC microgrid network using the topology of DC boost converters as discussed in the following sections.

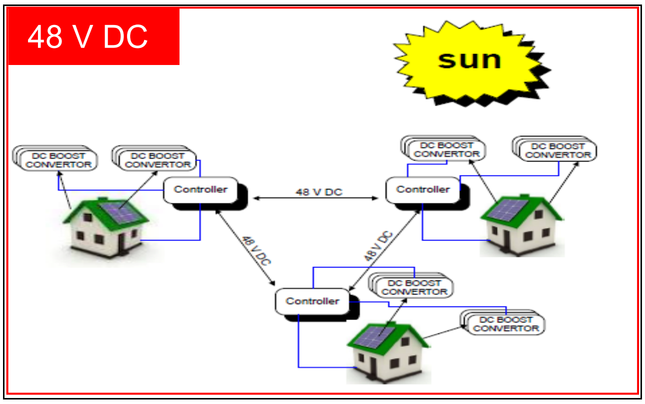


Fig. 1. DC powered microgrid based on photovoltaic energy

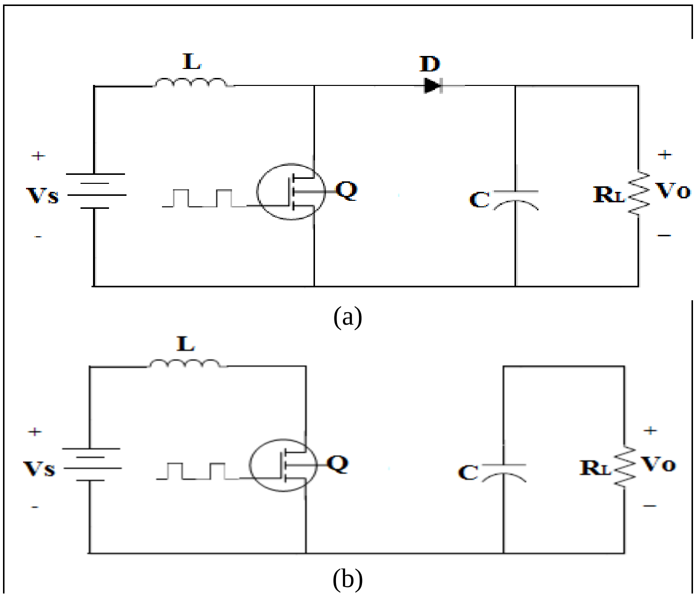
In such systems, the design of current sharing mechanism becomes a significant factor for the reliability of the system. In this paper, the focus is on using a current mode controller with paralleled non-isolated boost converters. This parallel converter will regulate the unregulated DC voltage of the PV modules which is due to irradiance and temperature variations throughout the day. As the varying voltages of both PV modules are regulated at 48 volts, here in this work by the parallel converter, there will addition of current from both converters. This DC power can be used by DC appliances and here a resistive load is used in place of DC appliance such as vacuum cleaner, toasters etc. However, maximum power point tracking (MPPT) is not the priority of this paper as discussed in [33] for maximum power harvesting. The current mode control (CMC) method used in this work is more superior to voltage mode control method in terms of stability, response time and reliability [34]. Here, it is also strived to show the current contribution among the two converters at varying irradiance. In section 2, the basic operation of a boost converter and its proposed parallel configuration interfaced with PV modules is discussed. Detailed current mode controller integrated circuit (IC) UC3843 with boost converter is described in section 3. The design of the boost converter along with components and various mode of operation are given in section 4. Experimental and simulation result is presented in section5.

2. Boost Converter Basic Operation and its Proposed Parallel Configuration

The boost (step-up) converter consists of a switching element (S), diode (D), inductor (L), filter capacitor (C), load resistance (R) and DC input voltage source (Vs). If the switch operates with a Duty ratio D, the DC Voltage gain of the boost converter is given equation 1.

$$M = \frac{V_o}{V_s} = \frac{1}{1-D} \quad (1)$$

by equation (1) where V_o is the output voltage and D is the duty cycle. The duty ratio of pulse width modulation (PWM) signal controls the metal–oxide–semiconductor field-effect transistor (MOSFET) switching states. A DC\DC converter operates in two modes, namely continuous current mode (CCM) mode and discontinuous current mode (DCM) mode. The portion of the switching period over which the inductor current of the converter is never zero is called continuous current mode (CCM). In discontinuous current mode (DCM), the inductor current is zero during some parts of switching period of converter [35]. In continuous current mode (CCM) mode, when the switch is ON, the diode is reversed biased and the polarity of the left side of the inductor is positive. The inductor being an energy storing device starts storing energy due to the flow of current in clockwise direction. When the switch is OFF, the polarity of the left of the side inductor is reversed due to decrease in current because of high impedance and as a result the supplied input voltage and voltage across inductor will be added up. This is the reason for output voltages of boost converter are always higher than the input voltage.



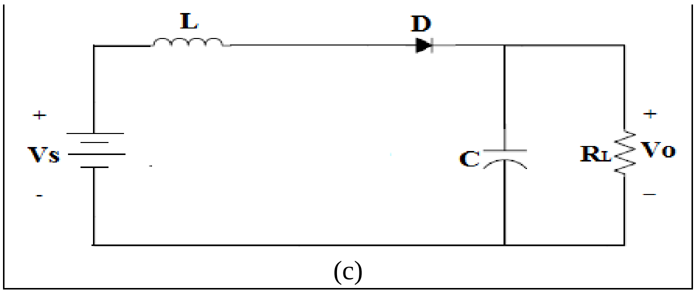


Fig. 2. Step-up (boost) converter (a) equivalent circuit, (b) equivalent circuit when switch-on and (c) equivalent circuit when switch-off.

The circuit diagram of the Boost converter is shown in Figure 2(a). The schematics of equivalent circuits of boost converter when the switch is in ON state and OFF state is shown in figure 2(b) and 2(c) respectively.

In this work, unregulated voltage of PV modules under varying insolation and temperature, which is input to this DC\DC converter is for getting a constant voltage as output. The high voltage gain of DC\DC converters helps in harvesting large quantity power production from renewable sources [36, 37]. In CMC mode, two closed loop controlled namely voltage and current loop is employed for regulation of output voltage and by comparison of output voltage and reference voltage, the reference current is obtained [38, 39]. The proposed parallel configuration of DC power converter interfaced with PV module and rheostat as resistive load is shown in Figure 3.

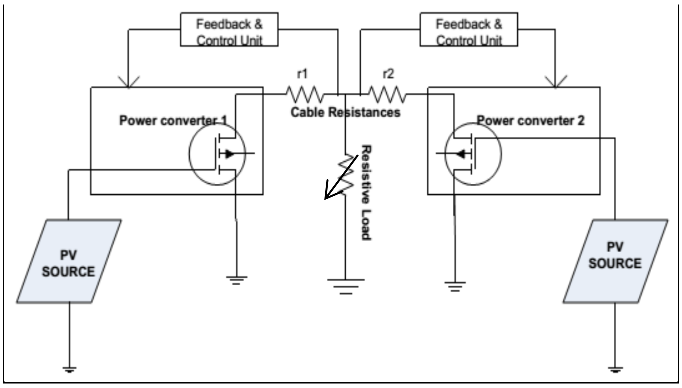


Fig.3. Proposed parallel configuration of the boost converter interfaced with PV modules.

3. Using UC3843 Controller For Closed Loop Parallel Boost Converter Operation

The controller UC3843 is a versatile IC and finds its applications in switched mode power supply (SMPS) [40]. There are several controller ICs such as TL494, UC384X and L6565 series available based on the mode of operations, namely voltage control mode, current control mode and green mode respectively. The voltage mode control method with PID tuned controller is used with three boost converters in parallel and the converters input power is from same source, is discussed in [41]. The results obtained are higher efficiency, reduced ripple current/voltage and a stable system, but the cable resistance impact on the system is not considered. In another work, the effectiveness of interleaved boost converter using the sliding mode control is discussed with PSIM simulation [42]. The drawback of this system is that it cannot be operated under high frequency due to limitation of analog-digital converter's (ADC) sampling frequency and operating frequency of the used switches.

3(a). UC3843 Internal Block Description and Their Functions

Among mentioned control methods previously, UC3843 IC is used here for several reasons, the major being the two loops namely voltage and current loop implementation and MOSFETs triggering is easier without extra driver circuits. This current mode controller (CMC) IC UC3843 uses the voltage feedback from the output of the boost converter and the average inductor current is sensed at pin-3 of the IC and it gets added to the slope compensation voltage. Using this compensation voltage, the average inductor current follows the control voltage. This process is called a current mode control method. The schematic diagram of the internal blocks of this IC is shown in Figure 4.

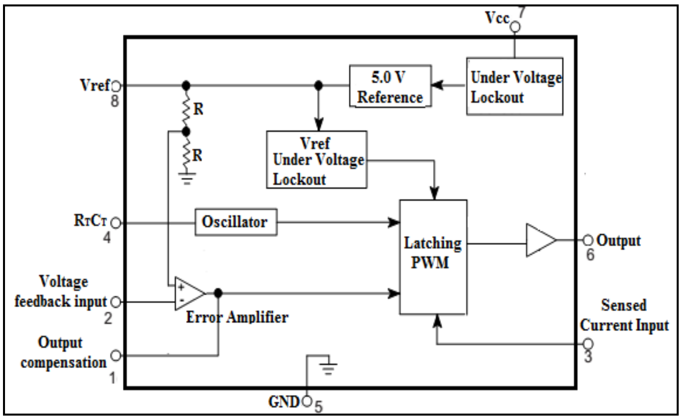


Fig. 4. Schematic diagram of internal blocks in UC3843.

In boost convertor the average value of the inductor current (IL) is equal to the DC input current (Iin). The output of the converter is set by the potentiometer to the desired output voltage. The latching PWM block generates the duty ratio according to the difference in voltage feedback and output compensation voltage and as per sensed current input.

Resistor RT and capacitor CT are selected such that switching frequency is obtained for the designed inductor value and maximum obtained switching frequency is 250 kHz. Vcc is the voltage for the operation of the internal blocks which is 5 volts obtained by voltage divider circuit. As per IC datasheet the range of Vcc is 8.6 volts to 35 volts [43]. The dynamic response of the power converter is a significant parameter for measuring its performance [44-45].

3(b). Proposed Closed Loop Parallel Boost Converter Using UC3843 Controller

The closed loop CMC boost converter schematic is shown in Figure 5 and two such converters are paralleled and connected to a common resistive load as shown in Figure 6. This IC uses a part of PV module power for its functioning and no external supply is required for its operation. In controller ICs the sub harmonic instability of the current-mode converter is improved by avoiding the extreme duty ratios [46] or using programmed compensation ramp to be mixed with a reference current. To reduce the stress on switching component during transient period, an optimum number of MOSFETs can be paralleled so that complexity in interconnections is avoided and on-state resistance $R_{ds(ON)}$ of MOSFET is reduced to half of single MOSFET resistance [47-48] as shown in figure 5.These paralleled MOSFETS when hard triggered synchronously, it helps with the flow of twice the current through the converter inductor and this helps in the modular design of the converter [49]. Here two such similar converters are paralleled with cable resistance consideration and tested with varying irradiance on PV modules which are current source.

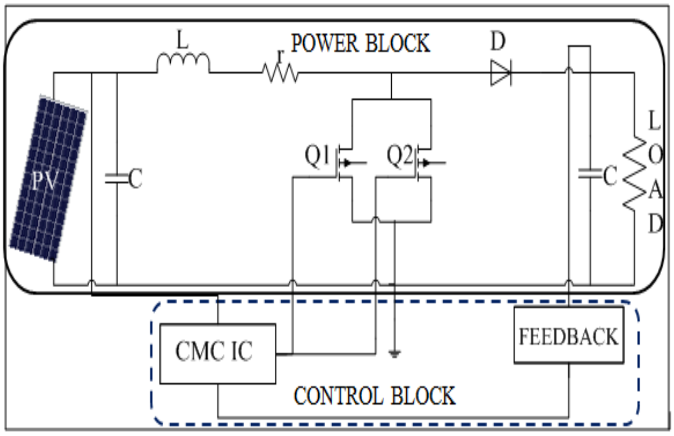


Fig. 5. Closed loop Step-up converter using current mode controller IC (UC3843).

The schematic diagram and its experimental setup are shown in Figure 6 and Figure 7 respectively. G1 and G2 as shown in the Figure 6 are the feedback for the paralleled DC\DC converters. In Figure 6, R_{27} and R_{48} represent the cable resistances and it is fixed in simulation as well as in experimental work.

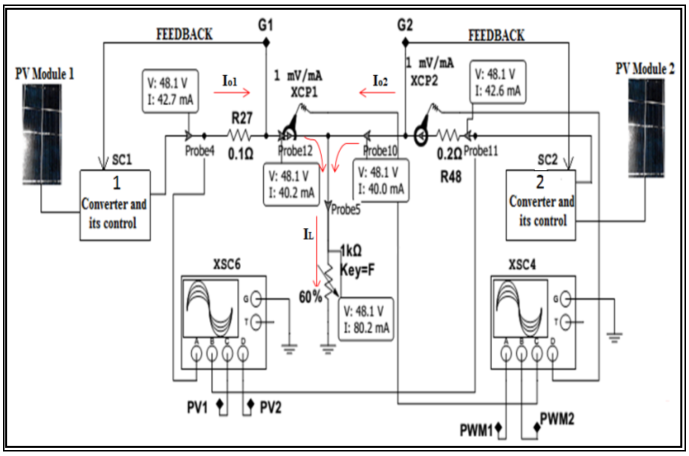


Fig.6. Parallel step-up converter with cable resistance interfaced with PV modules.

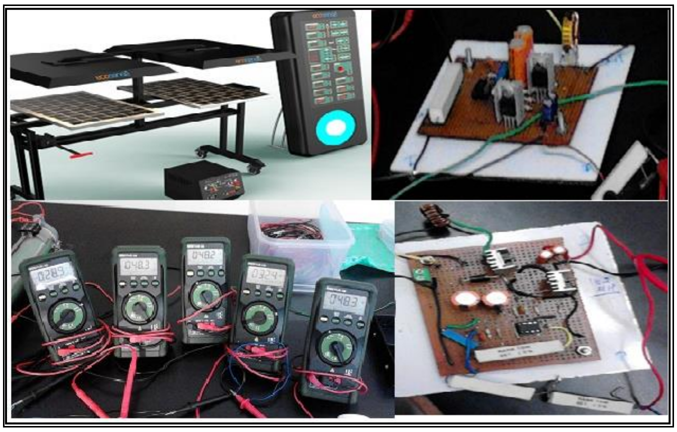


Fig. 7. Experimental setup of closed loop cable paralleled Step-up converter with resistive load.

The main objective of this work is to integrate several renewable energy sources using power electronic components and investigate how the power contribution from each source occurs under varying parameters. Here the role of control theory plays a vital role in the regulation of voltage and and current sharing between the converters in parallel. At a higher duty ratio, the parasitic elements of the basic components of the converter become dominating and alleviate the risk of high current and voltage stress and as a result the control and efficiency of conversion is aggravated [50]. The under voltage lockout (ULVO) of this PWM controller IC is 8.6 volts and it can be operated to 100% duty cycle [40].

4. Selection of Components in Boost Converters

In this work, only non-isolated boost convertor is considered as it finds it application in automobile and its schematic diagram is shown in Figure 2(a). The design of inductors is significant for stable operation of boost convertor and its value is obtained from equation 1. Here a T94-26 and T80-6 iron powder core is used. The choice of inductor value is made from the acceptable ripple current at maximum input voltage and at the minimum duty cycle of PWM switching [50]. The boost convertor's operation in CCM or DCM mode depends on the inductor value which is given by the equation

$$L = \frac{[V_o - V_{in(\max)}] * V^2{}_{in} * T_s}{2 * P_{in} * V_o} \quad \ldots\ldots\ldots\ldots \quad \ldots\ldots\ldots.(2)$$

and the required number of turns is given by equation (3), where A_L is Inductive index.

$$\left[\frac{\text{desired L (nH)}}{A_L(\frac{nH}{N^2})}\right]^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \ldots.(3)$$

The inductor for converter 1 is 18.2 µH and convertor 2 is 30.2 µH for 9.6 W and 7.2 W as input power respectively. The designed inductor core's electrical properties are given in Table 2.The output capacitor used in boost converter is 94 µF and input capacitor is of 940 µF. The choice of capacitor value depends mainly on the equivalent series resistance (ESR) as the converter's efficiency is influenced. Hence, ESR values of the capacitors used should be small or it can be achieved by paralleling capacitors [51]. The component values are tabulated in Table 3.

Table 2. Design of Inductor for Step-Up Converters

Inductor	Inductance(µH)	Core part No.	Wire gauge	No. of turn	Max Ipk (A)	Core AL
L_1	18.2	T 94-26	21	47	1.2	8.4
L_2	30.2	T 80-6	23	52	0.8	10

Table 3. Design parameters of boost converter.

Component Value	Boost converter value
Input DC voltage, Vs	19.2 V
Output DC voltage,Vo	48.2 V
Switching freq., Fs	18.2 kHz
Inductance, L_1, L_2	18.2 µH, 30.2 µH
Capacitance, C	94 µF
Diode	1N5187
MOSFET	IRF540

The designed hardware is for low power applications, but it can scaled up to hundreds of watts by making the changes in inductor design and appropriate component ratings.

5. Simulation and Experimental Results

Two similar boost converters with L_1=18.2 µH and L_2=30.2 µH respectively, were implemented in parallel configuration on hardware for investigating the power contribution from both the converters and the mode of operation. The parallel converters are connected to two similar DC PV module units of 6.87 watts each with common load and the cable resistance of converter 1 is 0.1 Ω and converter 2 is connected to load with cable of resistance 0.2 Ω as shown in figure 6. The cable resistance has a significant role in uneven current contribution to load in case of paralleled DC converters located at varying distance from the load.

As a result, even though, the PV modules are under same radiance, the load current should be nearly equal but there is difference in load current. This difference in load current can be minimized by suitable control methods. However, with a similar setup of the paralleled DC converter is tested with PV modules, but without secondary control, it was possible to minimize this difference in current with regulation of voltage to 48.1 volts.

A similar investigation is performed on two parallel converters in [52], but with a common source. Here a comparator with low pass filter is used to make the circuit to process the current error signal precisely and help in current sharing loop stability with current sharing difference of 330 mA throughout the load range. In another similar work reported in [53], the researchers used signal injection method without using any interconnections among them and obtained proper current sharing with changes in output voltage less than 3%. In this work the resistive load is varied in steps of 20 Ω from 600 Ω to 800 Ω and the regulated voltage is 48 volts. When PV modules are under different irradiance, the power contribution to load is different, but regulation of voltage is maintained with changes less than 1 % and it is shown in Figure 8(b).

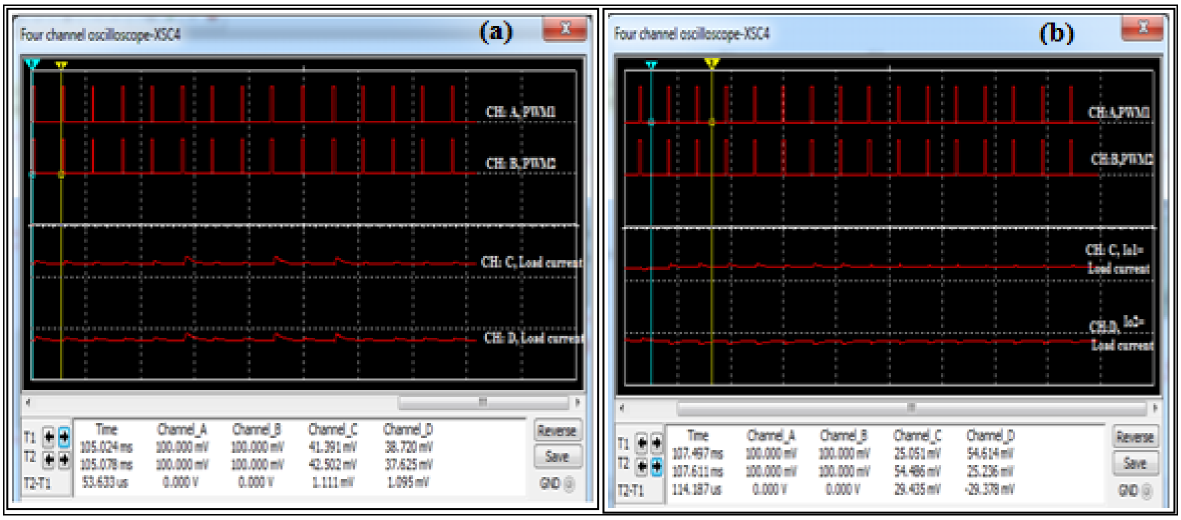


Fig. 8. Simulation setup performance (a) PV_1 and PV_2 at 900 W/m^2 Irradiance (b) PV_1 at 800 W/m^2 and PV_2 at 1000W/m^2 connected to converter 1and 2 respectively.

Similar PV modules and DC boost converters in parallel with same resistive load was simulated using Multisim software. The simulation result as shown in Figure 8(a) and 8(b) matches close to the experimental result. In Figure 8(a) and 8(b), the channel C and channel D represent the load current of converter 1 and converter 2 respectively. This simulation result is obtained by fixing the resistive load to 600 Ω as shown in Figure 8(a) and (b). The load currents in terms of millivolts (mV) represented by channel C and D as shown in Figure 8(a) are close to each other as both PV modules are at same irradiance, while it differs in Figure 8(b) due to the modules at two different irradiance. Here, the simulation results of Figure 8(a) & (b) matches with hardware results in Figure 9(a) & (b).

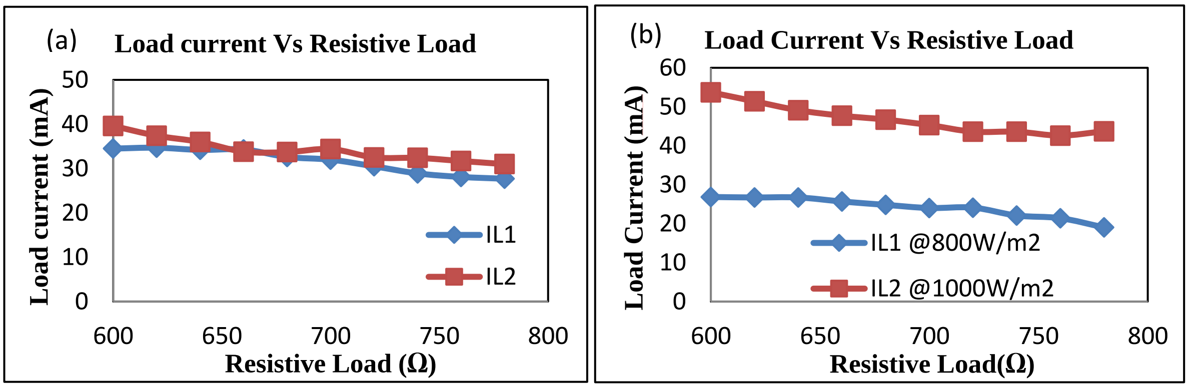


Fig. 9. Hardware performance of the setup under (a) PV_1 and PV_2 at 900 W/m^2 Irradiance

(b) PV_1 at 800 W/m^{2}and PV_2 at 1000 W/m^2 connected to converter 1& 2 respectively.

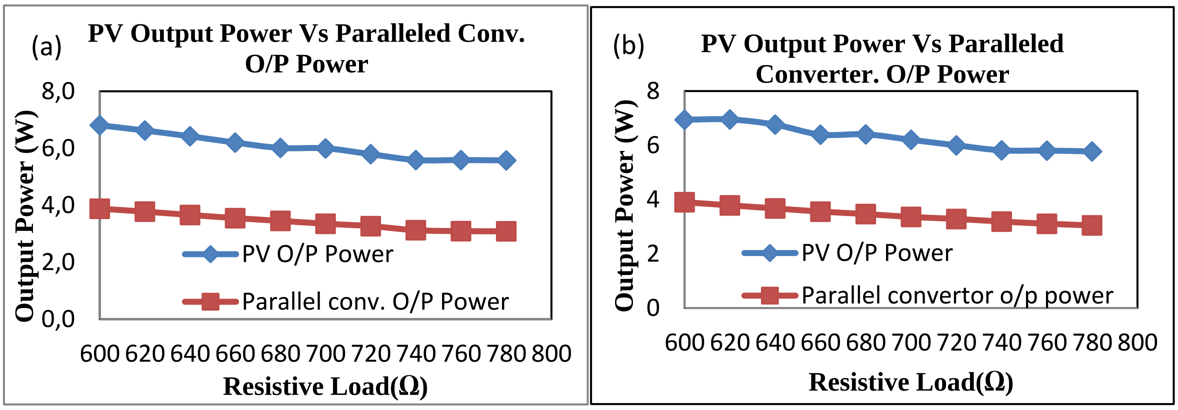


Fig. 10. Power comparison of paralleled converter against PV modules when (a) Both PV_1 & PV_2 at 900 W/m^2 irradiance (b) PV_1 at 800 W/m^2 and PV_2 at 1000 W/m^2.

The efficiency of the designed converter is approximately 65%, which can be improved with the use of MOSFETs with low on state resistance, inductors and capacitor with low ESR values. As the radiance varies, the switching PWM duty cycle is adjusted in order to regulate the set voltage. In Figure 10(a), the total power output of paralleled converters and the input power of PV modules under the same radiance and in Figure 10(b), both PV modules combined power output at different irradiation is shown. The power obtained from paralleled converter is close to 65% of the input power of the PV modules as converters are about the same efficiency. The simulation result of both PV modules input voltages under varying irradiance and regulated output voltage of the paralleled converter is shown in Figure 11(a) and 11(b). In Figure 11(a) and 11(b), the regulated output voltage of the paralleled converter 1 and converter 2 close to 48 Volts is obtained and the same is represented by channel A and B. PV_1 and PV_2 module output voltage are represented by channel C and D respectively under varying irradiance conditions.

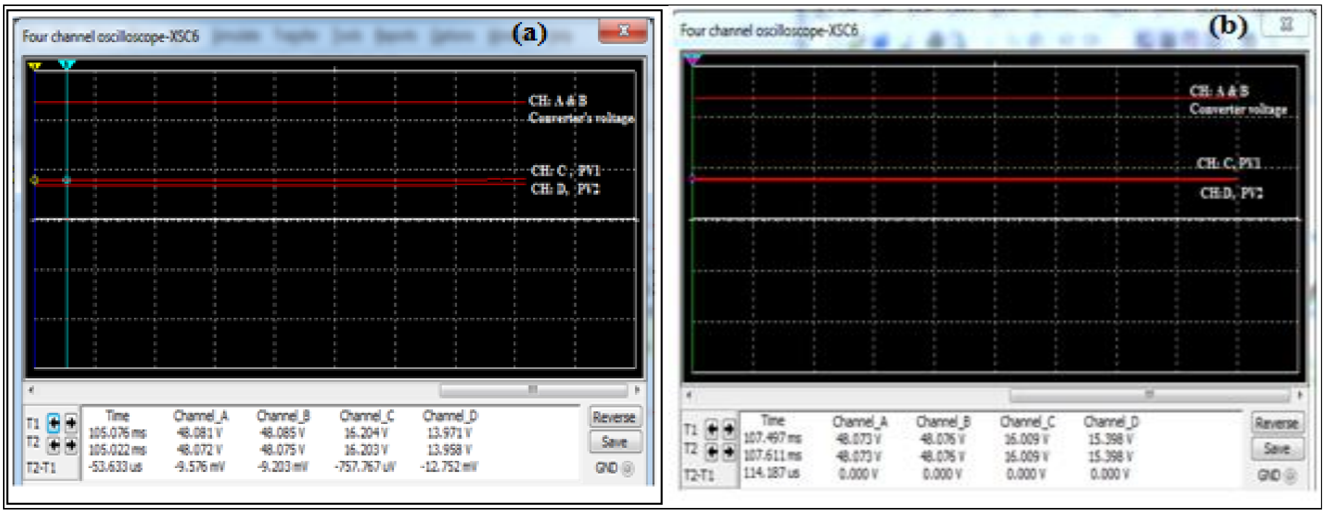


Fig. 11. Simulation output voltage of Step-up converter and PV output voltages (a) 900 W/m^2 (b) PV_1 at 800 W/m^2 & PV_2 1000W/m^2.

6. Conclusions

By integrating the power of photovoltaic modules and small wind turbines to the paralleled power conditioning devices such as DC\DC converters can suffice the everyday's power consumption to at least DC light loads in every house of villagers which are remotely located and unreachable by the utility line. The cost of designed parallel system in this module is of low cost. Here an attempt to power a resistive load from photovoltaic module is performed and how the contribution of the power takes place between the two boost converters in parallel is studied. The voltage at load terminal is also maintained close to 48 volts by the paralleled converters. The resistance of the cable is considered and trade off between voltage regulation and load sharing is minimized for the resistive load (600-800Ω) range. The proposed topology is modular and therefore it can be scaled up as per energy requirement. In future the regulated 48 volt DC, because of several benefits such as cable cost reduction and safety point of view can be considered as standard operating voltage for DC appliances.

Acknowledgements

We would like to acknowledge Solar energy department HOD,Dr.Indrajit Mukhopadhyay for constant encouragement and also all the research, technical, and scientific staff of PDPU for the support.

References

[1] L. L. Hammons T.,"International Practices in Distributed Generation", IEEE Power Engineering Society Energy Development and Power Generation Committee, Tampa, FL, USA, 2007.

[2] Jakir Hossain, Nazmus Sakib, Eklas Hossain, Ramazan Bayindir, "Modelling and Simulation of Solar Plant and Storage System: A Step to Microgrid Technology", International Journal Of Renewable Energy Research, Vol.7, No.2, 2017.

[3] Oyedepo, S, "Efficient energy utilization as a tool for sustainable development in Nigeria", Int. J. of Energy and Environ. Engineering +3,11, 2012.

[4] Patterson, B. T. "DC, come home", IEEE power & energy magazine, 60-69, Nov./Dec, 2012.

[5] H. Kakigano, Y. Miura, T. Ise, J. Van Roy and J. Diresen, "Basic Sensitivity Analysis of Conversion Losses in a DC Microgrid", International Conference on Renewable Energy Research and Applications, pp- 1-6(2012).

[6] J. H. Ahn, et.al., "DC appliance safety standards guideline through comparative analysis of AC and DC supplied home appliances", Journal of Electrical Engineering & Technology (JEET), vol. 7, no. 1, pp. 51-57, Jan,2012.

[7] Daniel Salomonsson and Ambra Sannino, "Low voltage DC distribution system for commercial power systems with sensitive electronic loads", IEEE Trans. Power Delivery, vol. 22, no. 3, pp. 1620-1627, 2007.

[8] http://www.reportlinker.com/p0794287-summary/DC-Building-Power-Emerging-Trends-Application-Drivers-and-Market-Adoption-Forecasts-Second-Edition.html

[9] A. Sannino, G. Postiglione and M. Bollen, “Feasibility of a dc network for commercial facilities”, IEEE Trans. Industry Applications, vol. 39, no. 5, pp. 1499-1507, 2003.

[10] Houseman, D., Sciacca, S., Abi-Samra, N., McDonald, J., Imhoff, C.,Amin, M., IEEE Smart Grid Experts Roundup: AC vs. DC Power.

[11] Symanski DP. 380VDC Data Center Duke Energy Charlotte, NC.Electric Power Research Institute;Available:http://greensvlg.org/wp-content/ uploads/ 2011/11/3A-DC-Power-Symanski.

[12] Loh P,Li D,Chai YK, Blaabjerg F, “Autonomous operation of hybrid microgrid with AC and DC sub-grids”,In:IEEE transactions on power electronics,’99, Early access.

[13] Hatti M, Meharrar A,Tioursi M., “Power management strategy in the alternative energy photovoltaic/PEM fuel cell hybrid system”, Renewable and Sustainable Energy Reviews;15(9):5104–10, 2011.

[14] Sun K, Zhang L,Xing Y,Guarrero JMA, “Distributed control strategy based on DC bus signalling for modular photovoltaic generation system with battery energy storage”, IEEE Transactions on Power Electronics; 26(10): 3032–3045, 2011.

[15] Biczel P., “Power electronic converters in a DC microgrid”,.In:5th International conference – workshop – CPE, 2007.

[16] Lago J,Heldwein ML., “Operation and control-oriented modelling of a power converter for Current balancing and stability improvement of DC active distribution networks”, IEEE Transactions on Power Electronics ;26(3): 877–885, 2011.

[17] Kwasinski A, Onwuchekwa CN, “Dynamic behaviour and stabilization of DC microgrids within stantaneous constant-power loads”, IEEE Transactions on Power Electronics;26(3):822–34, 2011.

[18] Salonen P., Kaipia T., Nuutinen P., Peltoniemi P., Partanen J., “An LVDC Distribution System Concept”, Department of electrical engineering, Lappeenranta University of Technology, IEEE, 2008.

[19] Weixing Li et.al., “On voltage standards for DC home microgrids energised by distributed sources”, ECCE asia,IEEE, 2012.

[20] Rodriguez-Otero, M.A.; O'Neill-Carrillo, E., “Efficient Home Appliances for a Future DC Residence Energy 2030 Conference, ENERGY. pp.1-6, IEEE, 2008.

[21] S. Anand and B.G. Fernandes, “Optimal Voltage Level for DC Microgrids”, 36th Annu. IEEE Ind. Electron. Society Conf., IECON'2010, pp.3034-3039, 2010.

[22] D. Nilsson and A. Sannino, “Efficiency analysis of low and medium voltage dc distribution systems”, IEEE PES General Meeting, 2004.

[23] D. Salomonsson, L. S¨oder, and A. Sannino, “Protection of low-voltage dc microgrids”. IEEE Transcations on Power Delivery, 24(3):1045–1053, 2009.

[24] Deshang Shay, Zhiqiang Guo and Xiaozhong Liao, “Digital Control Strategy for input-series-output-parallel modular DC\DC converters”, Journal of power electronics, 10(3), 245-250, 2010.

[25] Mohamed Salamah.A, Finney S.J, Williams B.W., “An autonomous controller for improved dynamic performance of parallel connected, single phase inverters”, International Journal of Electronics, 1251-1263, 2008.

[26] A. Ezhilarasi & M. Ramaswamy , “Fpga Implementation of Current Sharing Strategy For Parallel Connected Sepics”, International Journal of Electronics, DOI: 10.1080/00207217.2015.1028477, 2015.

[27] Radwan, A.A.A.; Mohamed, Y.A.-R.I., “Linear Active Stabilization of Converter-Dominated DC Microgrids, Smart Grid”, IEEE Transactions on, vol.3, no.1, pp.203,216, 2012.

[28] A. Kwasinski and C. Onwuchekwa, “Dynamic behavior and stabilization of DC micro-grids with instantaneous constant-power loads”, IEEE Trans. Power Electron., vol. 26, no. 3, pp. 822–834, 2011.

[29] H. Kakigano, Y. Miura, T. Ise, and R. Uchida, “DC micro-grid for super high quality distribution—System configuration and control of distributed generations and energy storage devices”,Proc. IEEE PESC, pp. 1–7, 2006.

[30] H. Kakigano, Y. Miura, andT.Ise, “Configuration and control of a DC microgrid for residential houses”, in Proc. Transm. Distrib. Conf.Expo., pp. 1–4, 2009.

[31] S. Luo, Z. Ye, R. Lin, and F. C. Lee, “ A classification and evaluation of parallel methods for power supply modules”, in Proc. IEEE PESC’99, vol. 1, pp. 901–908, 1999.

[32] B. T. Irving and M. M. Jovanovic, “Analysis, design and performance evaluation of droop current-sharing method”, in Proc. IEEE APEC’2000, vol. 1, pp. 235–241, 2000.

[33] Naoufel Khaldi , Youssef Barradi, Hassan Mahmoudi, Malika Zazi, “Experimental Test Bench of Photovoltaic Systems Using Backstepping MPPT Algorithm”, International Journal Of Renewable Energy Research, Vol.7, No.2, 2017.

[34] Xiaodong Liu; Pengyi Yang; Yan-Fei Liu; Jiaojiao Deng, “Modeling and simulation of Parallel Current Mode controlled boost converter”, Industrial Electronics and Applications, ICIEA, 3rd IEEE Conference on, vol., no., pp.2199,2204, 3-5, 2008.

[35] Manjita Srivastava, M. C. S. a. S. B, “Control Systems”, New Delhi, Tata McGraw-Hill Publishing Company Limited, 2009.

[36] R.J wai, W-H. Wang, C-Y Lin, “High-Performance Stand-Alone Photovoltaic Generation System”, Industrial Electronics, IEEE Transcation on, Vol. 55, No. 1, Page. 240-250, 2008.

[37] W. Li, W. Li, X. He, D. Xu, B. Wu, "General Derivation Law of Non-isolated High-Step-Up Interleaved Converters With Built-In Transformer", IEEE Transaction on Industrial Electronics, Vol. 59 No. 3, Pag. 1650-1661, 2012.

[38] C.W. Deisch, "Simple switching control method changes power converter into a current source", in Proc. IEEE Power Electron. Spec. Conf. , pp. 300–306, 1979.

[39] R.D. Middlebrook, "Topics in multiple-loop regulators and current-mode programming", in Proc. IEEE Power Electron. Spec. Conf., p. 716, 1985.

[40] 'UC3842/3/4/5 provides low-cost current-mode control'. Unitrode Application Note U-100A.

[41] Farag. S. Alargt, Ahmed. S. Ashur, "Analysis and Simulation of Interleaved Boost Converter for Automotive Applications", International Journal of Engineering and Innovative Technology Volume 2, Issue 11, 2013.

[42] C. Sudhakarababu, Mummadi Veerachary, "DSP based control of interleaved Boost converter", Journal of power electronics, Vol.5, No.3, 2005.

[43] L.T. Jakobsen, M.A.E. Andersen, "Digitally controlled point of load converter with very fast transient response", European Conference on Power Electronics and Applications, pp. 1 – 10, 2007.

[44] Yu-Huei Lee, Shih-Jung Wang, Chun-Yu Hsieh, Ke-Horng Chen, "Current mode DC-DC buck converters with optimal fast-transient control", IEEE International Symposium on Circuits and Systems, ISCAS, pp. 3045 – 3048, 2008.

[45] Pallab Midya, Philip T. Krein, and Matthew F. Greuel, "Sensorless Current Mode Control—An Observer-Based Technique for DC–DC Converters", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 16, NO. 4, 2001.

[46] Trip, N.D, Schiop, A, Tomse, M., "Increase of the Efficiency for a Solar Renewable Source Using a Soft Switched DC-DC Boost Converter", Signals, Circuits and Systems, ISSCS International Symposium on, vol.2, no., pp.1,4, 13-14, 2007.

[47] J. G. Kassakian and D. Lau, "An analysis and experimental verification of parasitic oscillations in parralleled power MOSFET's", Electron Devices, IEEE Transactions on, vol. 31, pp. 959-963, 1984.

[48] Klimczak, P, Munk-Nielsen, S., "Comparative study on paralleled vs. scaled dc-dc converters in high voltage gain applications", Power Electronics and Motion Control Conference, EPE-PEMC 2008. 13th, vol., no., pp. 108,113, 1-3, 2008.

[49] R.W Erickson, D. Maksimovi´c, "Funamentals of Power Electronics", 2nd Edn., John Wiley, New York, USA, Page. 39-55,1950.

[50] M. Veerachary, "PSIM circuit-oriented simulator model for the nonlinear photovoltaic sources", IEEE Trans. Aerosp. Electron Syst., vol. 42, no. 2, pp. 735–740, 2006.

[51] Bhatnagar P., Nema R.K, "Control techniques analysis of DC-DC converter for photovoltaic application using SIMSCAPE", Power Electronics (IICPE), IEEE 5th India International Conference on , vol., no., pp.1,6, 6-8, 2012.

[52] M. M. Jovanovic, "A novel, low-cost implementation of 'democratic' load current sharing of parallel converter modules, IEEE Trans. Power Electron., vol. 11, pp. 604 – 611, 1996.

[53] Tuladhar, A, Jin. K, "A novel control technique to operate DC/DC converters in parallel with no control interconnections", Power Electronics Specialists Conference, PESC 98 Record. 29th Annual IEEE, vol.1, no., pp.892,898 vol.1, 17-22,1998.