International Journal of Advance Research in Science and Engineering
Volume No.06, Issue No. 12, December 2017
www.ijarse.com
IJARSE
ISSN: 2319-8354

Improved Performance of Load Sharing and Voltage Regulation in Paralleled DC-DC Converters using Modified Droop Control Scheme

Amrita Jain[1] , Shobhit Jain[2], D.K.Palwalia[3]

[1,2,3]*(Department of Electrical Engineering, Rajasthan Technical University, India)*

ABSTRACT

This paper introduces modified droop control scheme for considerable improving the load sharing and voltage regulation performance in parallel DC-DC converters in DC microgrid. The control design overcomes problems such as unequal current distribution and voltage drop. This method reduces the circulating current and provides improved current sharing among parallel converters. The proposed analysis and control scheme is introduced for two DC-DC boost converters. Simulation studies verify the proposed approach.

Key Terms- Current sharing, droop control method, DC microgrid, parallel DC-DC converters. voltage regulation.

I.INTRODUCTION

The concept of low voltage DC microgrid is shown in fig. 1. There are lot of issues associated with a low voltage DC microgrid but this work mainly shows the voltage deviation control and load sharing issues between various DERs linked with DC-DC converters to a dc microgrid [1]-[3].

Paralleling of DC-DC converters is a key technology for a distributed power supply system in DC microgrid. It provides proper control and synchronization among power supply modules to sustain power balance between source and loads [4].

Without current sharing control scheme, even small disturbances in modules, output voltages can cause the output currents to be considerably different [5]-[6]. Distributed power converters include several advantages like (i) high reliability (ii) easy scalability (iii) design standardization (iv) effectiveness (v) improved power quality (vi) improvement in system performance etc [7].

Various current control schemes have been proposed to control the current imbalance [8],[9]. Among all, droop current control is mainly used because it provides a redundant configuration for a high reliability power system [10]. Existing droop control scheme causes poor voltage regulation. To address this limitation modified droop current control method is introduced which provide better current control among the parallel DC-DC converters.

International Journal of Advance Research in Science and Engineering
Volume No.06, Issue No. 12, December 2017
www.ijarse.com
IJARSE
ISSN: 2319-8354

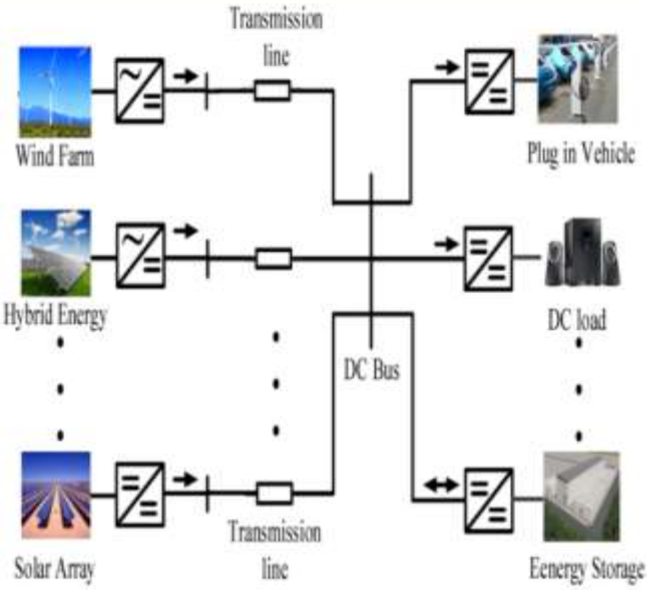

Fig. 1. Structural diagram of low-voltage dc microgrid.

II.CONTROL STRATEGY FOR LOAD SHARING ISSUES

This section presents load sharing imbalance for parallel DC-DC converters connected to a low voltage microgrid. Fig 2(a) shows the converter configuration of two parallel DC-DC boost converters interfaced with PV array. The fig is characterized by their output voltages, output current and cable resistances as V_{DC1} ,V_{DC} , I_1, I_2 and R_1, R_2 respectively. Case studies for current division, circulating current and cable resistances are mentioned in table –I. Fig. 2 (b) shows the equivalent circuit of output side of parallel converters.

Case studies for current distribution and load sharing are presented in table-I.

TABLE –I

Case Studies for Load Sharing and Current Division

Case	$V_{DC1,}V_{DC2}$	R_1, R_2	I_1, I_2	I_{C12}/I_{C21}
1	equal	Equal	equal	zero
2	equal	Different	different	zero
3	equal	Equal	different	non zero
4	equal	Different	different	non zero

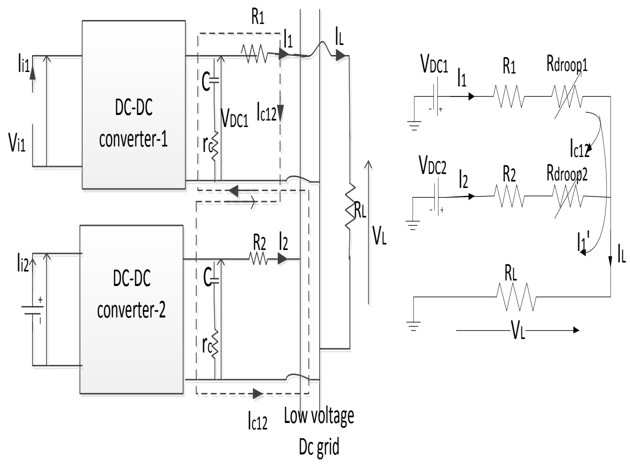

Fig.2.(a) Parallel dc–dc converters with different output voltages. (b) Steady state equivalent circuit for the dc output side.

A. Mathematical estimation of currents sharing in two parallel boost converter:

By using application of Kirchhoff's Voltage Law (KVL) in fig.(2)

$$V_{DC1} - I_1 R_1 - I_L R_L = 0 \quad . 1$$

$$V_{DC2} - I_2 R_2 - I_L R_L = 0 \quad (2)$$

The output currents in converters are expressed by following equations:

$$I_1 = \frac{(R_2+R_L)V_{DC1} - R_L V_{DC2}}{R_1 R_2 + R_1 R_L + R_2 R_L} \quad (3)$$

$$I_2 = \frac{(R_1+R_L)V_{DC2} - R_L V_{DC1}}{R_1 R_2 + R_1 R_L + R_2 R_L} \quad (4)$$

The circulating current can be expressed as:

$$I_{c12} = -I_{c21} = \frac{V_{DC1} - V_{DC2}}{R_1 + R_2}$$

$$= \frac{I_1 - I_2}{2} \text{ (If } R_1 = R_2\text{)}$$

$$= \frac{I_1 R_1 - I_2 R_2}{R_1 + R_2} \text{ (If } R_1 \neq R_2\text{)} \quad (5)$$

Now $R_L >> R_1$ and R_2 so the product $R_1.R_2$ can be ignored. By substituting (5) in (3) and (4) we get

$$I_1 = \frac{R_2 V_{DC1}}{R_1 R_L + R_2 R_L} + \frac{V_{DC1} - V_{DC2}}{R_1 + R_2} \quad (6)$$

Load Current (I_1') Circulating Current (I_{C12})

$$I_2 = \frac{R_1 V_{DC2}}{R_1 R_L + R_2 R_L} - \frac{V_{DC2} - V_{DC1}}{R_1 + R_2} \quad (7)$$

Load Current (I_2')

Circulating Current (I_{C21})

III. VOLTAGE DEVIATION CONTROL BY INSERTING R_{DROOP}

This part of paper gives an overview about the method which allows the distribution of converter currents by connecting a series resistance R_{droop} to each converter as shown in fig 3(a). The equivalent circuit is shown in fig. 3(b).

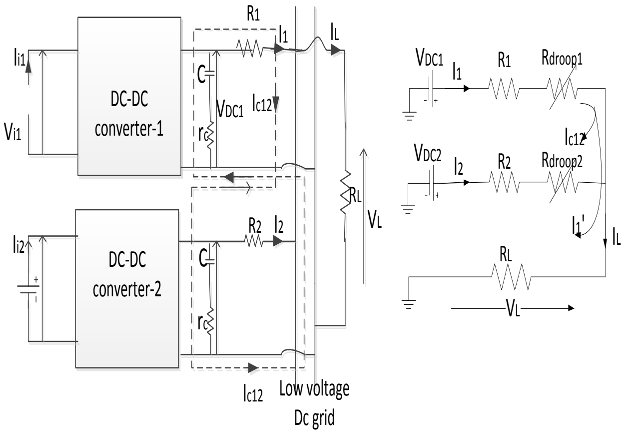

Fig.3. (a) Two parallel boost converter in series with R_{droop} (b) study state equivalent circuit of dc output side.

IV. PROPOSED CIRCULATING CURRENT CONTROL METHOD

The major purpose of this segment is to manage load sharing and to diminish circulating current from the converters by using proposed control method.

A. Droop Index Scheme (DI)

In parallel DC-DC converters there is uniform current distribution in case of proper current sharing hence no circulating current occurs in the parallel system. At the same time realisation of a voltage drop in converter output voltage due to inclusion of series resistance. Hence, DI is expressed as a function of power output loss and current sharing difference.

$$DI = \min[1/2[|I_1 - I_2| N_i + (P_{loss}) N_p]] \quad (8)$$

Where the P_{loss} belonging to fig. 3 (b) can be written as

$$P_{loss} = I_1^2(R_1 + R_{droop\,1}) + I_2^2(R_2 + R_{droop\,2}) \quad (9)$$

International Journal of Advance Research in Science and Engineering
Volume No.06, Issue No. 12, December 2017
www.ijarse.com
IJARSE
ISSN: 2319-8354

In above equation (8), "Ni" represents normalization of variation in current contribution based on the rated load current and "N_p" indicates normalization of power output loss. Additionally, the normalized power loss eventually indicates the reference voltage drop.

The calculation of Minimum droop index can be considered by varying R_{droop} and its highest value will depend on the voltage control i.e. the product of R_{droop} and output current have to be smaller amount than the maximum deflection in dc voltage. The calculation of current sharing variation for two boost converters depended on Fig.3 (b) by suggesting variables x, y, and m given as

$$x = \frac{V_{DC1}}{V_{DC2}} \;, y = \frac{R_1}{R_2}, \;\; m = R_2 + R_{droop2} \tag{10}$$

The converter output currents I_1 and I_2 can be given as

$$I_1 = \frac{[((R_2 + R_{droop2}) + R_L)xV_{DC2} - R_L V_{dc2}]}{q} \tag{11}$$

$$I_2 = \frac{[(y(R_2 + R_{droop2}) + R_L)xV_{DC2} - xR_L V_{dc2}]}{q} \tag{12}$$

Where

$$q = y(R_2 + R_{droop2})(R_2 + R_{droop2}) + y(R_2 + R_{droop2})R_L + ((R_2 + R_{droop2})R_L$$

From eq.(10) the current sharing difference $|I_1 - I_2|$ is calculated as

$$|I_1 - I_2| = |\frac{mxV_{DC2} - myV_{DC2} + 2(x-1)V_{DC2}R_L}{m^2y + mR_L(y+1)}| \tag{13}$$

Correspondingly, the output power loss can be expressed as

$$P_{loss} = V_{DC}^2 [\frac{a - b + c}{(m^2y + mR_L(y+1)^2}] \tag{14}$$

Where

$$a = myx^2(R_L^2 + (m + R_L))^2$$

$$b = 2xR_L(m + R_L) + mR_L^2x^2$$

$$c = my + R_L^2 - 2xR_L(my + R_L)$$

By changing the value of R_{droop2} from zero to its maximum value the minimum value of DI can be carried out.

V. SIMULATION RESULTS

To illustrate the above mentioned scheme and to validate the minimization of circulating current, experimental and comparative set up is carried out for both cases using modified droop index method. The simulation diagram is as shown in Fig. (4).The nominal parameters of boost converter are mentioned in table III.

IJARSE
ISSN: 2319-8354

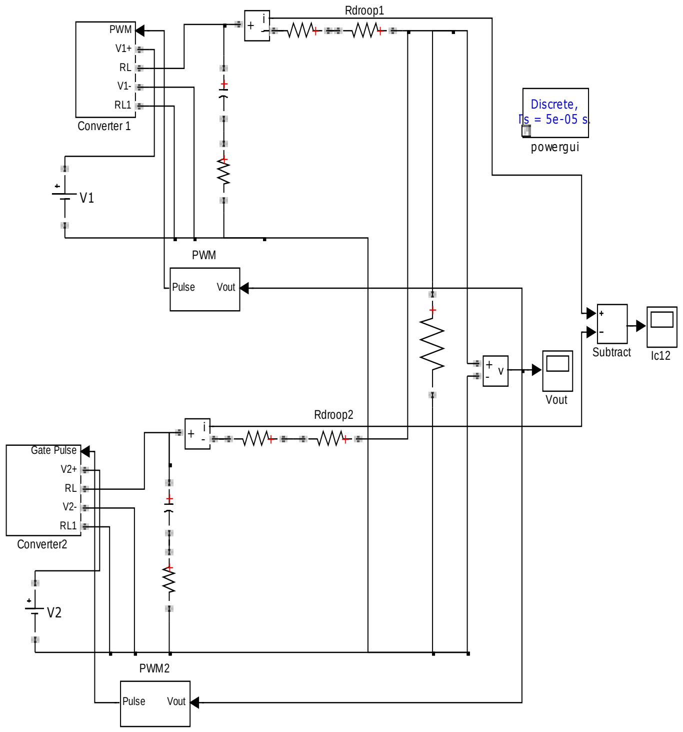

Fig.4. Simulation model of two parallel boost converters

TABLE- II

Parameters of Boost Converters

Parameters	Symbol	Value
Input voltage	V_{in}	24V
Output voltage	V_{out}	48V
Filter inductor	L	710µH
Filter capacitor	C	220µF
Nominal switching frequency	f_{SW}	10kHz
ESR of filter inductor	r_L	0.03Ω
ESR of filter capacitor	r_C	0.05Ω

B. Paralleling of two boost converters without adding any droop control method.

TABLE-III

Simulation Results without Droop Control

Time(s)	V_{DC1}, V_{DC2}, V_L	$I_L(I_1,I_2)$	ΔI_{err} (%)	I_c
0-0.1s	48,48, 47.74	5(2.5,2.5)	0	0
0.1-0.3s	48,48.45,47.98	5(0.2,4.8)	(4.6) 92%	2.3
0.3-0.5s	48,48,47.74	5(2.5,2.5)	0	0
0.5-0.7s	48,47.52,47.5	5(4.8,0.2)	(4.6) 92%	2.3

The above table shows the % current error without any droop method. When converter output voltages V_{DC1} and V_{DC2} are different then the % current error was found to be 92% which is not proper. The simulation results without droop control method are shown in fig. (5), (6) and (7).

C. Paralleling of two boost converters with Proposed droop index calculation

TABLE-IV

Simulation Results with R_{droop} Using DI Calculation

Time(s)	V_{DC1}, V_{DC2}, V_L	$I_L(I_1,I_2)$	ΔI_{err} (%)	I_c
0-0.1s	48,48, 47.15	5(2.5,2.5)	0	0
0.1-0.3s	47.99,48.46,47.36	5(1.9,3.1)	24%	0.12A
0.3-0.5s	48,48,47.15	5(2.46, 2.54)	1.6%	0.04A
0.5-0.7s	47.92,47.52,46.99	5(3.2,1.8)	28%	0.14A

The simulation results by calculating the value of R_{droop} using DI method is shown in above table. The output cable resistance for each converter is taken 100mΩ. The table clearly shows the % current sharing error for the different possibilities. The simulation results using modified droop index method are obtained in fig (8),(9) and (10). It is observed that the % current sharing error is limited by 24% which is less as compared with previous method.

International Journal of Advance Research in Science and Engineering
Volume No.06, Issue No. 12, December 2017
www.ijarse.com
IJARSE
ISSN: 2319-8354

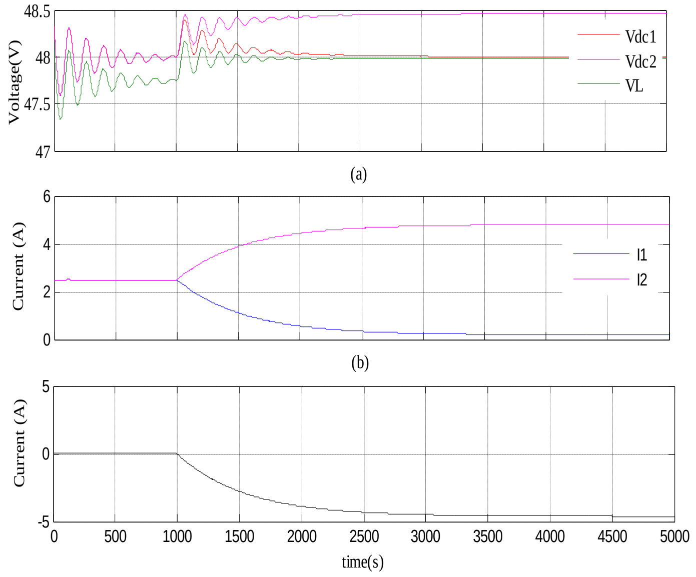

Fig.5 Simulation results without R_{droop} calculation upto 0.3s (a) converter output voltages, load voltage. (b) Output currents (c) circulating current.

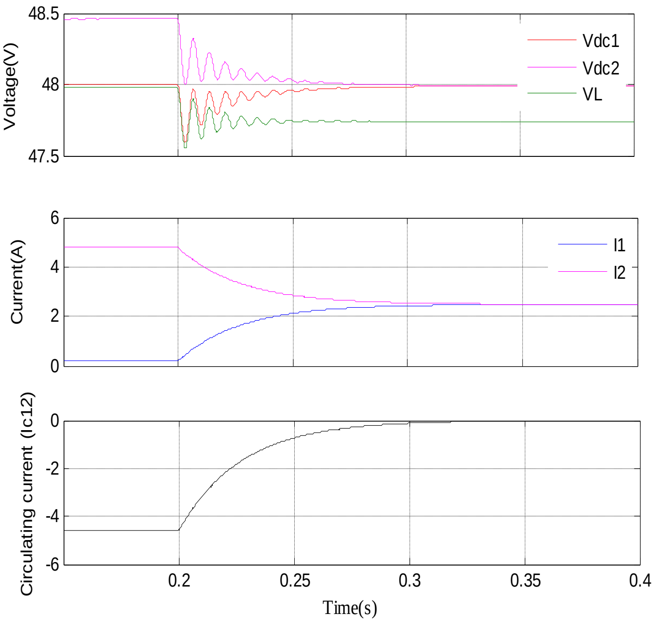

Fig.6. Simulation results without R_{droop} calculation during 0.3s-0.5s (a) converter output voltages, load voltage. (b) Output currents (c) circulating current

International Journal of Advance Research in Science and Engineering
Volume No.06, Issue No. 12, December 2017
www.ijarse.com
IJARSE
ISSN: 2319-8354

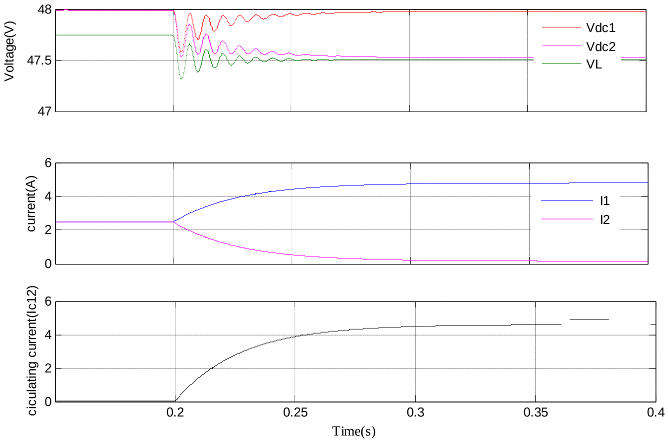

Fig7.Simulation results without R_{droop} calculation up to 0.5-0.7s (a) converter output voltages, load voltage. (b) Output currents (c) circulating current

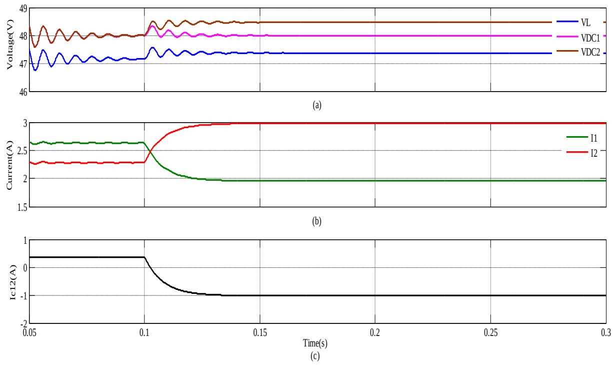

Fig.8 Simulation results using modified R_{droop} calculation upto 0.3s (a) converter output voltages, load voltage. (b) Output currents (c) circulating current.

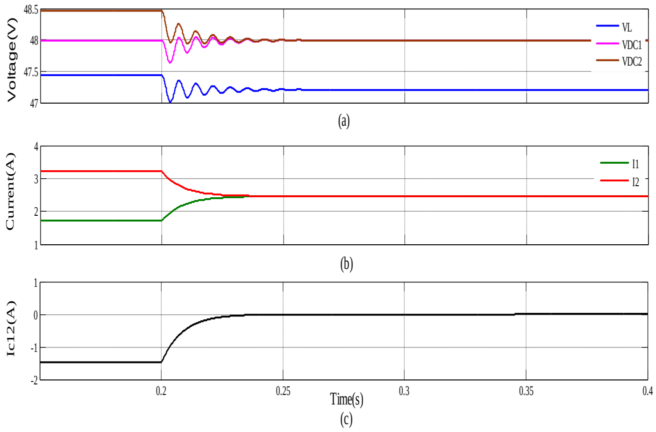

Fig.9. Simulation results using modified R_{droop} calculation during 0.3s-0.5s (a) converter output voltages, load voltage. (b) Output currents (c) circulating current.

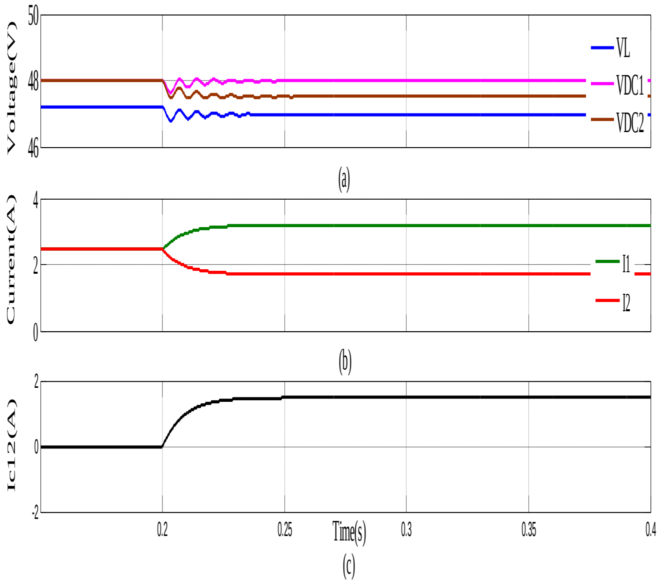

Fig10.Simulation results using modified R_{droop} calculation up to 0.5-0.7s (a) converter output voltages, load voltage. (b) Output currents (c) circulating current

VI. CONCLUSION

In this paper, the modified droop index method for load sharing and voltage regulation for parallel DC-DC converters for low voltage dc micro-grid is developed. It allows better current sharing between dc-dc converters. This proposed scheme provides improved load current contribution by eliminating circulating current between the converters and boost up the stability of micro-grid. The performance of different techniques using parallel converters has been implemented through experimental and simulation studies in MATLAB.

REFERENCES

[1] S. Bull, “Renewable energy today and tomorrow,” Proc. IEEE, vol. 89, no. 8, pp. 1216–1226, Aug. 2001.

[2] N. Tummuru, M. K. Mishra, and S. Srinivas, “Multifunctional VSC controlled microgrid using instantaneous symmetrical components theory,” IEEE Trans. Sustain. Energy, vol. 5, no. 1, pp. 313–322, Jan. 2014.

[3] A. Bonfiglio et al., “The smart poly generation microgrid test-bed facility of Genoa University,” in Proc. IEEE UPEC Conf., Sep. 2012, pp. 1–6.

[4] P. Basak, S. Chowdhury, S. H. nee Dey, and S. Chowdhury, “A literature review on integration of distributed energy resources in the perspective of control, protection and stability of microgrid,” Renew. Sustain. Energy Rev., vol. 16, pp. 5545–5556, Oct. 2012.

[5] D. Salomonsson, L. Soder, and A. Sannino, “An adaptive control system for a dc microgrid for data centers,” IEEE Trans. Ind Appl., vol. 44, no. 6, pp. 1910–1917, Nov. 2008.

[6] T. Vandoorn, B. Meersman, L. Degroote, B. Renders, and L. Vandevelde, “A control strategy for islanded microgrids with dc-link voltage control,” IEEE Trans. Power Del., vol. 26, no. 2, pp. 703–713, Apr. 2011.

[7] S. Augustine, M. K. Mishra and N. Lakshminarasamma, "Circulating current minimization and current sharing control of parallel boost converters based on droop index," in Proc. IEEE SDEMPED Conf., Aug. 2013, pp. 454–460.

[8] J. Rajagopalan, K. Xing, Y. Guo, F. Lee, and B. Manners, "Modeling anddynamic analysis of paralleled dc/dc converters with master-slave current sharing control," in Proc. IEEE 11th Annu. APEC Conf., vol. 2, Mar. 1996, pp. 678–684.

[9] I. Batarseh, K. Siri, and H. Lee, "Investigation of the output droop characteristics of parallel-connnected dc–dc converters," in Proc. IEEE 25th Annu. PESC Conf., Jun. 1994, vol. 2, pp. 1342–1351.

[10] S. Anand and B. Fernandes, "Modified droop controller for paralleling of dc–dc converters in standalone dc system," IET Power Electron., vol. 5, no. 6, pp. 782–789, Jul. 2012.