Comparison of Two Approaches of Resolving Power Sharing Error in Droop Based DC Microgrids

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Received: October 2019 Revised: December 2019 Accepted: February 2020

ABSTRACT:
DC microgrids have gained extensive attention in the recent years. In the islanded mode of operation power sharing between sources is required. The power sharing usually is provided by employing P-V droop characteristics while the voltage local property results in power sharing error. In this paper two decentralized approaches for resolving power sharing error are studied and compared. In the first approach, sources employ proper virtual resistance. In second approach, droop characteristics are realized in the Point of Common Coupling (PCC). It is shown that by using second approach, the voltage drop is reduced and equally the voltage quality is improved. It is discussed that the reason is bypassing the voltage drop associated with the sources output resistance in the second approach. Time domain simulations of a test DC microgrid are provided to verify the results.

KEYWORDS: DC Microgrids, Distributed Energy Resources, Droop Characteristics, Power Sharing.

1. INTRODUCTION

Distributed energy resources and microgrids are two new concepts in power systems which have attracted great attention in recent years [1]. Microgrids are parts of distribution systems with resources and loads that could operate autonomously [2], [3]. Under normal conditions, microgrids are connected to the upstream grid. In the case of any major disturbance in the upstream grid, the microgrids can be disconnected and enter into the so-called islanded mode [4].

Advances in traditional AC distribution systems have led to the realization of AC microgrids. DC distribution systems, as well as DC microgrids, have gained extensive attention in recent years [5]. Using photovoltaic systems and fuel cells as sources as well as electronic equipments as consumers, all of which are inherently DC, is extensively increasing. Under these conditions, employing DC distribution systems can reduce energy conversion stages, leading the efficiency and reliability to be increased and costs to be diminished [6], [7].

In the islanded mode of DC microgrids which is considered in this paper, sources regulate the microgrid voltage. Supply-demand balancing is also established by these sources. This balancing should be provided with no overloaded source and no circulating current. Centralized or decentralized control methods are used for this purpose. In the decentralized control method, sources make decisions based on local information with no dependence on the central controller and fast communication links. In this regard, the most common decentralized method proposed by the researchers is employing droop characteristics [8].

Droop characteristics have some limitations. One of them is error in power sharing among sources that is raised due to the voltage local property, i.e. voltage magnitude change at different points of the microgrid [9], [10]. For resolving this problem several attempts have been made. Injecting harmonic signals through sources is an approach [11] that results in harmonic current flow through the lines and voltage distortion [12]. Employing secondary control level is another approach [10, 13, 14], but this approach increases the costs as requires low bandwidth communication links. In [12, 15], accurate power sharing is achieved by activating a process for a specific interval. However, if load variation happens in this interval, error in power sharing and stability problems could occur. Two other approaches have been proposed that are not involved with the shortcoming of the reviewed ones. In the first approach, by employing virtual resistances, the output resistance of the sources is tuned properly to achieve the accurate power sharing [16]. In the second approach, by realizing droop characteristics at the Point of Common Coupling (PCC), the accurate power sharing is achieved [17]. Although both approaches are successful in resolving power sharing error, but no comparison has been made between them until now. In this paper these two approaches are studied in details and subsequently comparison in terms of voltage quality is performed.

The remainder of this paper is organized as follows. In section II, the droop characteristics of sources in a DC microgrid are studied and occurrence of error in power sharing is discussed. In section III, the approaches to address the power sharing error are assessed and the voltage quality provided by them is compared. The simulation results of a test microgrid are presented to confirm the studies in Section IV. The paper concludes in Section V.

2. DROOP CHARACTERISTICS OF SOURCES AND OCCURRENCE OF ERROR IN POWER SHARING

In islanded mode of operation, load sharing between sources is required. Droop characteristics are used to provide load sharing based on the decentralized method [8].

The conventional active power-voltage (P-V) droop characteristic used in DC microgrid sources is as follow:

$$V_i^* = V_0 - m_{,i}.P_i \quad (1)$$

Where, V_i^* is reference value of output voltage, V_0 is no-load voltage, P_i is filtered power, and m_i is the droop slope of the i^th source. The droop slope is selected according to:

$$m_i = \frac{\Delta V}{P_{i,rated}} \quad (2)$$

Where, ΔV is voltage variation range in the microgrid and $P_{i,rated}$ is the rated power of the i^th source. This droop slope selection approach will provide power sharing based on the rated capacity of sources [5]. Based on equations (1) and (2), the ‘’terminal voltage drop of the source’’ to the ‘’ voltage variation range’’ ratio determines the relative amount of power generation of that source. The terminal voltage of the sources varies due to line resistance, so error in the power sharing between the sources occurs. If the voltage variation range is considered to be large, then the difference in the relative drop of the terminal voltage of the source will decrease which is equivalent to reduction in power sharing. However, this itself causes a large voltage deviation in the microgrid [6].

3. STUDY AND COMPARISON OF POWER SHARING ERROR resolving aproaches

3.1. Using Virtual Resistance

A DC microgrid with n sources and load that is connected to PCC is considered. In this structure, the sources are connected to the PCC through their lines (Fig. 1).

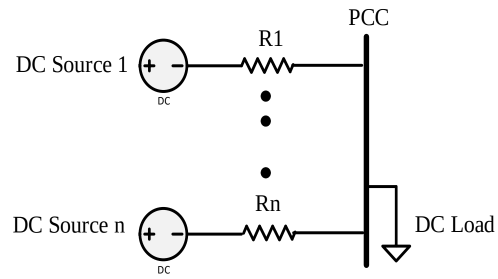


Fig. 1. DC microgrid structure with n sources and load that are connected to PCC.

Suppose the droop characteristic studied in section 2 is applied to sources. Since the resistance of the lines affect the terminal voltage of the sources, these resistances can affect the sources output power. In other words, the resistance of lines is the origin of error in power sharing [16], [17]. For resolving this error, the line resistance of each source should be inversely proportional to the source rated power [16]. On the other hand, the design of the distribution lines is independent of the power sharing concept which means that the desired relation between the rated power and the line resistance of sources is not provided spontaneously.

To reach this purpose, virtual resistance is used in the control structure of sources. Therefore, by properly adjusting the virtual resistances, the suitable output resistance of sources can be provided [9]. Equation (3) calculates the source output resistance:

$$R_{out,i} = R_i + R_{v,i} \quad (3)$$

Where, R_i is line resistance, $R_{out,i}$ is output resistance, and $R_{v,i}$ is virtual resistance of the i^th source. To reach an accurate power sharing, the output resistance of the sources must be inversely proportional to their rated power, according to:

$$P_{1,rated}.R_{out,1} = P_{2,rated}.R_{out,2} = ... = P_{n,rated}.R_{out,n} \quad (4)$$

The virtual resistance of the sources is calculated after determining the line resistance and the required output resistance based on the equation (4).

The source control structure for the realization of the droop characteristics and the virtual resistance is shown in Fig. 2. As seen, the virtual resistance voltage drop is subtracted from the source voltage designated by the droop characteristic to determine the voltage reference value. With this method, the droop characteristic is realized before the virtual resistance (Fig. 2). Consequently, the resistance seen by the droop is equal to the sum of the line resistance and the virtual resistance.

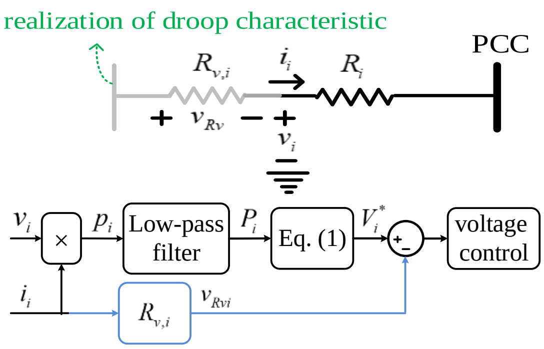


Fig. 2. Sources control structure for realization of the droop characteristic and the virtual resistance.

3.2. Realization of the Droop Characteristics in PCC

As explained in section 2, by considering the droop characteristic of equation (1), the ‘’terminal voltage drop of the source’’ to the ‘’voltage variation range’’ ratio determines the relative amount of power generation of that source. The terminal voltage of the sources varies due to lines resistance, so error in the power sharing between sources occurs. Consider the microgrid structure shown in Fig. 1. In the approach studied in this section, droop characteristics use the PCC voltage instead of the sources terminal voltage. In this case, the voltage determines the power generation of sources which becomes the common PCC voltage and thereby the error in power sharing between the sources will be resolved [17]. Accordingly, the droop characteristics are as follow:

$$V_{PCC} = V_0 - m_{,i}.P_i \tag{5}$$

Where, V_{PCC} is the PCC voltage that must be realized. Realization of this droop characteristic in sources is not straightforward since the sources are only capable of controlling their terminal voltage. Now, sources must control their terminal voltage such that the PCC voltage becomes equal to the value determined by equation (5). In this regard, the equation of power flow in the source line is used:

$$P_i = \frac{V_i.(V_i - V_{PCC})}{R_i} \tag{6}$$

Now by substituting V_{PCC} from equation (6) to (5), the reference value of sources terminal voltage as a function of power generation is obtained as:

$$V_i^* = \frac{V_0 - m_i.P_i + \sqrt{(V_0 - m_i.P_i)^2 + 4P_i.R_i}}{2} \tag{7}$$

With the realization of the equation (7) by sources, the droop characteristic of equation (5) is also indirectly realized [17].

The source control structure is illustrated in Fig. 3. As seen, the source power is calculated and applied to equation (7) for determining the reference value of source terminal voltage so that the droop characteristics in the PCC can be realized.

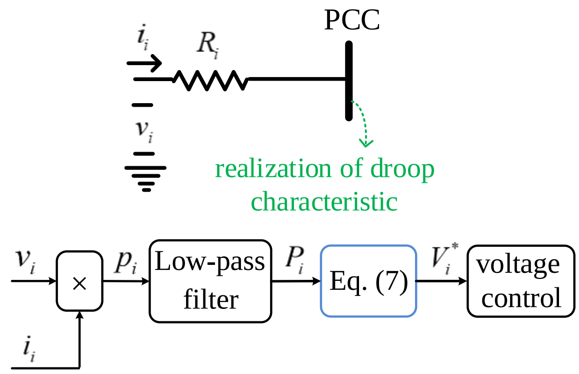


Fig. 3. Sources control structure for the realization of the droop characteristic in PCC.

3.3. Comparison of Virtual Resistance and PCC Realization Approaches

In the previous subsections, two approaches for accurate power sharing were presented. In the virtual resistance approach, with the realization of the virtual resistance in the sources, their output resistance was adjusted in inverse proportion to their capacity. This approach realizes the droop characteristics before the virtual resistor (see Fig. 3). Under these conditions, the voltage drop resulted from the droop characteristic and the voltage drop resulted from the source output resistance, both are imposed to the PCC. On the other hand, in the PCC droop realization approach, the sources voltage is controlled such that the droop characteristic realization in the PCC is achieved. In this case, only the voltage drop caused by the droop characteristic is imposed to the PCC. This means that the voltage drop is less and the voltage quality is better in PCC droop characteristic approach. These conditions will be prominent under heavy loading conditions, where the voltage drop of the sources output resistance is large.

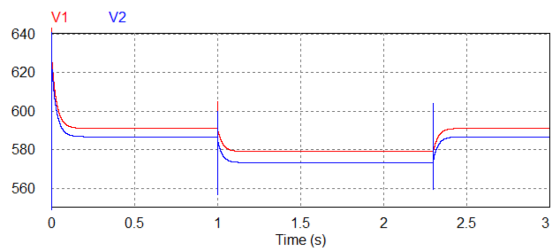
4. SIMULATION RESULTS

This section presents time domain simulations of a test microgrid. This microgrid has two sources and its structure is in accordance with Fig. 1, while its parameters are presented in Table 1.

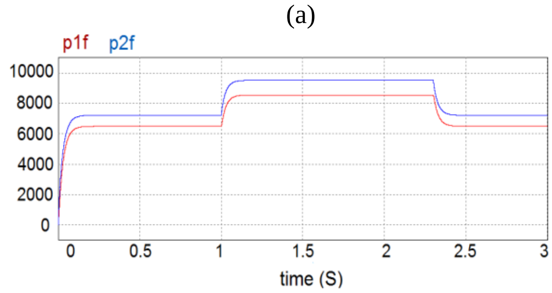
The microgrid load is initially 13 kW. At t=1 (s) the load increases to 18kW. At t=2.3 (s) the load returns to its initial value of 13kW. Fig. 4 shows the simulation results when the sources employ the conventional droop characteristic of equation (1).

Table 1. parameters of the test microgrid.

$P_{1,rated}$=10 kW	Source 1
V_0=630 V	
ΔV=60 V	
R_1=0.8 Ω	
$R_{v,1}$=0 Ω	
$P_{2,rated}$=10 kW	Source 2
V_0=630 V	
ΔV=60 V	
R_2=0.36 Ω	
$R_{v,2}$=0.44 Ω	
first order with cut off frequency of 30 rad/s	Low-pass filters



(a)



(b)

Fig. 4. Simulation results by employing the droop characteristic of equation (1). (a) sources terminal voltage. (b) sources power generation.

As seen, load increment is followed by sources voltage decrement which is the result of droop characteristic realization. In spite of equal sources rated powers, the power generation of them is not equal (see Fig. 4.b), which shows occurrence of error in power sharing. Difference between the sources terminal voltage which is the result of lines resistance shown in Fig. (4.a).

Figs. 5 and 6 illustrate the sources power generation using virtual resistance and realization of the droop characteristics in PCC, respectively. As seen, the power generation of sources are equal which emphasizes that the power sharing is accurate in both approaches.

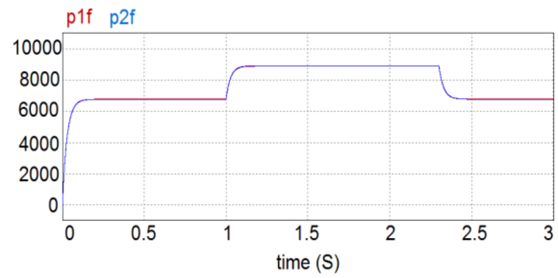


Fig. 5. Power generation of sources by employing the droop characteristic of equation (1) and virtual resistance.

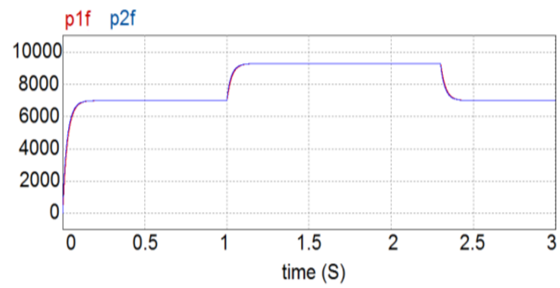


Fig. 6. Power generation of sources by realizing droop characteristic in the PCC.

Figs. 7 and 8 show the PCC voltage (which is the load voltage) employing virtual resistance and realization of the droop characteristics in PCC, respectively. In both approaches, as the power increases, the PCC voltage drops, which is the result of employing the sources droop characteristic. The nominal voltage of the microgrid that is equal to the no-load voltage in the droop characteristic (V0) is 630 v. Comparing Figs. 7 and 8 specifies that by realizing the droop characteristic in PCC, the voltage drop is less and the voltage quality is better.

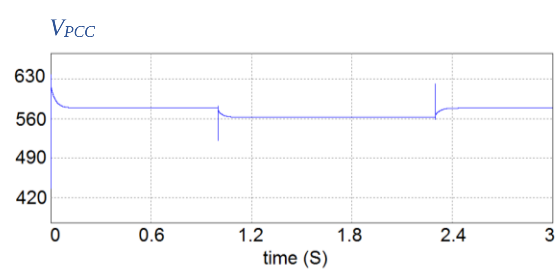


Fig. 7. PCC voltage by employing the droop characteristic of equation (1) and virtual resistance.

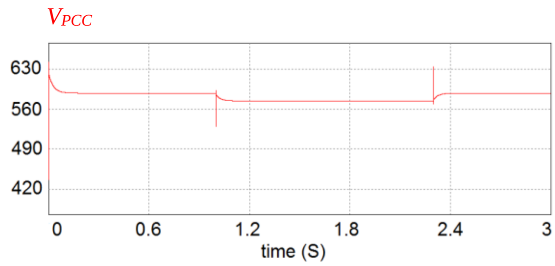


Fig. 8. PCC voltage by realizing droop characteristic in PCC.

5. CONCLUSION

In this paper, two approaches for resolving power sharing error in DC microgrids are studied and compared. In the first approach, by realization of the virtual resistances, the sources output resistance were properly tuned. In the second approach, the droop characteristics were realized in the PCC. It was shown that by employing the second approach, the voltage drop imposed to PCC is reduced and accordingly the voltage quality is improved. Discussed that the reason is bypassing the voltage drop associated with the sources output resistance. Time domain simulations were presented to verify the studies.

REFERENCES

[1] H., Nikos, H. Asano, R. Iravani, and Ch. Marnay. **"Microgrids."** *IEEE power and energy magazine* 5, No. 4, pp. 78-94, 2007.

[2] Lasseter, Robert H., and P. Piagi. **"Microgrid: A Conceptual Solution."** In *IEEE Power Electronics Specialists Conference*, Vol. 6, pp. 4285-4291, 2004.

[3] Katiraei, F., Iravani, R., Hatziargyriou, N. and Dimeas, A., **"Microgrids Management."** *IEEE power and energy magazine*, *6*(3), pp. 54-65, 2008.

[4] Guerrero, J M., .Juan C. Vasquez, José Matas, Luis García De Vicuña, and Miguel Castilla. **"Hierarchical Control of Droop-controlled AC and DC Microgrids—A General Approach toward Standardization."** *IEEE Transactions on industrial electronics* 58, No. 1, pp. 158-172, 2010.

[5] Dragičević, T., Xiaonan L., Juan C. Vasquez, and Josep M. Guerrero. **"DC microgrids—Part I: A Review of Control Strategies and Stabilization Techniques."** *IEEE Transactions on power electronics* 31, No. 7, pp. 4876-4891, 2015.

[6] Dragičević, Tomislav, Xiaonan Lu, Juan C. Vasquez, and Josep M. Guerrero. **"DC Microgrids—Part II: A Review of Power Architectures, Applications, and Standardization issues."** *IEEE transactions on power electronics* 31, No. 5, pp. 3528-3549, 2015.

[7] Baharizadeh, M., Karshenas, H. and Ghaisari, J., **"Limit Cycle Occurrence During Reactive Power Generation by Interlinking Converter in Hybrid Microgrids."** *Canadian Journal of Electrical and Computer Engineering*, *39*(2), pp. 181-189, 2016.

[8] Dragičević, Tomislav, Josep M. Guerrero, Juan C. Vasquez, and Davor Škrlec. **"Supervisory Control of an Adaptive-Droop Regulated DC Microgrid with Battery Management Capability."** *IEEE Transactions on power Electronics* 29, No. 2, pp. 695-706, 2013.

[9] Li, Yun Wei, and Ching-Nan Kao. **"An Accurate Power Control Strategy for Power-Electronics-Interfaced Distributed Generation Units Operating in a Low-Voltage Multibus Microgrid."** *IEEE Transactions on Power Electronics* 24, No. 12, pp. 2977-2988, 2009.

[10] Lu, X., Guerrero, J.M., Sun, K. and Vasquez, J.C., **"An Improved Droop Control Method for dc Microgrids based on Low Bandwidth Communication with DC Bus Voltage Restoration and Enhanced Current Sharing Accuracy."** *IEEE Transactions on Power Electronics*, *29*(4), pp. 1800-1812, 2013.

[11] Tuladhar, A., and H. Jin. **"A Novel Control Technique to Operate DC/DC Converters in Parallel with No Control Interconnections."** In *PESC 98 Record. 29th Annual IEEE Power Electronics Specialists Conference (Cat. No. 98CH36196)*, Vol. 1, pp. 892-898, 1998.

[12] Saghafi, Hadi, and Hamid Reza Karshenas. **"Power Sharing Improvement in Standalone Microgrids with Decentralized Control Strategy."** *Electric Power Components and Systems* 42, No. 12, pp. 1278-1288, 2014.

[13] Shafiee, Qobad, Josep M. Guerrero, and Juan C. Vasquez. **"Distributed Secondary Control for Islanded Microgrids—A Novel Approach."** *IEEE Transactions on power electronics* 29, No. 2, pp. 1018-1031, 2013.

[14] Anand, S., Fernandes, B.G. and Guerrero, J., **"Distributed Control to Ensure Proportional Load Sharing and Improve Voltage Regulation in Low-Voltage DC Microgrids."** *IEEE transactions on power electronics*, *28*(4), pp. 1900-1913, 2012.

[15] He, J. and Li, Y.W., **"An Enhanced Microgrid Load Demand Sharing Strategy."** *IEEE Transactions on Power Electronics*, *27*(9), pp. 3984-3995, 2012.

[16] He, Jinwei, Yun Wei Li, Josep M. Guerrero, Frede Blaabjerg, and Juan C. Vasquez. **"An Islanding Microgrid Power Sharing Approach Using Enhanced Virtual Impedance Control Scheme."** *IEEE Transactions on Power Electronics* 28, No. 11, pp. 5272-5282, 2013.

[17] Baharizadeh, Mehdi, Hamid Reza Karshenas, and Josep M. Guerrero. **"An Improved Power Control Strategy for Hybrid AC-DC Microgrids."** *International Journal of Electrical Power & Energy Systems* 95, pp. 364-373, 2018.