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A DROOP CONTROL BASED PROPOTIONAL POWER SHARING METHOD FOR DC MICROGRIDS WITHOUT COMMUNICATION

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ABSTRACT

Although DC microgrids are getting popular, load sharing is still an unsolved obstacle for widespread operation. Conventional droop method which is one of the most preferred load sharing method partially manages load sharing however this is related to equal line resistance. Also extra voltage drop arise out of the droop method is another disadvantage of the system. In this study a new approach which achieves proportional load sharing without communication is proposed for DC Microgrids. This method presents a variable DC voltage level like rectified sinusoidal voltage instead of a constant DC Voltage. By this way a periodical signal is generated and frequency of this signal is controlled according to loading level like the AC droop control. A comparative simulation study with conventional droop control is done to verify the proposed method. Results show that proposed method increased the voltage performance of the system nearly %5, load sharing performance %17.10.

Keywords: DC microgrid, Droop control, Power management, Load sharing

HABERLEŞME İÇERMEYEN MİKRO ŞEBEKELER İÇİN DÜŞÜM KONTROL TABANLI ORANTISAL GÜÇ PAYLAŞIM YÖNTEMİ

ÖZET

DC mikro şebekelerinin popülerliği oldukça artsa da yük paylaşımı mikro şebekelerde yaygın kullanımın önüne geçen çözümlenmemiş bir engel teşkil etmektedir. En çok tercih edilen yük paylaşım yöntemlerinden biri olan geleneksel düşüm yöntemi kısmen yük paylaşımını sağlasa da bu hatların eşit direnç değerlerine sahip olmasına bağlıdır. Ayrıca bu sistemin bir diğer dezavantajı ise baralarda oluşan düşüm tabanlı kontrolden kaynaklanan fazladan gerilim düşümüdür. Bu çalışma da DC mikro şebekeleri için orantısal yük paylaşımını haberleşme içermeyen bir şekilde başarı ile sağlayan yeni bir yaklaşım önerilmiştir. Bu yöntem sabit bir gerilim yerine doğrultulmuş sinüzoidal dalga şekline sahip DC gerilimi önermektedir. Bu sayede periyodik bir sinyal üretilerek AC düşüm tabanlı kontrolde olduğu gibi yüklenmeye bağlı olarak sinyalin frekansı düşürülmüştür. Önerilen yöntemi doğrulamak amacı ile geleneksek düşüm yöntemi ile karşılaştırıcı bir benzetim çalışması gerçekleştirilmiştir. Önerilen yöntem sistemin gerilim performansını yaklaşık olarak %5 ve yük paylaşım performansını da %17.10 oranında arttırdığı görülmüştür.

Anahtar kelimeler: DC mikro şebeke, Düşüm kontrolü, Güç yönetimi, Yük paylaşımı

1. INTRODUCTION

The increasing interest in technology, the developments on the energy consuming loads lead modern challenges in electric power grids. The rising demand on electric energy, forces researchers to use the grid in a more efficient way. Smart grid is a new and fast growing subject that attracts attentions of the researchers as a great amount of investments are referred from the governments of both developed and developing countries. Increasing renewable energy penetration and new types of loads such as electric vehicles have necessitated the "smart" solutions for electric power industry [1]–[3]. One of the key aspects of smart grid vision is to enable the integration of more renewable energy and together with this vision and recent environmental and economic concerns regarding the utilization of depleting fossil fuel resources, the penetration of renewable based distributed generation (DG) has significantly increased in electric power grid structure over the last decade.

In order to enable the local utilization of the energy produced and to defer the need of new investments in power delivery systems, Distributed Generation Units (DGUs) are considered a promising solution within the smart grid vision. DG of electric

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energy is a popular research area to achieve low-cost power systems expansions [4], improve power quality [5], and other environmental benefits [6]. Also DG allows more efficient usage of Renewable Energy Sources (RES) [7].

Microgrid (MG) is a remarkable electrical network concept that provides control and operation flexibility to distribution networks having large amount of DGUs [8]. Most DGUs use Power Electronic Converters (PECs) to connect the grid. Therefore, local control schemes of PECs substantially dictate the transient and steady-state responses of MGs. But, there are some challenges in DG operation that motivates researchers to investigate the use of DGs in the context of MGs. A MG is a group of loads and sources in a distribution level [9], [10] that operates connected or islanded from the grid. The grid absence in islanded MG introduces many challenges [11]. In islanded operation of a MG; stability, voltage regulation and the load sharing of the sources and energy storage units are the most challenging problems. One of the research areas related to MG that captures the interest of researchers is the energy management. In MGs, a group of sources that have particular characterization connected together and expected to share energy demand in a preferred way. At the same time, the power quality and stability of the grid has to be preserved. The trend in the control of DG PECS in MGs is; current control scheme in the main grid connected operation and droop based voltage control scheme for the island mode of operation [10], [12]–[15].

There are two general approaches to control the sources in islanded MGs. One of them is based on using communication between the sources. This approach could be very effective, however the need of communication between sources increases the costs and the system complexity [16], [17]. The other way does not require communication which ensures a higher level of reliability and flexibility [18], [19]. The most popular power sharing method without communication is the droop control.

According to load types that are connected to MG; DC, AC or Hybrid MGs can be preferred. For example to supply electronic loads, variable speed drivers, LED loads that need several ac-dc and dc-ac conversions DC MGs preferred to decrease the losses. For this kind of applications as there is no reactive power and high frequency components in the electrical parameters DC MGs presents higher power quality and system efficiency [20], [21]. The aim of the conventional droop control in DC MGs is to reduce the PEC output voltage proportionally to drawn current. However as a result of this the conventional droop control method has limited power sharing accuracy. The voltage drop across the line resistance has a negative effect on proportional load sharing. Several studies on literature focused to achieve proportional or economical load sharing in DC MGs. Most of them add additional control layers to solve the undesired extra voltage drop due to the load sharing problem [22]. The ones manage to solve the mentioned limitation used communication to update droop gains dynamically or similar control parameters in their proposed methods [23]. The effect of the communication in this kind of MG control strategies is undeniable and there is no doubt that the best results are always with the control strategies with communication. However as it is mentioned before communication itself has some drawbacks and in addition to that sometimes connection loss can occur in communication and the controllers have to operate without communication [24]. In this study a novel approach is presented for DC MGs that achieves proportional load sharing without communication. The main idea of the proposed method is instead of changing an electric parameter that will be effected by the line resistances using another electrical parameter that do not be effected by the line resistances. In AC MGs the proportional load sharing with conventional droop control is achieved as the method change the frequency due to the power. As the frequency is same at all the busses in AC MGs it can be achieved. However there is no frequency in DC MGs. The proposed method suggests a DC MG with a rectified sinusoidal voltage waveform instead of a constant one. The main contribution of this study should be said that it proposes a novel method that achieves proportional load sharing in DC MG without communication.

The mathematical details of the proposed method is explained in detail in Section 2, System and Methodology. The method is verified with a simulation and it is shown in Section 3 and the paper ends with the conclusion section where the results analyzed and discussed.

2. SYSTEM AND METHODOLOGY

The main objective of a MG control system is to achieve the desired power sharing between the sources and keep the demanded and generated power in balance. By this way a sustainable small size grid can be functionally operated. All the advantages of the DG like power quality, more efficient usage of RES is depended on this controller. As mentioned before droop control without communication is chosen for efficient and cost effective power sharing. A brief information about the conventional and proposed droop strategy is given in this section respectively.

2.1. Droop Control

Conventional droop control in DC MGs aims to reduce the output voltage of the PEC due to the drawn current or power either of them are similar. In another word the reference output voltage of the PEC is a function of output current or power shown in Eq.1 and Eq.2 respectively [22], [25].

$$v_{Oref} = V_O - K_i . i_o \tag{1}$$
$$v_{Oref} = V_O - K_P . P_o \tag{2}$$

where v_{Oref} is the reference output voltage, $V_O$is the no load (open circuit) voltage, i_o is the output current, P_o is the output power of the PEC and K_P and K_i are the droop coefficients that determine the voltage drop due to the power or current to prevent confusion Eq.2 will be chosen as a conventional droop equation in the rest of the paper

In a simple way to calculate droop coefficients maximum allowed voltage drop is generally divided maximum power of the PEC as shown in Eq.3.

$$K_{pi} = \max(\Delta V) \Big/ P_{ir} \tag{3}$$

where K_{pi} is the droop coefficient of the i’th PEC, $\max(\Delta V)$ is the max allowed voltage drop in the MG system and P_{ir} is the rated power of the mentioned PEC.

However in literature there are more complicated studies that focused to reduce the voltage drop in the load busses where there is too much voltage drop due to the line resistance. In that studies the authors do not use a constant coefficient or constant no load voltage in every PEC. Some studies V_O can vary in every PEC due to the location of the PEC to achieve better voltage profile in MG [26]. In some studies instead of using a constant coefficient, a function of power, SoC of the batteries or fuel cost is used to achieve cost based power sharing between the sources [27]. As these methods are not directly related to this study no further details are going to be given about them.

In this study instead of using Eq.2 a new droop function is proposed. As varying voltage due to the power does not achieve proportional power sharing because of the voltage drop in the lines, frequency is chosen as control parameter of the droop function. The equation of the reference output voltage of the PEC is shown in Eq. 4.

$$V_{refi} = |V_{maxi} . sin(2\pi f_i t + \alpha_i)| \tag{4}$$

where V_{maxi} is the amplitude of the reference output voltage of the i’th inverter with rectified sinusoidal waveform, t is time in seconds, α_i is the phase angle between reference and the i’th PEC. The α angle of the master PEC or the first one that start operating without any reference voltage feedback is 0. f_i is the frequency of the ith inverter. The absolute value of the output voltage function is used to prevent ac-dc and dc-ac conversions and to keep it still DC MG. The proposed frequency related to power droop equation is shown in Eq. 5.

$$f_i = f_0 - P_{if} . K_i \tag{5}$$

where f_0 is the half of the initial or no load frequency of the PEC output voltage, as the absolute value of the voltage equation is used the frequency of the PEC is doubled. For example if the f_i is 50 Hz the frequency of the V_{refi} will be 100 Hz. K_i is the droop coefficient and P_{if} is the filtered power value of the i’th PEC as shown in Eq.(6).

$$P_{if}(t) = \frac{1}{T_i} \int_{t-T_i}^{t} v_i(t) \times i_i(t)\, dt \tag{6}$$

where T_i is the period which is equal to 1/(2.f$_i$) ,v_i is the output voltage and i_i is the output current of the of the i’th PEC.

2.2 DC Microgrid Test System

A DC MG Test system is needed to test and verify the proposed droop approach. For this purpose, a 3 Bus DC MG test system [28] is modified into a 5 Bus DC MG test bench. The aim of the mentioned specified DC MG is to see the power sharing performance of the proposed method. For this reason a DC MG that consists of 2 sources, 3 loads and 4 lines is designed, a block diagram of the DC MG is shown in Fig. 1.

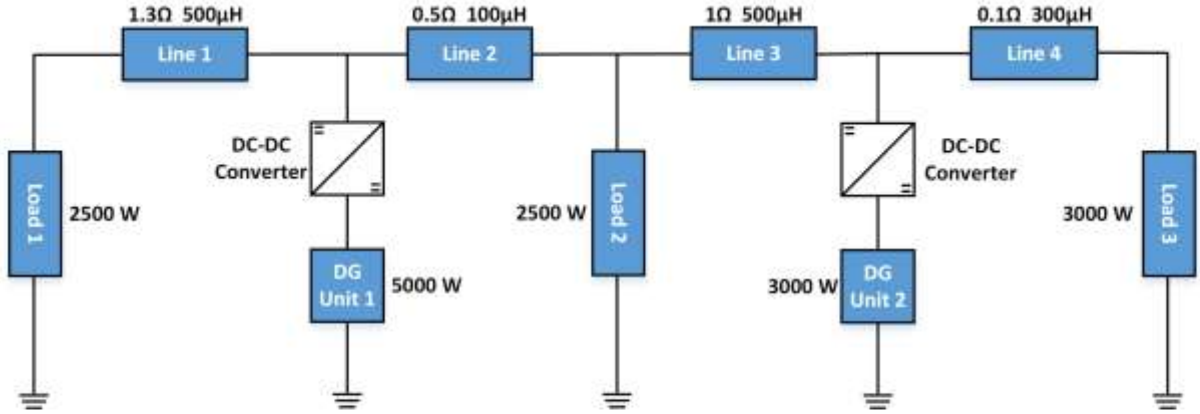

Figure 1. DC Microgrid test system block diagram

Each lines has to have different impedances for a better way of testing the system in worst conditions. Also the power of the loads are not symmetrical to test the power sharing capability of the both conventional and the proposed systems. Line parameters, source and load powers are shown in Fig.1. Details of the tests are going to be explained in following sections.

3. SIMULATION STUDIES AND RESULTS

Two simulation studies are done in MATLAB Simulink environment to compare the conventional and the proposed droop methods. For a fair comparison RMS values of the DC Bus voltages has to be equal for this reason maximum value of the rectified sinusoidal wave is chosen 400V in proposed method and in the conventional one DC bus voltage is 282.8427 V which is equal to 400 / $\sqrt{2}$. Both DGU voltage level is 700V and buck converters are used to generate desired waveforms. In both simulations to show the plug and play capability the DGU 2 is activated after 0.25s. In first 0.25s the whole MG system is supplied by the DGU 1 and after the DGU 2 is activated the both conventional and the proposed methods aim to share the power in 5/3 rate.

The conventional method uses Eq.2 where the V_o is 282.8427 V as explained and the K_p values are calculate by using Eq. 3. The maximum voltage droop that allowed in the system is chosen %5 and the K_{p1} and K_{p2} are 0.0028 and 0.0047 respectively.

The novel approach uses proposed Eq. 4 for the droop control where V_{max} is 400 V and f_i is calculated from Eq. 5 where f_o is 50 Hz, the K_1 and K_2 is 0.0002 and 0.00033 respectively. The both simulations are run for 1 second and the results are shown in following figures. The rectified sinusoidal voltage waveform of the DGU 1 is shown in Fig. 2.

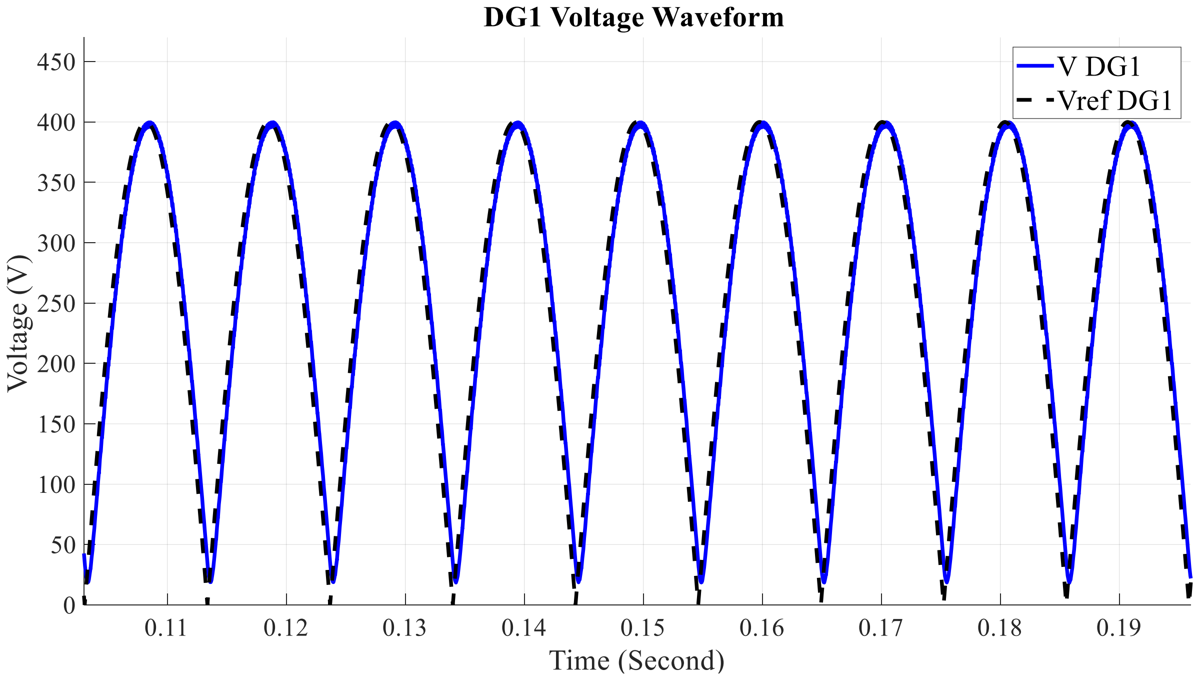

Figure 2. Output voltage waveform of the DGU 1in proposed droop method

As seen the reference DC voltage waveform is properly generated by buck converter of the first DGU in the simulation of the proposed method. Only DGU 1 is active at the time interval shown in the Fig.2 so it can be said that this is the general waveform in all the busses. The second DGU is activated at 0.25s and the change of the frequencies of the both PEC is shown in Fig. 3.

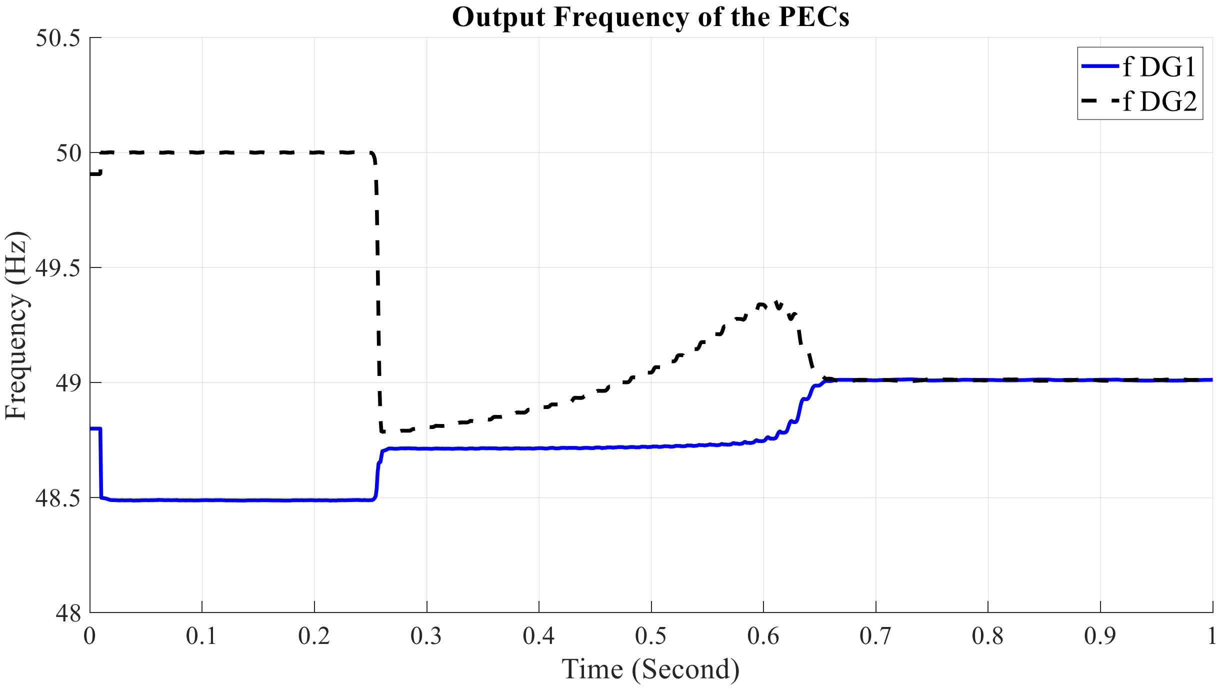

Figure 3. Output frequency of the DGUs in proposed droop method

In the beginning of the simulation all the loads are supplied from the DGU 1 for this reason the output frequency of the first buck PEC is 48.5 Hz and the second ones frequency is equal to f_o which is 50 Hz as it is in no load condition. When the second DGU is activated at 0.25s, there is a transient oscillation between two DGU for 0.4s and the system get stable after 0.65s and the frequency of the both PEC is equal at approximately 49 Hz. Power values of the PECs are shown in Fig. 4.

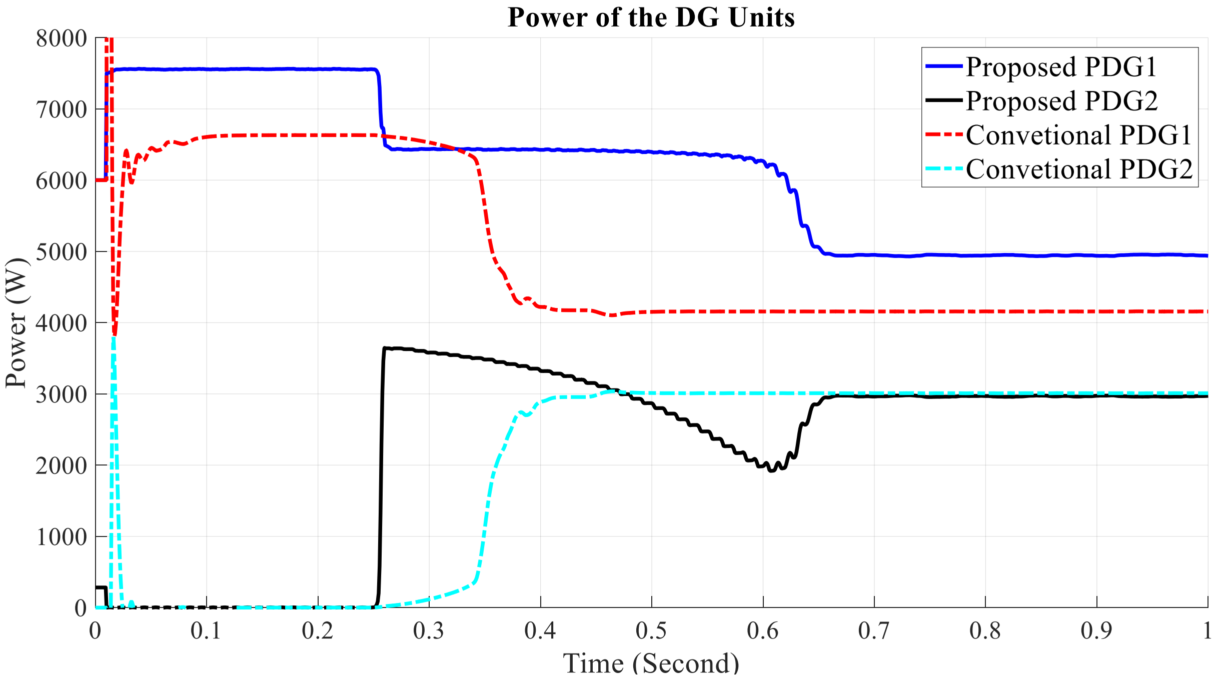

Figure 4. The power values of the DGUs in proposed droop method

The total power is nearly 7500 W which is 500 W less than the nominal power at the beginning of the proposed method simulation. That is because of the voltage drop in the system which is too much as the whole MG is supplied from one DGU. However in the conventional method the total power approximately 6500 W in addition to voltage drop in the line also the voltage drop because of the droop method decreases voltage level at the beginning. In the proposed method the second one is activated at the second of 0.25 and when the system is stable after the second 0.65 the first DGU power is 5000 W and the second one is 3000 W as it is desired. However in conventional one it is 4100W and 2900W respectively which is far from the desired levels. The successful proportional load sharing is achieved by the proposed system. The ratio between the DGU 1 and DGU 2 (P_{DG1}/P_{DG2}) shows the performance of the proposed algorithm and comparative result between proposed and conventional droop method is shown in Fig.5

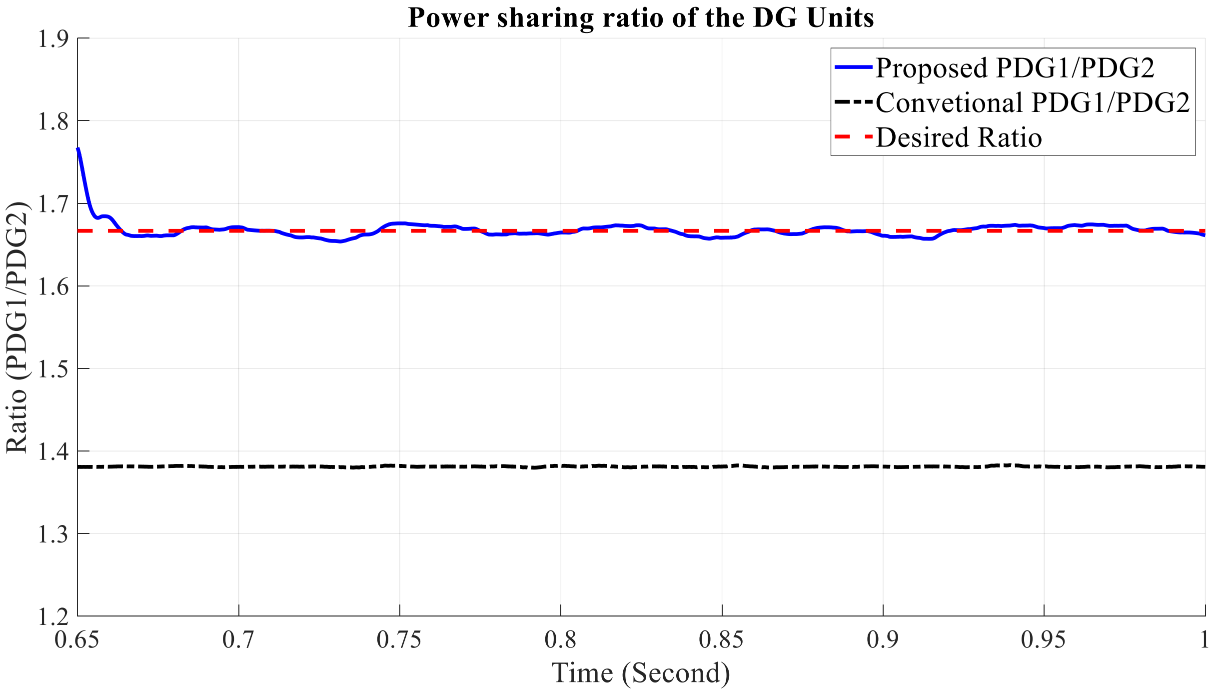

Figure 5. Comparative results for the power sharing capacity of the proposed and conventional droop method

The power sharing performance of the proposed system is seen from the Fig. 5 at the time interval when the both DG is active. The desired, proposed and conventional method is compared. The success of the proposed method is better seen in the Fig. 5 desired level is 1.667 and proposed method achieve to keep the ratio at that level however the conventional cannot. The RMS value of the voltage for each bus at steady state condition is shown in Table 1.

Table 1. Bus voltages for both method

	Load 1 Bus (V)	DG 1 Bus (V)	Load 2 Bus (V)	DG 2 Bus (V)	Load 3 Bus (V)
Proposed	273.6457	284.7869	280.4482	280.7657	279.6994
Conventional	260.5023	271.0852	267.4887	268.6546	267.6509

The Table 1 shows that Bus voltages are better kept in desired levels as a result of proposed method. To overcome this disadvantage of conventional droop control several control mechanisms are added in past studies. This method also has extremely better voltage level on each node.

4. CONCLUSION

As the MGs and DG are getting popular due to the mentioned advantages on the introduction part, the handicaps like extra voltage drop and power sharing in DC MGs are obstacles of widespread usage. In this study a new approach is proposed for DC MGs to achieve proportional load sharing. Instead of the conventional one the proposed method presents power sharing between sources in desired ratio. In literature authors try to achieve this by using communication methods however in the proposed study no communication is used. The average voltage level on each bus proportionately to nominal voltage is %94.45 in conventional method. However in proposed method this value is %98.95. This means that voltage performance of the MG system is increased nearly %5. Another performance indicator of the MG system is power sharing ratio as the desired ratio is chosen 5/3 the conventional method can only achieve %82.87 of this goal however proposed method is %99.97 which is a highly remarkable performance.

REFERENCES

[1] A. Battaglini, J. Lilliestam, A. Haas, and A. Patt, "Development of SuperSmart Grids for a more efficient utilisation of electricity from renewable sources," *J. Clean. Prod.*, vol. 17, no. 10, pp. 911–918, Jul. 2009.

[2] J. A. Cardenas, L. Gemoets, J. H. Ablanedo Rosas, and R. Sarfi, "A literature survey on Smart Grid distribution: an analytical approach," *J. Clean. Prod.*, vol. 65, pp. 202–216, Feb. 2014.

[3] P. D. Lund, J. Mikkola, and J. Ypyä, "Smart energy system design for large clean power schemes in urban areas," *J. Clean. Prod.*, vol. 103, pp. 437–445, Sep. 2015.

[4] S. S. Venkata, A. Pahwa, R. E. Brown, and R. D. Christie, "What Future Distribution Engineers Need to Learn," *IEEE Trans. Power Syst.*, vol. 19, no. 1, pp. 17–23, Feb. 2004.

[5] S.-J. Ahn, J.-W. Park, I.-Y. Chung, S.-I. Moon, S.-H. Kang, and S.-R. Nam, "Power-Sharing Method of Multiple Distributed Generators Considering Control Modes and Configurations of a Microgrid," *IEEE Trans. Power Deliv.*, vol. 25, no. 3, pp. 2007–2016, Jul. 2010.

[6] P. Chiradeja and R. Ramakumar, "An Approach to Quantify the Technical Benefits of Distributed Generation," *IEEE Trans. Energy Convers.*, vol. 19, no. 4, pp. 764–773, Dec. 2004.

[7] A. Tascikaraoglu, A. R. Boynuegri, and M. Uzunoglu, "A demand side management strategy based on forecasting of residential renewable sources: A smart home system in Turkey," *Energy Build.*, vol. 80, pp. 309–320, Sep. 2014.

[8] A. Arulampalam, M. Barnes *, A. Engler, A. Goodwin, and N. Jenkins, "Control of power electronic interfaces in distributed generation microgrids," *Int. J. Electron.*, vol. 91, no. 9, pp. 503–523, Sep. 2004.

[9] A. G. Tsikalakis and N. D. Hatziargyriou, "Centralized control for optimizing microgrids operation," in *2011 IEEE Power and Energy Society General Meeting*, 2011, pp. 1–8.

[10] F. Katiraei and M. R. Iravani, "Power Management Strategies for a Microgrid With Multiple Distributed Generation Units," *IEEE Trans. POWER Syst.*, vol. 21, no. 4, 2006.

[11] M. B. Delghavi and A. Yazdani, "A Unified Control Strategy for Electronically Interfaced Distributed Energy Resources," *IEEE Trans. Power Deliv.*, vol. 27, no. 2, pp. 803–812, Apr. 2012.

[12] J. M. Guerrero, J. Matas, L. G. de Vicuna, N. Berbel, and J. Sosa, "Wireless-control strategy for parallel operation of distributed generation inverters," in *Proceedings of the IEEE International Symposium on Industrial Electronics, 2005. ISIE 2005.*, 2005, pp. 845–850 vol. 2.

[13] J. A. P. Lopes, C. L. Moreira, and A. G. Madureira, "Defining Control Strategies for MicroGrids Islanded Operation," *IEEE Trans. Power Syst.*, vol. 21, no. 2, pp. 916–924, May 2006.

[14] J. M. Guerrero, M. Chandorkar, T.-L. Lee, and P. C. Loh, "Advanced Control Architectures for Intelligent Microgrids—Part I: Decentralized and Hierarchical Control," *IEEE Trans. Ind. Electron.*, vol. 60, no. 4, pp. 1254–1262, Apr. 2013.

[15] D. E. Olivares, A. Mehrizi-Sani, A. H. Etemadi, C. A. Canizares, R. Iravani, M. Kazerani, A. H. Hajimiragha, O. Gomis-Bellmunt, M. Saeedifard, R. Palma-Behnke, G. A. Jimenez-Estevez, and N. D. Hatziargyriou, "Trends in Microgrid Control," *IEEE Trans. Smart Grid*, vol. 5, no. 4, pp. 1905–1919, Jul. 2014.

[16] F. Cingoz, A. Elrayyah, and Y. Sozer, "Optimized Droop Control Parameters for Effective Load Sharing and Voltage Regulation in DC Microgrids," *Electr. Power Components Syst.*, vol. 43, no. 8–10, pp. 879–889, Jun. 2015.

[17] F. Cingoz, A. Elrayyah, and Y. Sozer, "Optimized Settings of Droop Parameters Using Stochastic Load Modeling for Effective DC Microgrids Operation," *IEEE Trans. Ind. Appl.*, vol. 53, no. 2, pp. 1358–1371, Mar. 2017.

[18] A. Elrayyah, Y. Sozer, and M. E. Elbuluk, "A Novel Load-Flow Analysis for Stable and Optimized Microgrid Operation," *IEEE Trans. Power Deliv.*, vol. 29, no. 4, pp. 1709–1717, Aug. 2014.

[19] N. Pogaku, M. Prodanovic, and T. C. Green, "Modeling, Analysis and Testing of Autonomous Operation of an Inverter-Based Microgrid," *IEEE Trans. Power Electron.*, vol. 22, no. 2, pp. 613–625, Mar. 2007.

[20] D. Dong, I. Cvetkovic, D. Boroyevich, W. Zhang, R. Wang, and P. Mattavelli, "Grid-Interface Bidirectional Converter for Residential DC Distribution Systems—Part One: High-Density Two-Stage Topology," *IEEE Trans. Power Electron.*, vol. 28, no. 4, pp. 1655–1666, Apr. 2013.

[21] L. Xu and D. Chen, "Control and Operation of a DC Microgrid With Variable Generation and Energy Storage," *IEEE Trans. Power Deliv.*, vol. 26, no. 4, pp. 2513–2522, Oct. 2011.

[22] S. Anand, B. G. Fernandes, and J. Guerrero, "Distributed Control to Ensure Proportional Load Sharing and Improve Voltage Regulation in Low-Voltage DC Microgrids," *IEEE Trans. Power Electron.*, vol. 28, no. 4, pp. 1900–1913, Apr. 2013.

[23] V. Nasirian, A. Davoudi, F. L. Lewis, and J. M. Guerrero, "Distributed Adaptive Droop Control for DC Distribution Systems," *IEEE Trans. Energy Convers.*, vol. 29, no. 4, pp. 944–956, Dec. 2014.

[24] M. Saleh, Y. Esa, and A. Mohamed, "Impact of Communication Latency on the Bus Voltage of Centrally Controlled DC Microgrid during Islanding," *IEEE Trans. Sustain. Energy*, pp. 1–1, 2018.

[25] X. Lu, K. Sun, J. M. Guerrero, J. C. Vasquez, and L. Huang, "State-of-Charge Balance Using Adaptive Droop Control

for Distributed Energy Storage Systems in DC Microgrid Applications," *IEEE Trans. Ind. Electron.*, vol. 61, no. 6, pp. 2804–2815, Jun. 2014.

[26] D.-H. Dam and H.-H. Lee, "An adaptive power distributed control method to ensure proportional load power sharing in DC microgrid considering equivalent line impedances," in *2016 IEEE Energy Conversion Congress and Exposition (ECCE)*, 2016, pp. 1–6.

[27] I. U. Nutkani, W. Peng, P. C. Loh, and F. Blaabjerg, "Cost-based droop scheme for DC microgrid," in *2014 IEEE Energy Conversion Congress and Exposition (ECCE)*, 2014, pp. 765–769.

[28] X. Lu, J. M. Guerrero, K. Sun, and J. C. Vasquez, "An Improved Droop Control Method for DC Microgrids Based on Low Bandwidth Communication With DC Bus Voltage Restoration and Enhanced Current Sharing Accuracy," *IEEE Trans. POWER Electron.*, vol. 29, no. 4, 2014.