Centralised and decentralised data communication scheme for voltage regulation in DC Microgrids

M A Setiawan¹, E Sulistyoo

Politeknik Manufaktur Negeri Bangka Belitung, Sungailiat – Indonesia 33211

¹Email : made.andik.s@gmail.com

Abstract. Voltage regulation is one of the main control issues in DC Microgrids (MGs). To achieve voltage regulation in MGs, exchange information between distributed generation units (DG) is inevitable. There are two types of data exchange proposed and discussed, centralised and decentralised data communication schemes. Many papers in the literature did not give attention to the type of data communication infrastructure that will have a significant impact on both centralised and decentralised schemes. This paper proposes centralised and decentralised data communication scheme and their impact on voltage regulation in DC MGs. The dynamic performance of a DC MG with loads fluctuations, operating with the proposed technique, is evaluated through simulation analyses, realized in MATLAB. Both the proposed centralised and decentralised methods are able to maintain the voltage within acceptable limit during loads fluctuations; however the centralised method is around five times faster than the decentralised method. The results show the superiority of the proposed method for the DC MGs operations during load demands fluctuations, loads varieties, communication delays and structures.

1. Introduction

A cluster of distributed generation units (DGs) with several loads and energy storage systems (ESSs) that are interconnected by a network of lines, and located at the vicinity of each other is defined as a Microgrid (MG) [1]. An MG can act as an independent power supply and distribution system (islanded mode) or operates in grid-connected mode whenever required [2]. For proper operation and control of DGs within an MG, each DG should be updated with the information about the MG operating mode [3], [4]. It is expected that in the near future all the operations in an MG will be fully automated. The automation system of the future MGs includes fetching data from the sensors, passing the data to the controllers and finally passing the control commands to the actuators. Therefore, MGs need a fast and accurate data communication system to transfer the measured data and command signals; and hence the use of reliable communication technology is essential [5].

Implementing communication technology into MGs calls for several considerations; this includes, compressing data to avoid long communication delay [6], [7], adopting hierarchical communication network to reduce the number of data traffics [8], and improving data exchanging format among DGs, ESSs, electric vehicles (EVs), loads and sensors [9]. At this stage, no attention has been given to these parameters in designing data communication for MG operations. The required communication technology in the MG application is required to have a capability for covering the scattered location of the DGs, ESSs, loads, handling numerous and massive number of sensors/meters, and spread in geographical area [10], [11]. However, establishing data communication infrastructure in the MG leads to a significant installation cost. Each communication technology (i.e. wire and wireless...
technology) has a specific coverage area, and hence for the MGs with units scattered over a wide geographical area, repeaters for improving data transmission power, quality and strengthening the signals are required but this will be on the account of cost [12]. While several papers presenting various techniques for DC MG voltage regulation and power sharing can be found in the literatures, no attention was given to the communication infrastructure effects on their methods [10, 11]. Communication infrastructure has a significant impact on communication delay, data transmission method, communication technology type, and the installation costs [15].

To perform a proper control for voltage regulation and power/current sharing; data exchange and communication among DGs, loads, and ESSs for updating and synchronizing the outputs via established communication infrastructure is essential. There are two types of data exchange and data communication schemes which are proposed and discussed in the literature, i.e. centralised and decentralised data communication schemes [12, 13]. Centralised scheme is easy to implement and maintain. However, it has limitation in scalability, requires complex communication networks and is more prone to communication failure [13]. On the other hand, decentralised scheme offers more robust to communication failure and flexibility, however it requires longer processing time, less precision and more complex algorithm [18]. In centralised scheme, all data required from DG units, ESSs and loads are transmitted to MG central controller. Contrary with centralised scheme, in decentralised scheme, data in the DG units and ESSs and loads are transmitted to others DG units and ESSs. The completed exchange data received by each DG units or ESSs are compared, processed and executed by each DG units or ESSs itself [12, 10]. Figure 1 shows an illustration for centralised and decentralised data communication in DC MG.

A suitable data communication scheme can be determined by the established communication infrastructure which affects the communication delay that influences the power flow among DGs and in the interconnected lines [19]. A type of communication infrastructure might be suitable and has smaller communication delay for one type of data communication scheme which not be the same for another scheme. Most of the papers in the literature discussing voltage regulation in the MGs did not investigate the data communication delay effects on their proposed methods. These issues are the main gap of existing research that is addressed in this paper. The main contributions of this paper are:

- Proposing centralised and decentralised data communication scheme method for transmitting and exchanging data in DC MG regardless the type of communication technology, infrastructure and voltage regulation and power sharing method.
- Proposing a technique for voltage regulation in DC MG which can be employed for different data communication infrastructures and schemes.

![Figure 1. Illustration of data communication schemes in MG (a) centralised, (b) decentralised](image-url)
2. Proposed Method

Consider the DC MG of Fig. 1(a) that consists of two DGs and one load [20]. In this figure, the voltage and current of the load can be expressed as:

\[ V_L = \sum_{i=1}^{N} V_{DGi} \prod_{j=1, j \neq i}^{N} Z_{DGj} Z_L, \quad (1) \]

\[ I_L = \sum_{k} I_{DGk}, \quad \forall k \in \{1 \ldots N\} \]

According to (1), following a change in the load demand, the DGs voltages \( \sum V_{DGk} \) can compensate for this change. However, due to the fact that it is impractical to measure \( Z_C \), and hard to consider \( Z_L \) due to its dynamic changes, the iteration process of updating \( \Delta V_{DGk} \) is required to be continuously adjusted until it compensates for the load voltage changes \( \Delta V_L \), which can be expressed as:

\[ \Delta V_L = \Delta V_{DGk}, \quad \forall k \in \{1 \ldots N\} \]

\( \Delta V_{DGk} \) needs to be updated discretely to prevent instability for the power electronics-based DC-DC converters due to continuous variations of their references [21]. This method requires a feedback signal from the voltage of the closest load to a DG to regulate the load voltage following any fluctuations in the load demand. However due to unknown line and load impedances, coordination and synchronization outputs of each DG is required for proper current load sharing among DGs. Updating without any coordination and synchronization among DGs will lead to un-proportional or over/under currents in the load generated by DGs as described in (1). The adjusted output current of each DG can be expressed as:

\[ \Delta I_{DGk} = \frac{\Delta(\sum I_{DGk}, \forall k \in \{1 \ldots N\}), I_{DGk}}{\sum I_{DGk}, \forall k \in \{1 \ldots N\}}, \quad (3) \]

The method of (3) requires a MG central controller for collecting and computing all generated currents from DGs. Performing proper power/current sharing among DGs, therefore it also requires a weighting factor of the DG generated ratio \( R_{DG} \) in the range \( 0 \leq R_{DG} \leq 1 \). The proposed voltage regulation in (2) can be re-written as:

\[ \Delta V_{DGk} = \left( \sum R_{DG}, \Delta I_{DGk} \right) R_{DG} \Delta V_L, \quad \forall k \in \{1 \ldots N\} \]

\( R_{DG} \) of each DG is determined by the MG central controller based on capacity, or operational cost of the DGs. The renewable energy sources have an intermittent character and their energy output depends on environmental conditions. Hence, their generated power can be less than their capacity. The recent generated power by each renewable energy-based DG should be considered when determining a new value of \( R_{DG} \).

The proposed voltage regulation for DC MG is illustrated in Fig. 1. It is to be noted that the distance between the DGs, sensors and MG central controller of the MG can be quite far, and thereby the utilizing a communication technology is essential and avoidable [17]. In this paper, the DC-DC converter of a DG is assumed as a semi-ideal converter which has the ability to produce a voltage output equal to its reference in a short interval. In Fig. 1, \( R_1 \) and \( L_1 \) represent the internal resistance and inductance of the converter’s filter, while \( R_C \) and \( L_C \) represent the resistance and inductance of \( Z_C \).

As discussed above, the data communication infrastructure and technology determines the type of the data communication scheme that can be applied and implemented on the MG. In this paper, data communication can be classified as a centralised data communication scheme, which is when the required data is transmitted from DGs, ESSs, or loads to the MG central controller [12, 13]. The MG central controller calculates and processes the received data, according to the implemented technique, before re-transmitting to the DGs, ESSs, and loads. In a decentralised data communication scheme, all
the required data is transmitted and exchanged between the DGs and ESSs without any coordination from the MG central controller [10, 12].

According to (1), the load currents are supplied by the generated currents of all MG DGs. In a steady-state condition, the DGs generate the proportional current output according to their current ratio. However, voltage and current outputs generated proportionally require continuous data updating and proper synchronisation among DGs. Un-synchronised/randomly updating voltage and current outputs lead to an over/un-proportionally supplied current on the load side. Therefore, to achieve a proportional/designated voltage and current on the load side, periodic synchronisation among DGs for updating outputs is essential and performed via the proposed centralised and decentralised data communication schemes.

The required data to be exchanged and transmitted, using the proposed voltage method is presented in (1) to (4). In the proposed centralised data communication scheme, $I_{DG}$ and $V_{DG}$ are transmitted from the DGs to the MG central controller to determine $R_{DG}$ and $\frac{I_T}{P_T}$. The data $I_T/P_T$ is then calculated by the MG central controller and transmitted back to the DGs for re-calculating and updating of $R_{DG}$. To determine $N$, the data $s_{DG}$ is transmitted to the MG central controller by the DGs. On the other hand, in the proposed decentralised data communication scheme, all the above required data are transmitted to the next closest DG. The updated DG outputs are performed only when the above data is received in full from the previous closest DG. The proposed data flow in a decentralised scheme is designed to prevent data collision; it also shortens queues in the communication line.

In summary, in the proposed centralised data communication scheme, DG outputs are updated simultaneously, while in the proposed decentralised data communication scheme, the DG outputs are updated sequentially. The data flow transmissions and flowcharts of the proposed centralised and decentralised MG data communication schemes are illustrated in Figure 2 and Figure 3 respectively in which P1, P2, P3, and P4 represent the communication device Points of DGs, ESSs, or loads in MG.

![Diagram](image_url)

**Figure 2.** Data transmission flow of the proposed MG data communication scheme with: a) centralised scheme, b) decentralised scheme

In the proposed technique, all received data are saved in the DG controllers and in the MG central controller, and then used in the calculations until a new value is received. Upon failure in the communication system, the proposed control technique continues to function using the stored data. To prevent and eliminate communication failure problems, each communication technology has a protocol, such as the re-transmittal of the confirmation code to the transmitter [12]. Therefore, in this
paper, we assume that all transmitted data are received in a good and acceptable condition by the receiver.

Figure 3. One-cycle processing flowchart of the proposed MG data communication scheme with: a) centralised scheme, b) decentralised scheme

3. Simulation Results
The impacts of data latencies on the dynamic operation of the DC MG can be evaluated using the DC MG network consisting of four DGs and six loads points shown in Figure 4. The technical parameters of the investigated DC MG under are summarized in Table 1.

The DC MG is initially assumed to be in a steady-state condition, and the voltages at the load points are within an acceptable limit. The employed voltage and power/current load sharing techniques are the proposed techniques discussed in (1) through (4), and \( \Delta V_L \) is defined as \( \text{avg}(V_{Li}^{\max}, V_{Li}^{\min}, \forall i \in \{1 \ldots 6\}) \).

Table 1. Considered technical parameters for data communication scheme simulation

| Base parameters 220 V, 70 A, 34 kW. | Lines \( R_{CL10} = 0.1 \ \Omega, R_{C2} = 0.2 \ \Omega, L_{CL10} = 10 \ \text{mH} \). | Loads capacity \( \approx 5kW, R_{L_{1.6}} = 10 \ \Omega, L_{L_{1.6}} = 10 \ \text{mH}, C_{L_{1.6}} = 1 \ \text{mF} \). | DG1 Capacity \( \approx 6kW, V_{\max} = 250V, L_i = 4 \ \text{mH}, C_i = 1.5 \ \text{mF}, R_i = 0.1 \ \Omega \). |
| --- | --- | --- | --- |
| DG2 Capacity \( \approx 11kW \). | DG3 Capacity \( \approx 11kW \). | DG4 Capacity \( \approx 6kW \). |
According to the proposed data flows in Fig. 2, the proposed sequential charts in Fig. 3, the communication delay for the proposed centralised and decentralised data communication scheme for the investigated DC MG network is used. However, to examine the performance of the proposed methods in this paper, the maximum delay is used instead of the minimum delay.

Fig. 3 shows that in the proposed centralised data communication scheme, the periods are implemented for just one-cycle to update the DG outputs. When the analysis is conducted on the proposed decentralised data communication scheme, the periods are implemented for the total number of DGs and load cycles. When updating each DG individually, the required periods differ between DGs, as illustrated in Figs. 3(a) and 3(b).

In this simulation, the DGs power ratios are proportionally defined based on their capacities, i.e. $R_{DG1} = R_{DG4} = \frac{6}{34}$, and $R_{DG2} = R_{DG3} = \frac{11}{34}$. The maximum loads demand is simulated at $t = 3$ s. The impacts of the proposed centralised and decentralised data communication scheme on the voltage regulation of the DC MG network of Fig. 4 is shown in Fig. 5 and Fig. 6.

Simulation results reveal that the proposed centralised and decentralised data communication scheme can maintain all load voltages within acceptable limits during fluctuations of load demands as shown in Fig. 5 and Fig. 6. Results also indicate that the DGs can precisely generate power at designated rate. The DG1, DG2, and DG3 generate their voltage outputs higher than DG4 to provide the required power for Load-4 and Load-5 which are closer to DG4. On the other hand, the power in DC MG can be achieved faster in the proposed centralised data communication scheme than the decentralised one. In the proposed centralised data communication scheme, the proportionally power generated by DGs are achieved in a time less than 10s of the simulation time while it takes 60s in the decentralised scheme to achieve the designated power as depicted in Figure 5 and Figure 6. It can be noticed that there are no circulating currents among DGs occurring during the simulation time even though there are dissimilarities of the outputs voltages and powers generated.
4. Conclusions

The impacts of the proposed communication infrastructure approaches in the DC MG operation are examined by implementing the proposed centralised and decentralised data communication scheme. In the proposed centralised scheme, the synchronization among DGs for updating their outputs is conducted by MG central controller by transmitting the required data to all DGs at the time. On the other hand in the proposed decentralised scheme, updating DG outputs are performed after receiving the required data from another DG. Simulation results indicate that the proposed centralised and decentralised data communication schemes can maintain all loads voltages within acceptable limits during fluctuations of load demands. Meantime the designated generated power by DGs can be achieved.

References

[1] E. Planas, J. Andreu, J. I. Gárate, I. Martínez De Alegría, and E. Ibarra, “AC and DC technology in microgrids: A review,” Renew. Sustain. Energy Rev., vol. 43, pp. 726–749, 2015.

[2] P. Zhang, H. Zhao, H. Cai, J. Shi, and X. He, “Power decoupling strategy based on ’virtual negative resistor’ for inverters in low-voltage microgrids,” IET Power Electron., vol. 9, no. 5, pp. 1037–1044, 2016.

[3] J. J. Jamian, H. A. Illias, K. Gia Ing, and H. Mokhlis, “Optimum distribution network operation considering distributed generation mode of operations and safety margin,” IET Renew. Power Gener., vol. 10, no. 8, pp. 1049–1058, 2016.

[4] M. A. Setiawan, A. Abu-Siada, and F. Shahnia, “Voltage regulation in DC microgrids with various circuit configurations,” in 2016 IEEE 2nd Annual Southern Power Electronics Conference, SPEC 2016, 2016.

[5] P. Garcia, P. Arboleya, B. Mohamed, A. C. Vega, and M. C. Vega, “Implementation of a hybrid distributed / centralized real-time monitoring system for a DC / AC microgrid with energy storage capabilities,” IEEE Trans. Ind. Informatics, vol. 3203, no. 1551, pp. 1–10, 2016.
[6] M. Saleh, Y. Esa, S. Member, A. Mohamed, and S. Member, “Impact of Communication Latency on the Bus Voltage of Centrally Controlled DC Microgrids During Islanding,” IEEE Trans. Sustain. Energy, vol. PP, no. c, p. 1, 2018.

[7] N. C. F. Tse, J. Y. C. Chan, W. Lau, J. T. Y. Poon, and L. L. Lai, “Real-Time Power-Quality Monitoring With Hybrid Sinusoidal and Lifting Wavelet Compression Algorithm,” IEEE Trans. Power Deliv., vol. 27, no. 4, pp. 1718–1726, 2012.

[8] H. Y. Tung et al., “The Generic Design of a High-Traffic Advanced Metering Infrastructure Using ZigBee,” IEEE Trans. Ind. Informatics, vol. 10, no. 1, pp. 836–844, 2014.

[9] I. Hwang, D. Lee, and J. Baek, “Home network configuring scheme for all electric appliances using ZigBee-based integrated remote controller,” IEEE Trans. Consum. Electron., vol. 55, no. 3, pp. 1300–1307, Aug. 2009.

[10] M. A. Setiawan, F. Shahnia, R. P. S. Chandrasena, and A. Ghosh, “Data communication network and its delay effect on the dynamic operation of distributed generation units in a microgrid,” in Asia-Pacific Power and Energy Engineering Conference, APPEEC, 2014.

[11] A. Abdali, R. Noroozian, and K. Mazlumi, “Electrical Power and Energy Systems Simultaneous control and protection schemes for DC multi microgrids,” Electr. Power Energy Syst., vol. 104, no. June 2017, pp. 230–245, 2019.

[12] M. A. Setiawan, F. Shahnia, A. Ghosh, and S. Rajakaruna, “Developing the ZigBee based data payload coding for data communication in microgrids,” in 2014 Australasian Universities Power Engineering Conference, AUPEC 2014 - Proceedings, 2014.

[13] V. Nasirian, S. Moayedi, A. Davoudi, and F. Lewis, “Distributed Cooperative Control of DC Microgrids,” IEEE Trans. Power Electron., vol. 30, no. 4, pp. 2288–2303, 2014.

[14] M. Sechilariu, B. C. Wang, and F. Locment, “Supervision control for optimal energy cost management in DC microgrid: Design and simulation,” Int. J. Electr. Power Energy Syst., vol. 58, pp. 140–149, 2014.

[15] A. Usman and S. H. Shami, “Evolution of Communication Technologies for Smart Grid applications,” Renew. Sustain. Energy Rev., vol. 19, pp. 191–199, Mar. 2013.

[16] C. N. Papadimitriou, E. I. Zountouridou, and N. D. Hatziargyriou, “Review of hierarchical control in DC microgrids,” Electr. Power Syst. Res., vol. 122, pp. 159–167, 2015.

[17] S. Moayedi and A. Davoudi, “Distributed Tertiary Control of DC Microgrid Clusters,” IEEE Trans. Power Electron., vol. 31, no. 2, pp. 1717–1733, 2016.

[18] J. Chi, P. Wang, J. Xiao, Y. Tang, and F. H. Choo, “Implementation of Hierarchical Control in DC microgrids,” IEEE Trans. Ind. Electron., vol. 61, no. 8, pp. 4032–4042, 2014.

[19] K. A. Alobeidli, M. H. Syed, M. S. El Moursi, and H. H. Zeineldin, “Novel Coordinated Voltage Control for Hybrid Micro-Grid With Islanding Capability,” IEEE Trans. Smart Grid, vol. 6, no. 3, pp. 1116–1127, 2015.

[20] M. A. Setiawan, A. Abu-Siada, and F. Shahnia, “A New Technique for Power Sharing in DC Microgrids,” in IEEE Southern Power Electronics Conference, 2016, no. 1, pp. 1–5.

[21] J. Wang, B. Bao, J. Xu, G. Zhou, and W. Hu, “Dynamical Effects of Equivalent Series Resistance of Output Capacitor in Constant On-Time Controlled Buck Converter,” IEEE Trans. Ind. Electron., vol. 60, no. 5, pp. 1759–1768, 2013.

Acknowledgments
This research is supported and funded by Penelitian Dasar scheme from Ministry of RistekBrin Indonesian Government, No: 131/SP2H/AMD/LT/DRPM/2020.