A maximum flow evaluation method of microgrids comprised of ultra-small microgrid components

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SUMMARY Renewable energy power sources have large quantities of direct current (DC) power, and because most of the loads experienced by these sources also use direct current, there is an increase in attention to microgrids that limit their dependence on the power grid. To benefit DC microgrids, we are developing a virtual grid (VG) system using USB Type-C that supports the USB Power Delivery (PD) standard. In the VG-Hub network, a large amount of power must be synthesized and distributed with as few VG-Hubs as possible. A key problem is how to derive the maximum executable flow to create a VG-Hub network with both the smallest number of VG-Hubs and the largest combined distribution power. Therefore, the purpose of this study is to obtain a graph necessary for discussing the problem of deriving the maximum executable flow based on an arbitrary graph in which multiple VG-hubs are connected. We demonstrate that, by generating a connection matrix that represents the connection status of the power supply and loading it in advance, a graph of the VG-Hub network connected to the power supply and the load could be created.

keywords: *battery, Maximum executable flow, Virtual Grid, VG-Hub, IoT*

1. Introduction

Local production of energy for local consumption systems by solar power generation methods is an increasingly popular and mainstream approach. However, many renewable energy sources generate a large amount of direct current (DC) power, and most of the loads are also direct current. Therefore, the present paper focuses on "microgrids" that can limit their reliance on the grid. A "microgrid" is a small-scale energy network that aims to locally produce energy for local consumption by having the energy sources and the consumption facilities in the community, without relying on the power supply of large-scale power plants. However, two main problems associated with microgrids is that they require a long-distance power grid and they cannot be easily configured by the user.

Additionally, a power supply standard that supports USB Type-C, referred to as USB PD, has been attracting attention in recent years. USB Power Delivery (PD) can distribute electric power and is expected to be more commonly utilized as a power supply interface in the future. However, there is a problem in that power from USB PD cannot be combined. From the perspective of this challenge of intelligent power control, Morimoto proposed a method to determine power allocation for home appliances based on a variety of factors, thereby allowing for the control of the amount of power supplied to home appliances to minimize the negative impact on user quality-of-life [1]. However, with respect to power control, this method only performed power distribution and not power synthesis. Therefore, in the present study we have developed a virtual grid (VG)-Hub with a USB Type-C port that performs power synthesis and distribution, and supports USB PD. In addition, expanding the number of ports is desirable to ensure flexibility in the synthesis of power from various power devices and supplying power to many load devices. Therefore, the authors describe a method for networking VG-Hubs to configure a pseudo-VG-Hub with an arbitrary number of ports. The method of configuring a pseudo-VG-Hub requires a large power synthesis distribution with as few VG-Hubs as possible [2].

This manuscript presents a graph generation method for discussing the problem of deriving the maximum executable flow from an adjacency matrix representing an internal network.

2. Microgrid reconfigurable with an ultra-small power system

2.1 Virtual Grid System

A virtual grid [3] is a power control unit that an end-user configures dynamically or statically for a given purpose. The virtual grid consists of a load, a power supply, and a VG-Hub network that connects these two. The VG-Hub has a USB Type-C PD interface and internally synthesizes the connect power output and distributes it to the load. The USB Type-C PD interface allows the device to dynamically determine the role of either the power or the load [4]. A VG-Hub can connect the power supply and the load to any port. The controller is then built into the VG-Hub to control the power flow between the power supply and the load. Figure 1 shows a pseudo-VG-Hub configuration using the network VG-Hub.

2.1 VG-Hub network

The VG-Hub [5] is a hardware unit that synthesizes and distributes power, and its USB port is fixed. However, it is desirable to increase the number of ports to allow for the

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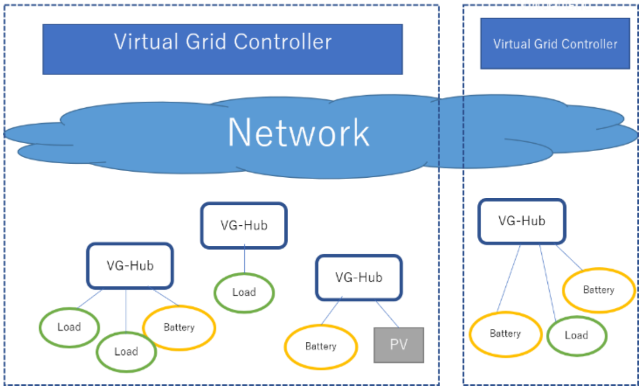

Fig. 1 Pseudo-VG-Hub configuration with networking VG-Hub

combination of power from various power supply devices and to ensure the capacity to supply power to many load devices. Therefore, in the present study, we considered networking the VG-Hub to configure a pseudo-VG-Hub with any number of ports. The method of networking the VG-Hubs to configure pseudo-VG-Hubs with an arbitrary number of ports requires a significant amount of power synthesis and distribution with as few VG-Hubs as possible. Lastly, the VG-Hub can handle the same amount of power flow in both directions for all ports. Therefore, the problem of configuring a VG-Hub network with the minimum number of VG-Hubs and the maximum combined distribution power can be treated as a graph configuration problem.

3. Network generation

In this section we describe how to attain the graph for a VG-Hub network based on: the smallest number of VG-Hubs and the largest combined distributed power, any graph with multiple VG-Hubs connected, unconnected ports of the VG-Hub connected to the power supply, or the load given. We also discuss the problem of deriving the maximum executable flow.

Three ports for four VG-Hubs can be depicted as an adjacency matrix, like the example below.

$$\begin{pmatrix} 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 \end{pmatrix}$$

The diagonal component of the adjacency matrix $\boldsymbol{A}$ is "0" because there can be no connections from any given port to itself. The regular graph of the VG-Hub network to which no power supply or load is connected is shown in Figure 2. The VG-Hub with the maximum power f that can be input and output by the port constitutes a pseudo-VG-Hub with 12 ports in the VG-Hub network. The upper limit of the power that can be handled by a VG-Hub with four nodes is $6f$, because the hub uses at least two ports for input and output.

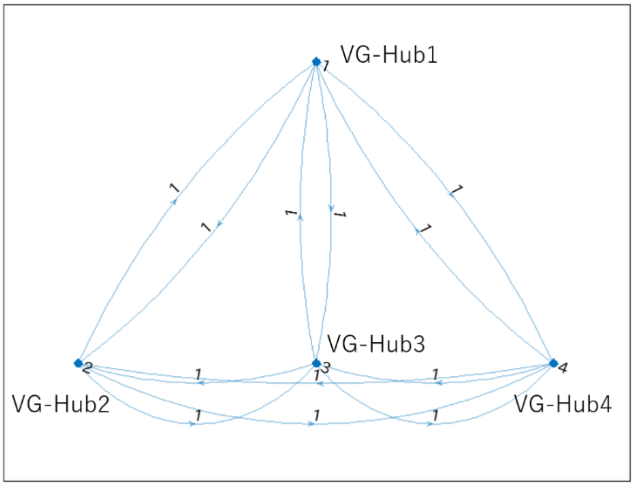

Fig. 2 VG-Hub network with no power load connected

4. Proposal for a maximum flow evaluation method

In this section, we present an arbitrary graph with multiple VG-Hubs connected, and describe how to evaluate the maximum executable flow given a VG-Hub unconnected port that connects to a power source or load. We can reduce the problem to the case where in the number of ports needed to connect the power supply or the load of each VG-Hub is the same. We use many of the steps suggested in previous research [5], namely:

(1) Set the adjacency matrix $\boldsymbol{A}$ of G, which represents the internal network.

(2) The concatenation matrix, which determines whether to play the role of power supply or load, is concatenated with the adjacency matrix $\boldsymbol{A}$. Let a be the number of ports connected to the power or load device, and let N be the number of nodes in the graph.

(2.1) The right-connected matrix (N rows, 2 × a columns) $\boldsymbol{R}$ is connected to the right of the adjacency matrix $\boldsymbol{A}$, and represents the matrix connected to the load.

(2.2) The low-concatenated matrix (2 × a rows, N columns) $\boldsymbol{L}$ is connected below, and represents the matrix connected to the power supply.

(3) The matrix $\boldsymbol{C}$ concatenates the matrices $\boldsymbol{A}$, $\boldsymbol{R}$, and $\boldsymbol{L}$

(4) To calculate the maximum executable flow, concatenate the nodes representing the power supply and load into one.

5. Example of the proposed method

If there are four VG-Hubs with three ports which have been networked to form a pseudo-VG-Hub, the evaluation method proposed in Section 4 will be executed, and can be described as follows.

(1) The adjacency matrix A with 4 VG-Hubs and 3 ports is:

$$\boldsymbol{A} = \begin{pmatrix} 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 \end{pmatrix}$$

(2) Because the number of ports is three and the number of nodes is four, $a = 3$ and $N = 4$. These connect all ports of the two VG-Hubs to the power and the remaining ports to the loads.

(2.1) The right-connection matrix (four columns, 6 rows) ***R*** is connected to the right of the adjacency matrix ***A***, representing the connection state to the load as depicted below:

$$\boldsymbol{R} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 \end{pmatrix}$$

(2.2) The low-connection matrix (four rows, 6 columns) ***L*** is connected under the adjacency matrix A, representing the status of the connection to the power supply is depicted below:

$$\boldsymbol{L} = \begin{pmatrix} 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

(3) Figure 3 presents a graph wherein G, which represents the internal network, is connected to matrix ***C***, which represents the VG-Hub network in which the load and power supply are connected. The matrix to represent this is depicted below.

$$\boldsymbol{C} = \begin{pmatrix} 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

(4) Combine the nodes that represent power and load into a single node to calculate the maximum executable flow. An example graph is shown in Figure 4.

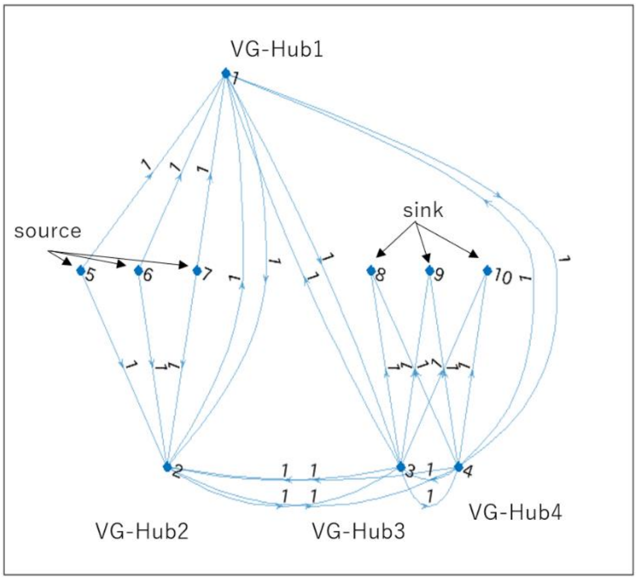

Fig. 3 VG-Hub network with power load connection

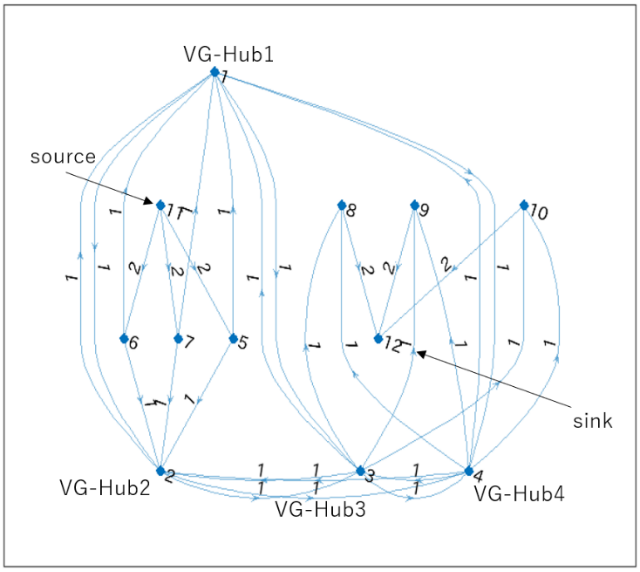

Fig.4 VG-Hub network with modified power load connections

6. Conclusion

In this manuscript, we described how to create a VG-Hub network with a power load connection from a VG-Hub network with no power and load connections. The matrix representing the connection status of the power and load can be determined by the size of the adjacency matrix representing the VG-Hub network. By generating a connection matrix that represents the connection status of the power supply and the load in advance, we demonstrated how a graph of the VG-Hub network connected to the power supply and load can be created. Also, the connection and adjacency matrices representing the connection states of the power supply and load to be created in advance will be placed in the cloud, which is currently under consideration [7]. Then, by obtaining those matrices from the cloud, depending on the connection status of VG-Hub, it is possible to create a VG-Hub network with power load connections. Therefore, we believe that the proposed system will work well because the proposed method is centralized.

Acknowledgments

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