A method for generating graphs to derive maximum flow and its evaluation

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Abstract: The study presents a "virtual grid system" currently being developed by the authors. The system consists of a power supply, load, and virtual grid hub (VG-Hub) network connecting them. The VG-Hub network must have a large power distribution capability. Therefore, the challenge is to obtain a graph to evaluate the maximum feasible flow when multiple VG-Hubs are connected to a power source or load. In this paper, we propose a method for generating a graph to derive the maximum feasible flow. A quantitative evaluation of the proposed method is presented.

Keywords: Maximum flow, Hub, Battery, Virtual Grid, VG-Hub, IoT

Classification: Network system

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1 Introduction

Recently, there has been a growing interest in renewable energy sources. Among renewable energy sources, solar and wind power have a weakness in that the amount of power generated depends on the weather and is difficult to control. Therefore, batteries are required to alleviate variations in power generation. Batteries are also required to increase the portability of devices, which means that they are required for different purposes, thus creating inefficiency. Combining the batteries through a system with various outputs and capacities is desirable. Morimoto proposed a method to minimize the impact on the user’s quality of life (QOL) by determining the power allocation of home appliances based on various factors and controlling the power supply of home appliances [1]. However, with respect to power control, this method only performed power distribution, not synthesis. We are trying to use the VG-Hub network to distribute power to the load on an arbitrary scale using a group of batteries, which do not necessarily have the same output and capacity [2]. The main challenge is to obtain a graph to evaluate the maximum feasible flow when multiple VG-Hubs are connected to a power source or load. To address the above challenge, we propose a method for generating a graph to derive the maximum feasible flow. We further compare and evaluate the proposed method with one that sequentially adds edges to nodes representing loads and power supply.

2 Virtual Grid System

Figure 1(a) shows a virtual grid system. The virtual grid system is an application system in which the power supply and loads are connected to a VG-Hub network. The VG-Hub network is responsible for power distribution and is monitored and controlled by a virtual grid controller (VG controller). The VG-Hub is a device that is controlled by the VG-Hub controller inside the VG-Hub. Furthermore, the VG-Hub communicates with the VG controller through the cloud and distributes power between the power supply and load devices connected to the VG-Hub port, as shown in Figure 1(a). The VG-Hub ports can be connected to any VG device that complies with the USB-C PD standard. USB-C PD is increasingly being used because of its versatile features to control the flow of power. The USB Type-C connector is bidirectional and nonpolar. Based on the results of the USB PD power rule negotiation, up to 100 W of power flow can be allowed [3]. The VG controller controls the flow of electricity in the VG-Hub by specifying the role and maximum power of each VG-Hub port [4]. The power flow from the port is synthesized with
the role of each load device in VG-Hub, and the synthesized power is distributed to VG devices connected to the port with the role of a power supply [5]. The prototype of VG-Hub is shown in Figure 1(b). VG-Hub is a hardware unit, and the number of ports is fixed for one VG-Hub unit. By networking VG-Hub and using some ports of VG-Hub to connect VG-Hub units to each other, we can build a large hub with many ports. An increase in the number of ports used to connect VG-Hub units means that the VG-Hub network can be designed to carry more power flows. A method for generating graphs for maximum flow derivation is presented in the next section.

![Diagram of Virtual Grid System](image)

**Fig.1.** (a) Overview of the virtual grid system, (b) the VG-Hub prototype

### 3 Proposed Method for Maximum Flow Derivation

Previously published literature presented a method for creating a VG-Hub network with power load connections from a VG-Hub network with no power and load...
connections [6]. In addition, the matrix representing the connection status of the power supply and load could be determined by the size of the adjacency matrix representing the VG-Hub network. It was shown that by generating the adjacency matrix representing the connection status of the power supply and load in advance, it was possible to create a graph of a VG-Hub network with power supply and load connections. In this section, as a comparison to the proposed method, we also explain the sequential method of adding nodes representing power supply and load to VG-Hub one by one.

Assume that there is a VG-Hub network as follows.

There were four VG-Hub units, and they were all interconnected. The number of ports on each VG-Hub unit was 6. Three ports were used to connect a VG-Hub unit to the rest. The other three ports were connected to the load and power supply.

Two of the four VG-Hub were connected to the load. The remaining two VG-Hub were connected to the power supply. First, we presented a sequential method.

1. Import the adjacency matrix representing the connection status of each VG-Hub unit.

   Figure 2(a) shows the graph of the VG-Hub network not connected to the power supply and load based on the VG-Hub connections assumed earlier.

2. For one VG-Hub unit, sequentially add edges to each node for power and load connections. Figure 2(b) shows the graph of the power supply and load connected to the VG-Hub using the sequential method based on the connection status of the power supply and load defined in the previous section.

3. Apply the Ford-Fulkerson algorithm to calculate the maximum flow.

Next, we present the proposed method.

1. Import the adjacency matrix representing the connection status of each VG-Hub.

   Figure 2(a) shows the graph of the VG-Hub network not connected to the power supply and load based on the VG-Hub connections assumed earlier.

2. Import the right-hand concatenation matrix representing the connection status of the load.

3. Import the lower concatenation matrix representing the connection status of the power supply.

4. Concatenate the right and lower matrices to the adjacency matrix

5. Add an edge to each node to combine the nodes into one node, load for load, and power for power. Figure 2(c) shows the graph of the power supply and load connected to each VG-Hub unit using the proposed method based on the connection status of the power supply and load defined in the previous section.

6. Apply the Ford-Fulkerson algorithm to calculate the maximum flow.

In the next section, we compare and evaluate the two methods presented in this section.
Fig.2. (a) A VG-Hub network with no power supply and load connected, (b) a VG-Hub network created using the sequential method with modified power load connections done using the sequential method, (c) a VG-Hub network created using the sequential method with modified power load connections done using the proposed method

4 Evaluation

We compared the sequential method with the proposed method and evaluated them using the ordered method and measured values. The number of VG-Hub units is used as the parameter. Let the number of VG-Hub units be $N$ and the number of ports connected to the load and power supply be $A$. Using the order method, the proposed method depends on the number of ports $A$ connected to the load and power supply, which can be expressed as $O(2A)$ since there are power supply and load nodes. The sequential method also depends on the number of VG-Hub units because it sequentially adds edges to the nodes representing the number of ports $A$ and each VG-Hub unit connected to the load and power supply. Thus, the sequential method can be expressed as $O(NA)$. The results are shown in Figure 3(a). The horizontal axis is the number of VG-Hub units, and the vertical axis represents the computational complexity. It can be seen that the computation time of the proposed algorithm is smaller than that of the sequential algorithm. The blue line in Figure 3 represents the proposed method, and the orange line represents the sequential method. The measured values were measured in MATLAB using tic and toc functions. The results are shown in Fig. 3(b). The proposed algorithm was faster by approximately 0.002 s during the actual measurement.
5 Conclusion
In this paper, we propose a graph-generation method for maximum flow derivation. The proposed method and sequential method were quantitatively evaluated and compared. The maximum flow rate can be easily derived using the proposed method. However, the proposed method is not necessarily faster than the sequential method. Therefore, in future work, we plan to increase the number of VG-Hub units to 10 to demonstrate the superiority of the proposed method.

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