ISSN: 2586-7652 (Print) Vol. 06, No. 01, March 2023
ISSN: 2635-7607 (Online)
International Journal of Advanced Engineering
Source: http://ictaes.org
Manuscript received: January 25, 2023; Revised: February 16, 2023; Accepted: March 2, 2023

Energy Flow Control Scheme for a Multiple Microgrids Network Integrating a Virtual Power Plant Model

Yeonwoo Lee

Dept. Of Information & Communication Engineering, Mokpo National University, Korea

ylee@mokpo.ac.kr

Abstract

In the context of the renewable distributed energy resources such as photovoltaic (PV) and wind turbine (WT), an efficient energy flow control scheme is regarded as a key technology in the multiple microgrids (MGs) network, which integrated into a virtual power plant (VPP). The energy flow control and management is a very inevitable issue to mitigate the power fluctuation. This paper presents the effect of energy flow control scheme in a VPP mode, in order to mitigate the power peak and power fluctuation. This paper presents the simulation result of power profiles of the renewable distributed energy resources. It is concluded that the proposed scheme shows the efficient energy flow control.

Keywords : *Microgrid Network, Virtual Power Plant, Regenerated Energy Resources, photovoltaic (PV), wind turbine (WT).*

1. Introduction

Recently, the concept of microgrid network (MG) which is well known as a promising way to guarantee a reliable energy supply and demand of users can be realized by aggregating conventional generators, renewable energy systems (RESs), and energy storage systems (ESS) along with different loads. One of most generally considered RESs is a photovoltaic (PV) prosumer utilizing solar power. A smart microgrid is defined as an energy production sources such as distributed energy resources (DERs), energy storage (battery) facilities, energy flow/distribution management such as microgrid operator (MGO). In general, the MGO is regarded as a traditional energy management of the microgrid, aiming at minimizing the cost of the distributed renewable energy sources (D-RESs) as well as energy pricing cost.

Corresponding author: Yeonwoo Lee
Author's affiliation: Dept. of Information & Communication Engineering, Mokpo National University, Korea
Email: ylee@mokpo.ac.kr
Copyright © ICT-AES

The virtual power plant (VPP) is believed to providing highly efficient power service to customers through virtually sharing of these dispersed DERs, and battery storage units in microgrids (MGs). An energy control system such as energy management system (EMS) has an important role in a MG in order to operate MG's components and DERs efficiently, and to achieve the goals of sustainability in the EMS are economic operation, reliability, and environmental impact. An energy flow control (EFC) has an important role in a MG in order to operate MG's components and DERs efficiently. The major goals of sustainability in the EMS are economic operation, reliability, and environmental impact, which is usually economically related to minimizing the operating costs of the MG or maximizing its income. However, due to new regulations of the network operators, a new objective related to the minimization of power peaks and fluctuations in the power profile exchanged with the utility network has taken great interest in recent years.

A microgrid is a small-scale energy system that can generate, store, and distribute electricity locally. Microgrids are gaining popularity due to their ability to operate independently from the main power grid, and their potential to integrate renewable energy sources. Efficient energy management is essential for the optimal operation and management of a microgrid. Energy flow control is a critical aspect of energy management in microgrids. Energy flow control involves managing the energy flow between the various components of the microgrid, such as generators, energy storage systems, and loads.

Thus, an optimization problem to minimize the operating costs of the MG or to maximize its income is the major open issue to be discussed. For this operating of optimization procedure, we should take into account the adjustment parameters to control the performance of the EMS, as well as considering DERs, the overall income. Of course, it is guaranteed only if the power peaks and fluctuation in the power profile is minimized or stable with certain utility. Therefore, the parameter adjustment becomes an optimization problem, which can be formulated in terms of a cost or utility function to be solved by the metaheuristic nature-inspired algorithms.

2. Related Works

Recently a new objective related to the minimization of power fluctuations in the power flow exchanged with the utility network has taken a great interest [1-3]. Hence, the VPP can contain distributed renewable energy power plants (DERs), traditional fossil–fuel-fired power plants (i.e., conventional heat-power plant (CHP)), energy storage facilities, and dispatchable loads. VPP can consist of a hierarchical aggregation of MGs [4, 5]. To achieve a fair power curtailment, the decentralized method is proposed in [6] and the centralized distributed optimal power flow (DOPF) strategies are proposed in [7]. An alternative approach of fair power curtailment combined DOPF is presented in [8] which suggests three equity redistribution principles, egalitarian, proportional and uniform curtailment.

3. Methodology

3.1. Microgrid

Compared to the existing power system, in a microgrid, energy prosumers have emerged who produce and supply electricity directly from among the existing power consumers. However, a phenomenon of decreased efficiency occurred as most of the surplus electricity produced could not be utilized and had to be discarded. However, microgrids are a technology that maximizes the energy of the entire network by utilizing the energy produced by these prosumers. With the participation of multiple prosumers based on bidirectional power

transmission and distribution, stable power supply becomes possible as power is dispersed. It also enables the efficient use of renewable energy. Therefore, the spread of energy prosumers can reduce the burden of central power generation (coal, nuclear power, etc.), ensure the stability of power supply, and reduce power demand-side costs. Smart grids consist of smart meters (AMI, Advanced Metering Infrastructure), energy management systems (EMS), energy storage systems (ESS), electric vehicles and charging stations, distributed support, renewable energy, bidirectional communication technology, and intelligent power transmission and distribution systems, as shown in Figure 1.



Figure 1. Conceptual Model of Smart grid by KESG Organization [9].

3.2. Multiple Microgrid Network

Microgrid networks are designed to improve stability and efficiency by producing electricity through small-scale generation facilities such as solar panels and small wind turbines. They are typically composed of local interconnection communities, university campuses, small buildings, small industrial parks, remote islands, etc., where power is generated, used, and stored locally. The renewable energy sources within the microgrid are typically produced by PV, fuel cells, small wind turbines, etc., collectively known as distributed energy resources (DERs). Figure 2 shows the components of the microgrid network considered in this paper.

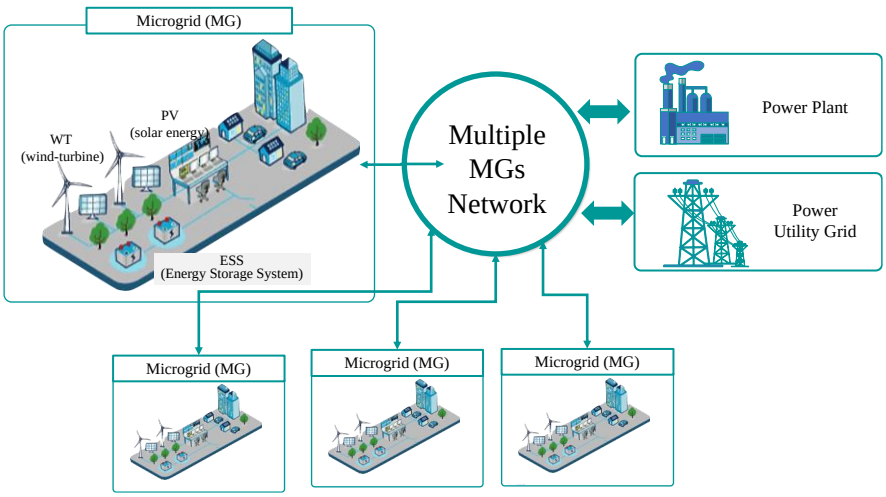


Figure 2. Model of multiple microgrid network.

3.3. Virtual Power Plant Model

The VPP can consist of multiple microgrids and also, it can hierarchically aggregate MGs and DERs. The energy control system in VPP with EFC (Energy Flow Control) is shown in Fig. 3.

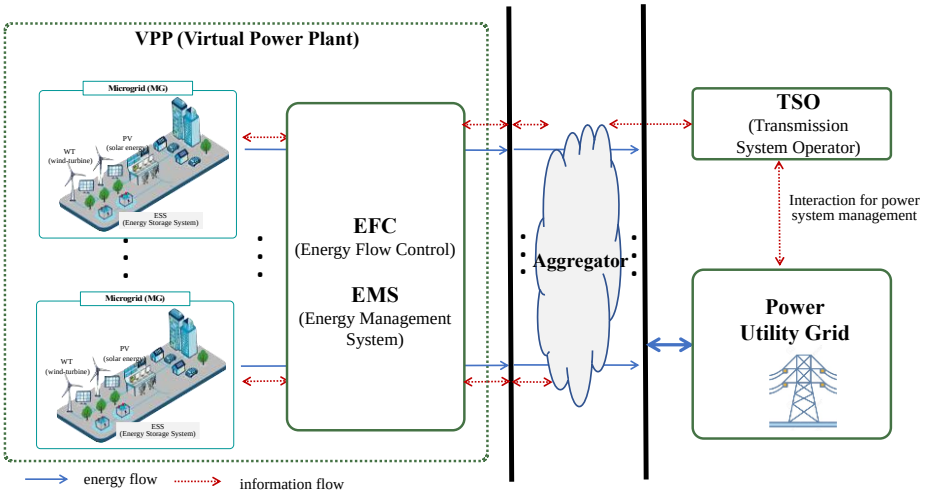


Figure 3. Virtual power plant Model with Energy Flow Control.

To achieve a fair energy control and curtailment, an efficient algorithm of estimating long-term (one-day ahead) and short-term (15 min. and 60 min. basis) power schedule is very essential. Thus, the efficient EFC application incorporating a fair DERs offering strategy applying the EFC seems alternative efficient approach for energy estimation in a VPP network.

The VPP can consist of separate DERs, traditional CHP, energy storage facilities, and dispatchable loads and also, it can hierarchically aggregate MGs and DERs. The structure of VPP is shown in Fig. 3. To achieve a fair power curtailment, a decentralized method and the centralized distributed optimal power flow strategies are proposed in [3, 4]. An alternative approach of fair power curtailment is presented in Fig. 3 which suggests three equity redistribution principles, egalitarian, proportional and uniform power curtailment. While those fair redistribution approaches contributed on achieving certain level of curtailment of the power peaks and fluctuation, the overall optimization profit of generating revenue on the energy market could not be sufficiently considered. Thus, the efficient EMS application incorporating a fair DERs offering strategy applying the EMS (Energy Management System) seems alternative efficient approach for power curtailment in a VPP network.

3.2. Objective Function in VPP

Many research on trying to solve problems of energy resource optimization in VPPs to either minimize the cost of VPP revenue and minimize the power fluctuation. The objective function is re-written as:

$$\min_{\boldsymbol{w}} f(\boldsymbol{w}, t) \qquad \min_{\boldsymbol{w}} \sum_{t=1}^{T} [\mathcal{S}(\boldsymbol{w}, t) + \mathcal{E}(t)] \,. \tag{1}$$

The total amount of surplus energy $\mathcal{S}(t)$ can be defined as

$$\mathcal{S}(t) = L(t) - \sum_k^K \tilde{P}_{PV,WT,CHP\,(k)}\,(t) \quad (2)$$

and the DER constraints and energy cost are respectively,

$$P_{PV,WT,CHP}^{min}\,(t) \leq \tilde{P}_{PV,WT,CHP\,(k)}(t) \leq P_{PV,WT,CHP}^{max}\,(t) \quad (3)$$

$$\mathcal{E}(t) = \sum_{t=1}^{\mathcal{T}} \left\{ \sum_k^K \tilde{P}_{PV,WT,CHP\,(k)}\,(t) \cdot C_k + P_{b_{grid}}(t) \cdot C_{b_{grid}}(t) - P_{s_{grid}}(t) \cdot C_{s_{grid}}(t) \right\} \quad (4)$$

4. Results and Analysis

4.1. Simulation Model: Microgrid Network Topology

To evaluate the robustness of microgrid systems, a program tool that can configure network topology should be used. This paper visualizes the process using Python and the NetworkX library. The following steps are involved in constructing a micro network:

- Microgrid system modeling: A microgrid network model is constructed using a network program tool, including system components and connectivity status.
- Simulation environment setup: After modeling, the simulation environment is set up, including the network nodes and edges, initial vectors, transition probability matrix, and simulation iteration count.
- Simulation execution: Once the setup is complete, simulation is performed using the Python program tool and the NetworkX library.
- Result analysis: After simulation, the results are analyzed to evaluate the system's robustness.
- The microgrid network considered in this paper consists of 20 microgrids as nodes in network theory, with power transmission lines (or energy flow) connecting each microgrid as links.

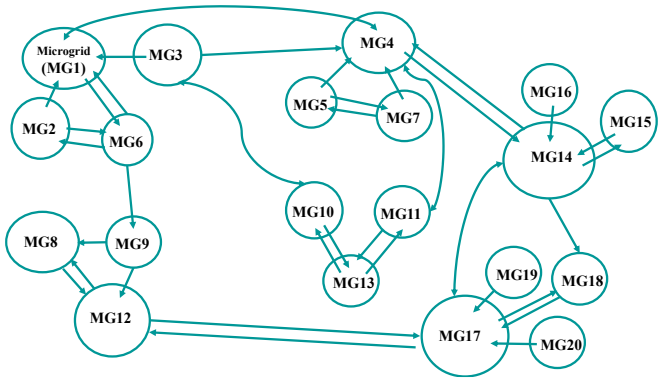


Figure 4. Micro Grid Network Configuration with 20 Nodes.

One way to consider the relative "importance" of nodes within the microgrid network is to measure how much damage the network structure would suffer if a particular node were removed. Node removal could occur due to network failure, attacks, or overload caused by weather or other factors.

4.2. Simulation Result

This paper presents the effect of power offering strategy in a Virtual Power Plant (VPP) model which consists of multiple DERs (Distributed Energy Resources) such as photovoltaic (PV) and wind turbine (WT). Simulation

result of power profiles of DERs with three different active power offering strategies in VPP is presented in Fig. 5. As shown in Fig. 5, it is concluded that the Egalitarian re-Distribution (ED) shows the most fairly energy flow control scheme in VPP network.

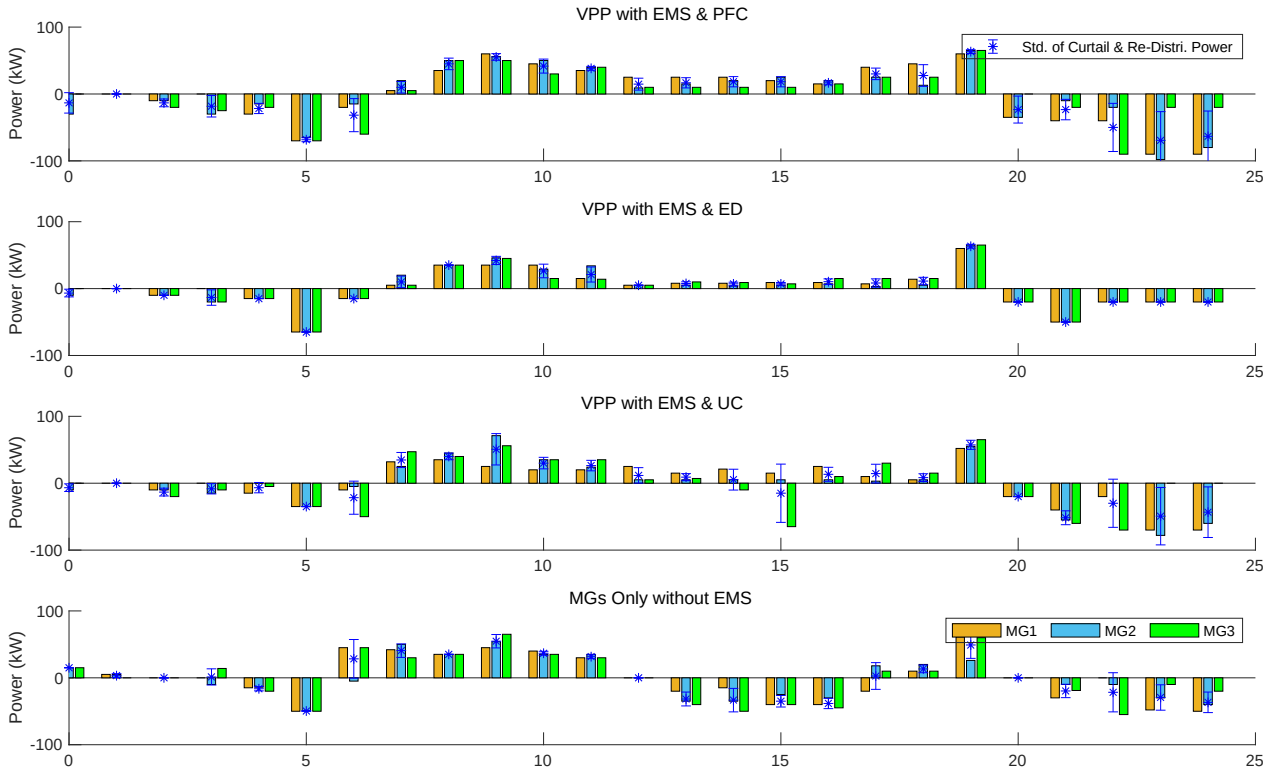


Figure 5. Simulation Result of three MGs in a VPP network with energy flow control.

7. Conclusion

This paper presents the effect of energy flow control scheme for the multiple microgrids (MGs) network, which integrated into a virtual power plant (VPP) with the renewable distributed energy resources such as photovoltaic (PV) and wind turbine (WT). The aim of energy flow control and management is to mitigate the power fluctuation. This paper presents the simulation result of power profiles of the renewable distributed energy resources according to energy flow variation scenario with 20 MG nodes network model. It is concluded that the proposed scheme shows the efficient energy flow control. It is concluded that the Egalitarian re-Distribution (ED) shows the most fairly energy flow control scheme in VPP network.

References

[1] Alyami S, Wang Y, Wang C, Zhao J, Zhao B. (2015). Adaptive real power capping method for fair overvoltage regulation of distribution networks with high penetration of PV systems. IEEE Trans Smart Grid, 5(6), 2729–2738.

[2] Liu M, Procopiou A, Petrou K, Ochoa L, Langstaff T, Harding J, et al. (2020). On the fairness of PV curtailment schemes in residential distribution networks. IEEE Trans Smart Grid 2020.

[3] Lusis P, Andrew LLH, Chakraborty S, Liebman A, Tack G. (2019). Reducing the unfairness of coordinated inverter dispatch in PV-rich distribution networks. In Proceedings of 2019 IEEE milan Powertech (pp. 1–6). IEEE.

[4] Gebbran, D., Mhanna, S., Ma, Y., Chapman, A. C., & Verbič, G. (2021). Fair coordination of distributed energy resources with Volt-Var control and PV curtailment. Applied Energy, 286, 116546.

[5] Hatziargyriou, N., Asano, H., Iravani, R., & Marnay, C. (2007). Microgrids. IEEE power and energy magazine, 5(4), 78-94.

[6] Lee, Y. (2022). Energy Management System with Power Offering Strategy for a Microgrid Integrated VPP. Accepted to be published, Computers, Materials and Continua.

[7] Elmouatamid, A., Ouladsine, R., Bakhouya, M., Zine-Dine, K., & Khaidar, M. (2019, October). A control strategy based on power forecasting for micro-grid systems. In 2019 IEEE International Smart Cities Conference (ISC2) (pp. 735-740). IEEE.

[8] Fan, D., Sun, H., Yao, J., Zhang, K., Yan, X., & Sun, Z. (2021). Well production forecasting based on ARIMA-LSTM model considering manual operations. Energy, 220, 119708

[9] Simens. https://new.siemens.com/kr/ko/products/energy/topics/smart-grid.html. (2023.03.01)