Determination of the Maximum Power Generation of Renewable Energy Generating Units in an Islanded Microgrid

Wen-Chih Yang
Department of Electrical Engineering
Technology and Science Institute of Northern Taiwan
Taipei, R.O.C

Wei-Tzer Huang
Department of Electrical Engineering
Chienkuo Technology University
Taipei, R.O.C

***Abstract*—Renewable energy generating units (REGNs) are widely used in microgrids (MGs). REGNs can reduce the operating cost of a MG; they also affect the operating states of the connected grids, especially the voltages. The larger the power generation of REGNs, the greater the impact on voltage of MGs. Therefore, the power generation of a REGN in a MG should be limited for the grid security. In the current study the binary search method is employed to determine the maximum power generation of REGNs in an islanded MG considering the current and voltage limits. The algorithm for determining the maximum power generation of a REGN without violating the current and voltage limits is presented. The practical applicability of the presented algorithm is demonstrated using an example MG with a 380V radial distribution feeder. Simulation results are also presented and discussed in this paper.**

Keywords-renewable energy; microgrid; binary search

I. INTRODUCTION

A microgrid (MG) is a small-scale power system composed of electric power generating sources, switchgears, conductors, protective facilities, control devices, loads, and so on. The sources of electric power generate sufficient electric power to meet the demand of all loads in the MG. The switchgears control the connection of the conductors in the MG. The protective facilities protect the safety of the MG when faults occur. The control devices control the generation of electric power in the source and the voltage, frequency, and power flow of the MG [1–4].

A MG can operate independently or with an adjacent power distribution system in parallel. The former is called a grid-tied mode and the latter is called an islanded mode. A MG generally contains renewable energy generating units (REGNs) such as wind generation systems (WGSs) or photovoltaic generation systems (PGSs). REGNs can provide clean energy and reduce the fuel cost of MGs; however, they also tend to make the voltages of MGs unstable. The larger the power generation of REGNs, the greater the impact on voltage of MGs. Once the variation of voltages becomes too large, the security of the MGs may be compromised [5,6]. For this reason, the power generation of REGNs in a MG needs to be limited to protect the integrity of the MGs.

In the current study, the binary search method is employed to determine the maximum power generation of REGNs in a MG operating in an islanded mode. The algorithm for determining the maximum power generation of a REGN without violating the current and voltage limits is presented. An example MG with a 380V radial distribution feeder is used to demonstrate the practical applicability of the presented algorithm via computer simulations. Simulation results are also presented and discussed.

II. THE ALGORITHM FOR SEARCHING THE MAXIMUM POWER GENARATION OF REGNS

A binary search, also called a half-interval search algorithm, is a method to search for a specific value from an array. The specific value is called the key value. The values in the array to be searched must be sorted before the binary search work can begin. When starting a binary search work, the first step is to compare the key value with the middle element of the array. The comparison determines whether the element is equal to, less than, or greater than the key value. If the answer is equal, the search work stops; otherwise, the algorithm determines whether the middle element is lesser than or greater than the element. If the middle element is greater, the search work starts over and searches only the top subset of the array elements. If the middle element is lesser, the search work searches only the bottom subset. These search steps are repeated until the key value is found [7–9].

The maximum power generation of a REGN in a MG can be determined using binary search method and power flow analysis. The algorithm is as follows.

1. Eq. (1) is used to calculate the maximum interconnection capacity, S_{max}, of a REGN:

$$S_{max} = \sqrt{3} \times V_{ll} \times I_{ap} \quad (1)$$

where V_{ll} is the line-to-line voltage of the distribution feeder which connects the REGN to be searched in the MG and I_{ap} is the ampacity of a distribution feeder connected to the REGN to be searched in the MG.

978-1-4244-9438-5/11/$26.00 ©2011 IEEE

2. The search range of S_{min} to S_{max} is defined, where S_{min} is the minimum value to be searched.
3. The minimum scale, ΔS_{sca}, for searching is defined.
4. Eq. (2) is used to calculate the key value, S_{key}:

$$S_{key} = \frac{S_{min} + S_{max}}{2} \quad (2)$$

5. The power generation of the REGN to be searched is set as S_{key}.
6. A power flow program for the MG is executed to solve for the voltage of the interconnection point of the REGN.
7. The magnitude of the voltage is determined if it is greater than the voltage limit.
8. If yes, let $S_{max} = S_{key}$ and go to Step 4.
9. Otherwise, let $S_{min} = S_{key}$ and (3) is used to calculate the power difference, ΔS_{pd}:

$$\Delta S_{pd} = S_{max} - S_{min} \quad (3)$$

10. The power difference is determined if it is greater than the minimum scale.
11. If yes, go to Step 4.
12. Otherwise, the maximum power generation of the REGN is found. The algorithm stops.

III. The Example MG

Figure 1 shows the single-line diagram of the example MG. This example MG contains one diesel engine generator (DEG) set, one or more WGSs, a power transformer, circuit breakers (CBs), a distribution feeder and the loads. When the MG operates in an islanded mode, the DEG and WGSs act as the main and auxiliary electric power sources, respectively. The DEG ratings are 300 kVA and 380 V. The WGS are all identical in rating (i.e., 200 kVA and 380 V). The DEG and WGSs are all installed with power controllers to control their power output. The power transformer has a capacity of 500 kVA, and nominal voltages of 11.4 k and 380 V on the primary and secondary side, separately. The primary and secondary windings connect with the utility grid and the distribution feeder separately. The distribution feeder has a length of 500 m. There are 10 virtual buses on the distribution feeder at distance intervals of 50 m. Each bus connects with a load of 25 kVA with 0.8 lagging power factor. Therefore, the total load of the example MG is 250 kVA. The main parameters of the distribution feeder are shown in Table I.

TABLE I. Parameters of the Distribution Feeder in the Example MG

Cross section	Diameter	Material	Impedance	Ampacity
200mm^2	15.958mm	Copper	0.101+j0.092Ω	300A

Under normal conditions, the example MG operates in a tied-grid mode; therefore, the DEG is disconnected from the MG. In abnormal conditions, this MG operates in an islanded mode; therefore, the DEG is connected to the MG and supplies electricity to loads. The WGSs can be connected with the MG in any operating mode. Because they depend on the needs of related studies, the number and connection locations of WGSs are described in the following section.

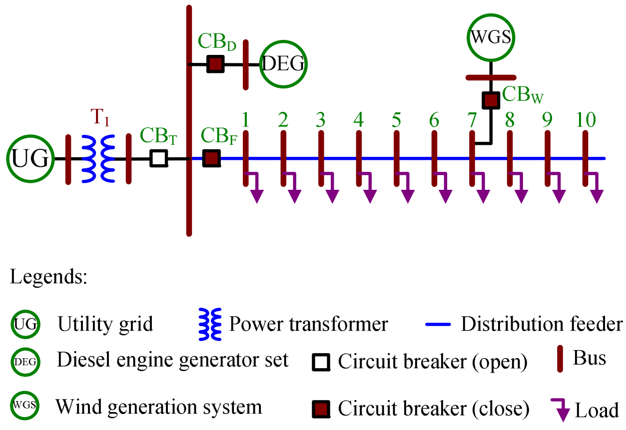

Figure 1. Single-line diagram of the example MG.

IV. Scenarios and Simulation Results

This paper employs two scenarios and several sub-scenarios to demonstrate the practical applicability of the proposed algorithm. The definitions of scenarios and simulation results are described below.

A. Scenarios

1) Scenario 1:

There is only one WGS in the MG. The WGS is in turn connected to the buses on the distribution feeder of the MG. Constraints for searching the maximum power generation of the WGS are defined in the following subscenarios.

a) Subscenario 1.1:

The current limit of the distribution feeder in the example MG is considered; however, the voltage limit is not. The thermal limit of the distribution feeder in the example MG is 300A.

b) Subscenario 1.2:

Both the current and voltage limits of the distribution feeder in the example MG are considered. The voltage limit is ±5% of the nominal voltage.

2) Scenario 2:

There are three WGSs in the example MG. The three WGSs are connected to Buses 3, 6, and 10 on the distribution feeder, respectively. Constraints for searching the maximum power generation of the WGS are the same as in Scenario 1. The power generation of WGS_A is known and defined in the following subscenarios.

a) Subscenario2. 1:

WGS_A exports 50kW of electric power.

b) Subscenario 2.2:

WGS_A exports 100kW of electric power.

c) Subscenario 2.3:

WGS_A exports 150kW of electric power.

d) Subscenario 2.4:

WGS_A exports 200kW of electric power.

B. Simulation results

1) Scenario 1:

Figure 2 shows the connecting location of a WGS in the example MG. Figure 3 shows the simulation results of Scenario 1. The results of Subscenario 1.1 show that the maximum power generation of the WGS in the example MG is 200kW regardless of the bus to which the WGS is connected. These results are only obtained by considering the current limit. In practice, a REGN with a large capacity is not suitable for connection to the end of a distribution feeder. The connecting location is closer to the end of a distribution feeder, and the effect on the feeder voltage is larger. Figure 4 shows the voltage profiles of the distribution feeder in the example MG when a WGS with a capacity of 200kW connected to buses 6 and 10, respectively. This figure points out that when the WGS is connected to the middle or end of the distribution feeder in the example MG, the magnitude of voltage exceeds the voltage limit.

The results of Subscenario 1.2 show that the maximum power generation of a WGS connected to the buses along the distribution feeder becomes gradually smaller if both the current and voltage limits of the distribution feeder are considered. The smaller power generation can ensure that the WGS connected to the end of a distribution feeder does not make the feeder voltage exceed the voltage limits.

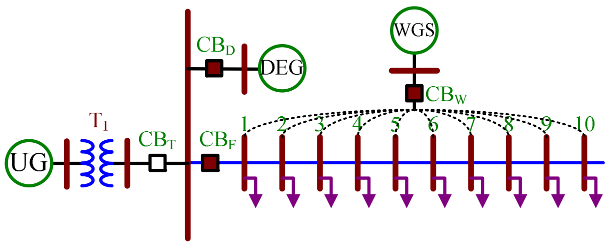

Figure 2. Connecting location of a WGS in the example MG.

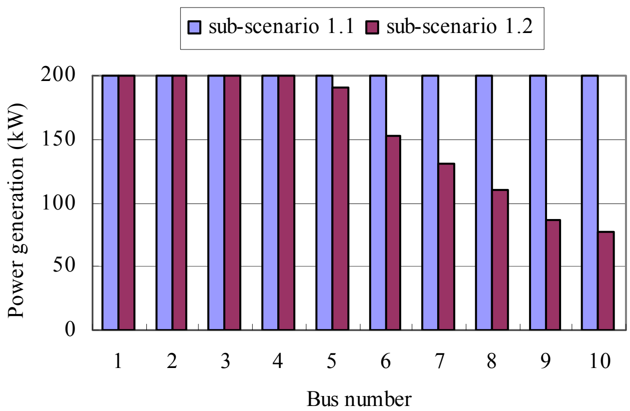

Figure 3. Simulation results of Scenario 1.

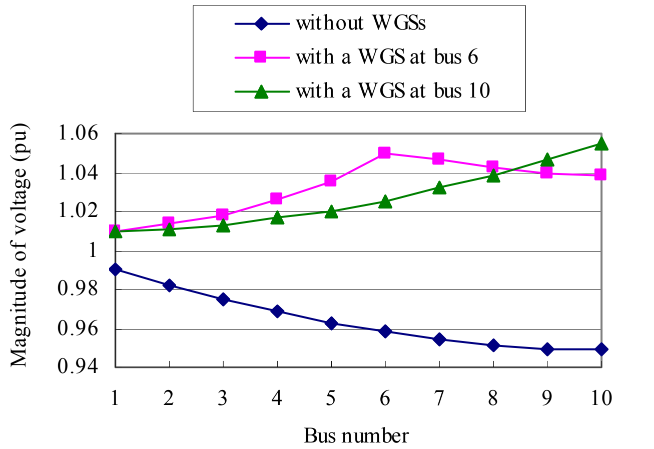

Figure 4. The voltage profiles of the distribution feeder in the example MG when a WGS with a capacity of 200kW was connected to buses 6 and 10, respectively.

2) Scenario 2:

Figure 5 shows the connecting locations of the three WGSs in the example MG. Figure 6 shows the simulation results of Scenario 2. This figure points out that the former WGS affects the maximum power generation of the latter WGS. If the maximum power generation of the former WGS is larger, the latter WGS becomes smaller, sometimes reaching a value of zero. Conversely, if the maximum power generation of the former WGS is smaller, the latter WGS becomes larger.

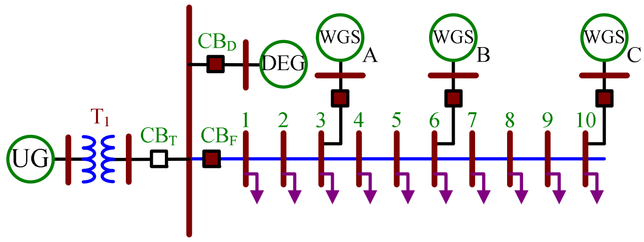

Figure 5. Connecting locations of three WGSs in the example MG.

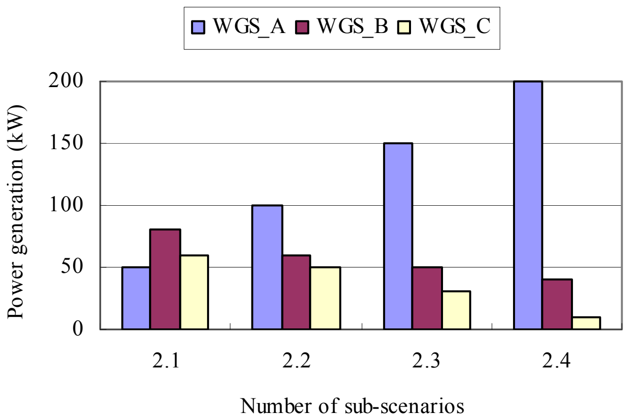

Figure 6. Simulation results of Scenario 2.

V. CONCLUSIONS

The binary search algorithm for determining the maximum power generation of REGNs in an islanded MG without violating current and voltage limits has been presented in this paper. A MG with a 380 V radial distribution feeder was employed to demonstrate the practical applicability of the presented algorithm. The simulation results point to three conclusions. First, the maximum power generation of a REGN considering both current and voltage limits is smaller than that considering only the current limit. Second, when the connecting location of a REGN is different, its maximum power generation is also different. Third, when more than one REGN is connected to a distribution feeder in a MG, a larger maximum power generation by the former REGN results in a smaller one by the latter REGN. Conversely, if the maximum power generation of the former REGN is smaller, that of the latter REGN becomes larger.

In promoting the penetration level of renewable energy in power distribution systems, an increasing number of REGNs are being connected to MGs to supply clean electricity [10]. In order to maintain the integrity of MGs, determining the maximum power generation of REGNs in an islanded MG under security requirements has become an important task for power engineers. Therefore, the presented algorithm for searching the maximum power generation of REGNs in an islanded MG is very useful for power engineers in planning and operating their MGs.

ACKNOWLEDGMENTS

The authors thank the National Science Council of the Republic of China, Taiwan, for financially supporting this research under Contract No. NSC 97-2221-E-149-010-MY3.

REFERENCES

[1] R. H. Lasseter and P. Paigi, "Microgrid: A Conceptual Solution," IEEE 35th Annual Power Electronics Specialists Conference, vol. 6, pp.4285-4290, June 2004.

[2] R. H. Lasseter, "MicroGrids," IEEE Power and Energy Magazine, vol. 5, pp.78- 94, July-August 2007.

[3] H. Jiayi, J. Chuanwen and X. Rong, "A Review on Distributed Energy Resources and MicroGrid," ELSEVIER Renewable and Sustainable Energy Reviews, vol.12, issue.9, pp.2472-2483, December 2008.

[4] W. C. Yang, and S. Y. Lee, "Development of Operational Procedures of Distributed Generation Sources in a Micro-Grid" IEEE 4th International Conference on Genetic and Evolutionary Computing, pp.48-488, December 2010.

[5] P. Fuangfoo, T. Meenual, W. J. Lee and C. Chompoo-inwai, "PEA Guidelines for Impact Study and Operation of DG for Islanding Operation," IEEE Transactions on industry applications, volL. 44, no. 5, pp.1348-1353, September/Octorber 2008.

[6] W. C. Yang, T. H. Chen and J. D. Wu, "Effects of Renewable Distributed Generation on the Operational Characteristics of Meshed Power Distribution Systems," WSEAS Transactions on Power Systems, vol.4, pp.136-145, April 2009.

[7] S. V. Nagaraj, "Optimal Binary Search Trees," ELSEVIER Theoretical Computer Science, vol.188, issue.1-2, pp.1-44, November 1997.

[8] K. Zamanifar and M. Koorangi, "Designing Optimal Binary Search Tree Using Parallel Genetic Algorithms," International Journal of Computer Science and Network Security, vol.7 no.1, pp.138-146, January 2007.

[9] T. P. Wang, "Enhanced Binary Search with Cut-through Operation for Anti-collision in RFID System," IEEE Communications Letters, vol. 10, issue. 4, pp.236-238, April 2006.

[10] S. M. Hashemi-Toghroljerdi and A. Ebrahimi, "Impact of Wind Power Penetration on Transients and Dynamics of Micro-grids due to Wind Turbine Structures and Operation Constraints" IEEE 2nd International Power and Energy Conference, pp.1581-1585, December 2008.