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The Optimal Network Configuration to Operate Economical Electric Stations

Sung-Yong Lim*, Jin-Gyu Seo*, Kyu-Ho Kim*, and Charles Kim**

Abstract– This paper presents the optimal network configuration for electric stations using HOMMER software. For the given data such as annual average wind speed and grid costs, this software calculates the NPC (Net Present Cost), operating cost and COE (Cost of Energy). Based on these simulation results, it is possible to find the optimal network configuration for electric stations and analyze the final result. When the rising grid cost is considered it is essential to use grid and renewable energy together. Depending on the increase of the grid cost, NPC of the configuration using renewable energy and grid can be gradually getting smaller than NPC of the configuration using grid only.

Keywords: Electric Stations, HOMER, Net Present Cost, Cost of Energy

1. Introduction

Electricity grid is an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations that produce electrical power, high voltage transmission lines that carry power from distant source to demand centers, and distribution lines that connect individual customers. Recently, the charging stations for electric vehicles have been built in a lot of areas, so supplying electricity to the charging stations becomes an issue in many researches. One of the methods to supply electricity to charging stations is to use electricity grid that is mostly generated by thermal power. Because fossil fuel for producing electricity of grid is finite, the renewable energy generation system connected to electricity grid is necessary.

In addition to this, because the pollution gas from the fossil fuel plants such as carbon monoxide and carbon dioxide and so on, causes many environmental problems like global warming, fossil fuel use in electricity generation is being greatly discouraged by rules and standards such as Korea's RPS (Renewable Energy Portfolio Standard) [1]. Therefore, distributed generation systems using renewable energy are getting more popular these days. In EU, Almost all the electrical energy will be produced by renewable energy sources in 2050 [2]. In renewable energy, especially, the wind power generation has been popular in the world and the ratio of the wind power has continuously increased [3]. However, generation systems using only renewable energy sources have a problem: intermittency and reliability. When generation systems supply electrical power to consumer, it is important to supply power more than amounts of demand. However, there is a limit to what renewable energy can satisfy this condition because renewable energy production depends on the weather condition. Whereas, supplying electrical power to consumer with only grid also has some problems since fossil fuel resource for production of electrical energy is emitting gases which may contribute global warming and other environmental problems. However, these problems can be solved by introducing a micro-grid (MG). Usually, MG consisting of the wind power generators, PV and so on, is connected to grid and can be installed in the place closed to consumers. So MG can reduce installation cost, maintenance cost, and energy losses in transmission and distribution. Furthermore, because MG is connected to grid it attains much needed stability and reliability. When MG is introduced, it is reported that power quality increases [4-9]. Recently, electric vehicles are being widely adopted, so we set the electric charging stations as the object for our research in seeking what microgrid configuration would be the optimal and economical under different conditions of sources, costs, and other factors. We utilize a renewable energy simulation software HOMER in the analysis. This paper presents the analysis result on the MG configurations which are most suitable for the given conditions like wind speed and grid cost. The paper also presents sensitivity analysis which in its essence, depending on the rising grid price and the MG sites, what and how much renewable energy would be needed under the changed economical environments. Based on this consequence, we propose the most optimal network configuration of microgrid for electric stations.

2. System Configuration

HOMER is the program which can help design optimal network configuration depending on specific weather condition such as solar radiation and wind speed, etc. It is the micropower optimization model developed from

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American's NREL (National Renewable Energy Laboratory). It calculates all combined system's NPC (Net Present Cost) and shows these results in ascending order of price.

2.1 Cost of Energy & Net Present Cost

The NPC includes all costs and revenues that occur within the project lifetime, with future cash flows discounted to the present. Any revenue from the sale of power to the grid reduces the total NPC. Cost of Energy (COE) is the constant unit cost of a payment stream that has the same present value as the total cost of building and operating a generating plant over its life. The NPC and COE are calculated by (1), (2) [10].

$$C_{NPC} = \frac{C_{ann.tot}}{CRF(i,N)} \quad CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{1}$$

$$COE = \frac{C_{ann.tot}}{E_{prim} + E_{def} + E_{grid.sales}} \tag{2}$$

E_{Prim} : Total amounts of primary load

E_{def} : Total amounts of deferrable load

$E_{grid.sales}$: The amounts of energy sold to the grid

$C_{ann.tot}$: Total annualized cost

$CRF(i,N)$: The capital recovery factor

i : The annual real interest rate

N : The project time

2.2 Solar Power Generation

Solar power generation P_{PV} is calculated as follows. In this paper, we assume that PV derating factor is 90%, and lifetime is 20 years.

$$P_{PV} = f_{PV} Y_{PV} \frac{I_T}{I_S} \tag{3}$$

f_{PV} : PV derating factor

Y_{PV} : Rated capacity [kW]

I_T : Global solar radiation incidence on the surface of the PV array [kW/m^2]

I_S : Standard amount of radiation [kW/m^2]

PV annual cost C_{PV} is calculated as follows:

$$C_{PV} = C_P \cdot [\frac{i(1+i)^n}{(1+i)^n - 1}] + OM \tag{4}$$

C_P : The principal amount.

OM : The operation and maintenance cost.

i : The interest rate

n : The loan term

2.3 Wind Power Generation

We used two wind turbine models, Generic 3kW and 10kW. Lifetime is 15 years and Wind Power Generation is calculated by

$$P_{Wind} = C_P \cdot \frac{1}{2} \rho A v^3 \tag{5}$$

C_P : Power Coefficient

ρ : The density of air

A : The swept area [m^2]

v : Wind speed [m/s]

Wind power generation's annual cost C_{Wind} is calculated as follows:

$$C_{Wind} = C_P \cdot [\frac{i(1+i)^n}{(1+i)^n - 1}] + OM \tag{6}$$

C_P : The principal amount.

OM : The operation and maintenance cost.

i : The interest rate

n : The loan term

2.4 Battery

There are two types of dispatch strategy for battery bank. One is Load-following dispatch strategy and the other is Cycle-charging strategy. Load-Following dispatch strategy means renewable power sources charge the battery but the generators do not. Cycle charging strategy represents that the generators operate and they produce more power than required to serve the load with surplus electricity going to charge the battery bank. Battery wear cost is calculated as follows.

$$C_{bw} = \frac{C_{rep,batt}}{N_{batt} Q_{lifetime} \sqrt{\eta_{rt}}} \tag{7}$$

$C_{rep,batt}$: The replacement cost of the battery bank

N_{batt} : The number of batteries in the battery bank

$Q_{lifetime}$: The lifetime throughput of a single battery [kWh]

η_{rt} : The round-trip efficiency

3. Micro-grid design and simulation

3.1 Micro-grid design

Micro-grid is designed and simulated like Fig. 1 using HOMER. It consists of grid, converter or inverter, wind turbine, photo voltaic and batteries to store the excess electricity.

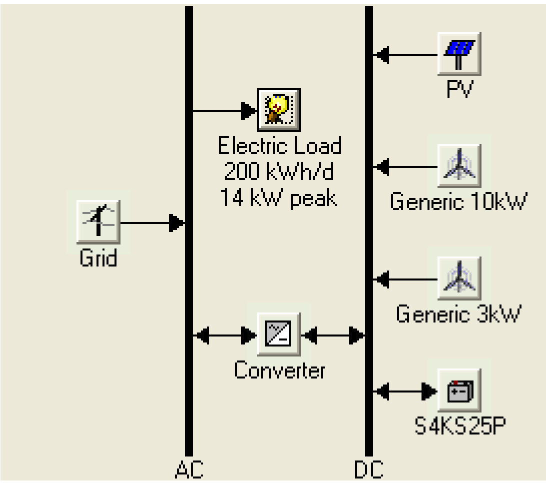

Fig.1. Design of micro-grid configuration

3.2 Micro-grid resources

Daily load profile and Global Horizontal Radiation data is input like Fig. 2 and Fig. 3. However, wind speed is considered as variable in this paper because wind speed is usually different in localities. Therefore, wind speed is considered from 3m/s to 8m/s at intervals of 1m/s.

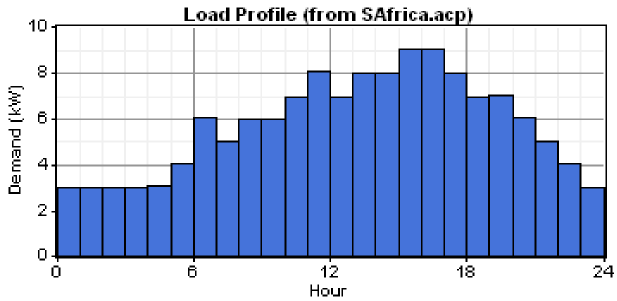

Fig.2. Daily load profile

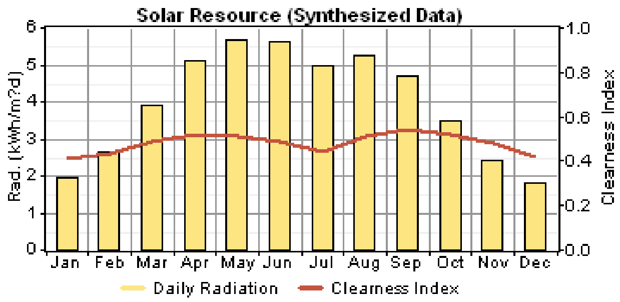

Fig.3. Global Horizontal Radiation

Table 1 shows the sizes of each device to consider in simulation.

Table 1 The sizes of each device to consider

Devices	Sizes
PV [kW]	0, 10, 15, 20, 25, 30, 50, 75
Generic 3kW [EA]	0, 1, 2, 3
Generic 10kW [EA]	0, 1, 2, 3
Battery [kW]	0, 5, 10, 20, 30, 40, 50, 100, 150, 200, 250
Converter [kW]	0, 5, 10, 15, 20

3.3 Micro-grid design

It is simulated using HOMER with data and the consequence is obtained as follows.

Grid Price ($/kWh)	Wind Speed(m/s) 3	4	5	6	7	8
0.3	G	G	G	G	G/W/B	G/W/B
0.4	G	G	G	G/W/B	G/W/B	G/W/B
0.5	G	G	G	G/W/B	G/W/B	G/W/B
0.6	G/P	G/P/B	G/P/W/B	G/P/W/B	G/P/W/B	G/P/W/B
0.7	G/P	G/P/B	G/P/W/B	G/P/W/B	G/P/W/B	G/P/W/B
0.8	G/P	G/P/B	G/P/W/B	G/P/W/B	G/P/W/B	G/P/W/B

Fig.4. Optimal configuration according to the conditions

As you can see in Fig.4, when the grid cost is below 0.5$/kWh and the average wind speed is below 5m/s then it is better to use only grid. However, if the average wind speed is beyond about 4.3m/s, then it is decided whether to install PV or Wind turbine depending on the grid cost. As shown in Fig.4, when the grid cost increases more than 0.5$/kWh in the district where the average wind speed is below 4m/s, it is better to install PV with grid. Also, in the district where the average wind speed is beyond 4.3m/s, and grid cost is beyond 0.5$/kWh, it is better to install wind turbine first and install PV later.

3.4 Comparison of consequence

Fig. 5 is the graph of NPC comparison in the district, where the wind average speed are over 6m/s and below.

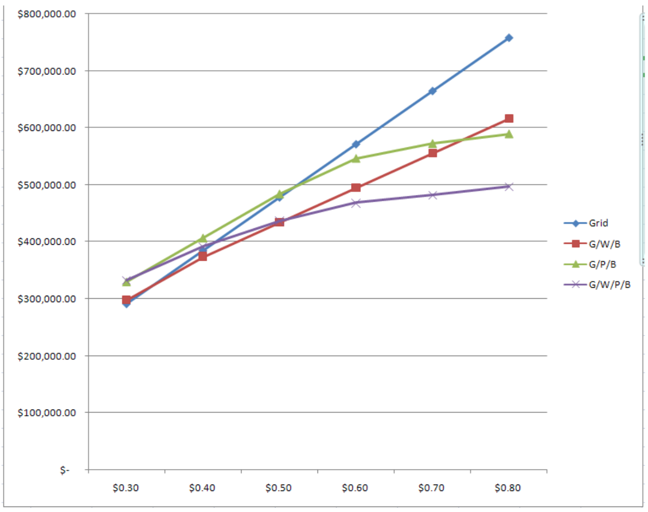

Fig.5. The graph of NPC comparison

Depending on the change of grid price, in supplying the same amount of electric power, it is found the optimal configuration for minimum cost changes. Fig. 6 is the graph of economical microgrid configuration depending on the grid cost. It is advantageous to use only grid, and it is confirmed that all micro-grid configurations have little difference compared with NPC if grid cost is low. However, the more fossil fuel is used, the more grid cost will be expensive. It means that there is a big difference when the grid price is getting high like Fig. 6. Therefore, it needs to ready for the rising grid price by introducing renewable energy.

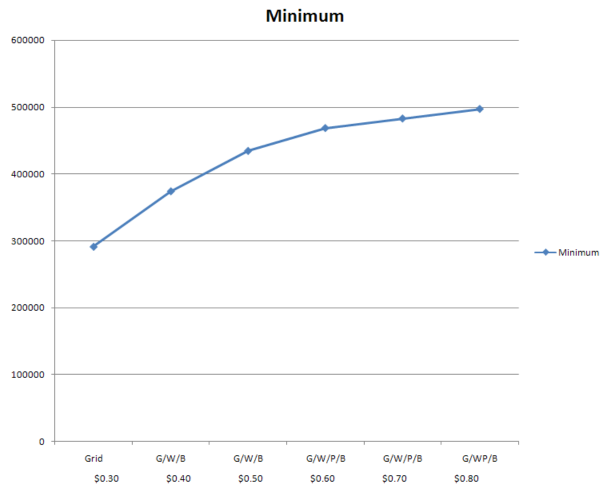

Fig.6. The optimal graph depending on grid cost

4. Conclusion

This paper presents the MG configuration analyses under different grid energy costs and MG site's renewable energy generation capability. Specifically, it is better to use only grid if the average wind speed is below 5m/s and the grid cost is also below 0.5$/kWh. However, if the grid cost is higher than 0.5$/kWh and the average wind speed is below 4.3m/s then it is better to install PV and use PV, grid together. Lastly, in the district where the average wind speed is higher than 4.3m/s and the grid cost is more than 0.5$/kWh, it is better to use wind turbine first and use PV later as grid cost is getting more expensive. This paper considered only two variables, the average wind speed and the grid cost. It could be somewhat inexact, so more variables like the average radiation, the average load profile, and so on will be considered and simulated to obtain more detailed and exact consequence in the later research.

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