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Economic Evaluation of Renewable Energy Systems for the Optimal Planning and Design in Korea – A Case Study

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ABSTRACT

In this study, an engineering economics software was developed to find the optimum design of renewable energy systems in micro-grid, off-grid, and on-grid cases. The software was used to calculate the renewable energy production from photovoltaic and wind turbines in local regions in Korea. TMY2 files were made for the renewable energy calculation based on meteorological data from 28 locations in Korea. To calculate the output of the photovoltaic and the wind turbine, a power generation model based on theoretical equations was developed. A fuel cell and diesel engine generator can be selected to use as a base power source model, and a battery energy storage device was included for efficient energy management. To verify the results of renewable power generations from solar and wind, the models were compared with commercial programs such as TRNSYS and HOMER. The results showed good agreement under the same conditions. A sensitivity analysis for a grid-connected factory in a specific region was carried out and the optimum investment design condition for a renewable energy system to reduce costs through peak load reduction was calculated. The sensitivity analysis for off-grid and grid-connected system designs was also performed and it will be continued to improve the accuracy of the model by comparing the data with that from a demonstration complex. The developed program can provide useful information for investment decisions through the optimal design of facility capacity and economic analysis when investing in renewable energy supply facilities.

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KEYWORDS

Economic evaluation, Optimal design, Renewable energy, Photovoltaic, Wind turbine, Battery energy storage system, Fuel cell, Diesel engine generator, Weather data.

INTRODUCTION

The proportion of renewable energy supply in the power system has increased significantly around the world to replace existing fossil fuel-based energy production and to reduce Carbon dioxide (CO_2) emissions. The total portfolio of Distributed Energy Resources (DER) including renewable energy sources is expected to surpass traditional forms of generation in 2018 [1]. Renewable Energy Sources (RES) have high output instability due to time and environmental influences, and it is difficult to predict the power generation output [2]. It is valuable to obtain the optimum capacity of renewable energy supply systems for specified load characteristics. It is necessary to study the optimum design conditions for facility capacity, including economic efficiency analysis based on energy production, initial investment cost and operating cost [3].

Several software tools are introduced and compared to analyze the electrical, economic and environmental performance of hybrid renewable energy systems in the reviews by Sinha and Chandel [4], and Connolly *et al*. [5]. Mendes *et al*. [6] and Markovic *et al*. [7] provide a survey of tools for efficient planning of Community Energy Systems (CES). Popular tools include TRNSYS and Hybrid Optimization of Multiple Energy Resources (HOMER). Numerous cases of studies of renewable energy system done with TRNSYS can be found. For example, De Luca *et al*. [8] studied a renewable energy system for a nearly zero greenhouse city in Italy, Venkataramani and Ramalingam [9] performed an analysis on the feasibility of compressed air. Behzadi and Niasati [10] compared the performance of a hybrid system of PV/FC/battery. Diverse topics are analyzed with HOMER worldwide. Examples include alternative energy scenarios in an island of Turkey by Kalinci [11], economic viability for PV/wind/diesel hybrid energy system in Malaysia by Ngan and Tan [12], techno-economic evaluation of various hybrid power systems for rural telecom by Amutha and Rajini [13] and change in electric energy cost by Demiroren and Yilmaz [14] in Turkey. Ghasemi *et al*. [15] and Asrari *et al*. [16] evaluated hybrid renewable energy systems for rural electrification of Iran, Sen and Bhattacharyya [17] studied off-grid electricity generation with renewable energy technologies in India. Ramli *et al*. [18] performed an economic analysis of PV/diesel hybrid system with flywheel energy storage and Ramli *et al*. [19] studied optimal sizing of grid-connected Photovoltaic (PV) energy system in Saudi Arabia. Shaahid *et al*. [20] reviewed the economic assessment of hybrid photovoltaic-diesel-battery power systems for residential loads in the same country. Similar research trends can be observed by the numerous authors in other countries such as: Kim *et al*. [21] of Korea, Bekele and Palm [22] of Ethiopia, Ma *et al*. [23] of China, Giannoulis and Haralambopoulos [24] of Greece, and Chmieland Bhattacharyya [25] of Scotland. Microgrid system is one of the popular arrangements that can be easily modeled by HOMER as seen in the studies by Hafez and Bhattacharya [26] and Abdilahi *et al*. [27]. Interesting studies such as a wind-to-hydrogen system for Arctic remote locations by Chade *et al*. [28] and wind-biogas hybrid energy production by Mudasser *et al*. [29] were reported.

Recently, intelligent management of power systems in conjunction with renewable energy penetration and user participation became one of the popular research topics. Pop *et al*. [30] investigated the use of decentralized blockchain mechanisms for delivering transparent timely energy flexibility, under the form of adaptation of energy demand profiles of Distributed Energy Prosumers. They found that blockchain based distributed demand side management can be used for matching energy demand and production at smart grid level. Brusco *et al*. [31] proposed a pair of laboratory prototypes of a low-cost energy box, suitable for cloud-based architectures for autonomous demand response of prosumers. They demonstrated through laboratory tests the feasibility of the proposed prototypes and their capability in executing thecustomers' loads scheduling returned by the solution of the demand-response problem. Guerrero-Martinez *et al*. [32] presented a smart multiconverter system for residential/housing sector with a Hybrid Energy Storage System consisting of supercapacitor and battery, and with local PV energy source integration. The multiconverter is responsible for complying with the reference active power set-points with proper power quality guaranteeing that the local PV modules operate with a Maximum Power Point Tracking algorithm, and extending the lifetime of the battery. Croce *et al*. [33] proposed Overgrid, a fully distributed peer-to-peer architecture designed to automatically control and implement distributed demand response schemes in a community of smart buildings with energy generation and storage capabilities. Belong to a virtual microgrid, the Overgrid can apply some power balance criteria to its system of buildings regardless of their physical location. For intelligent load control for smart buildings, Ashabani and Gooi [34] designed a simple versatile real-time control and management strategy for provision of adaptive and intelligent demand response for buildings. Their three-phase multiobjective autonomous automated intelligent load control strategy offers superiorities in a computationally-efficient approach.

Most new investors wishing to install renewable energy facilities such as PV and wind power require accurate information to examine the business feasibility by making preliminary calculations of the investment scale and operating profit. When designing the capacity of renewable energy facilities, it is first necessary to predict the electric power production accurately through operation simulations that consider climate information. The results of the economic analysis are important information for ensuring the profitability of the electric power provider. To expand investment in renewable energy, a tool is needed to examine information about the size and type of investment, which should be easily accessible through the internet. The customers, government, and electric power supplier also need to analyse user requirements and manage information to improve future renewable energy power policy.

The objective of this study is to maximize the efficiency of energy demand and supply by optimizing the capacity of renewable energy sources that are suitable for the location of an investment area or workplace. For the long-term strategy, it will be necessary to analyse the factors affecting the stability and reliability of the system when a large capacity of renewable energy facilities is connected to the national grid, and plans should be prepared to solve any problems that may arise. The final goal of the research is to increase the independence of the national energy supply by securing linkage management technology for renewable energy resources and supporting long-term investment expansion policy. For this reason, new software for the economic evaluation of energy production, initial investment cost, and operation cost based on new renewable energy capacity was developed. It can help a customer service to find the optimum capacity of a renewable energy plant that best suits the given load characteristics in the Korean energy market. The software tool was developed by using Visual Basic (VBA) based on MS Office Excel and Access.

DEVELOPMENT APPROACH

Figure 1 shows the main configuration and calculation procedure of the Korea Renewable Energy Project Optimization Program (KePOP©) program for the optimum design and economical evaluation of renewable energy facility capacity. To explore the optimal capacity design conditions and analyse the economic feasibility of the renewable energy facilities, the following steps were carried out:

- Step 1: The annual energy consumption data is used to analyse the customer's energy consumption characteristics, and the base load capacity for the initial investment is estimated from the Load Duration Curve (LDC);
- Step 2: The type and capacity of the investment target facility are selected, and the initial investment cost is calculated:
    - Renewable energy generation from PV, Wind Turbines (WT);
    - Operating flexibility from a Battery Energy Storage System (BESS);
    - Active supply system using Fuel Cells (FC) or Diesel Engine Generators (DEG);
- Step 3. Constraint data is set up, such as the fuel cost and trading price of renewable energy produced according to the domestic laws and regulations;
- Step 4. Operating simulations for energy balancing calculation based on regional climate data and user energy load model based on consumption data;
- Step 5. Annual production simulations are used to calculate total energy production from the selected facilities and estimate operating costs for energy supply and demand;
- Step 6. Economic indicators are calculated, such as the Payback Period (PP), Net Present Value (NPV) and Internal Rate of Return (IRR) of the initial investment cost through annual operating costs and trading profits;
- Step 7. Sensitivity analysis according to device type and capacity change;
- Step 8. Calculation of the optimal design conditions according to capacity constraints;
- Step 9. Output of the calculation results of the optimal capacity.

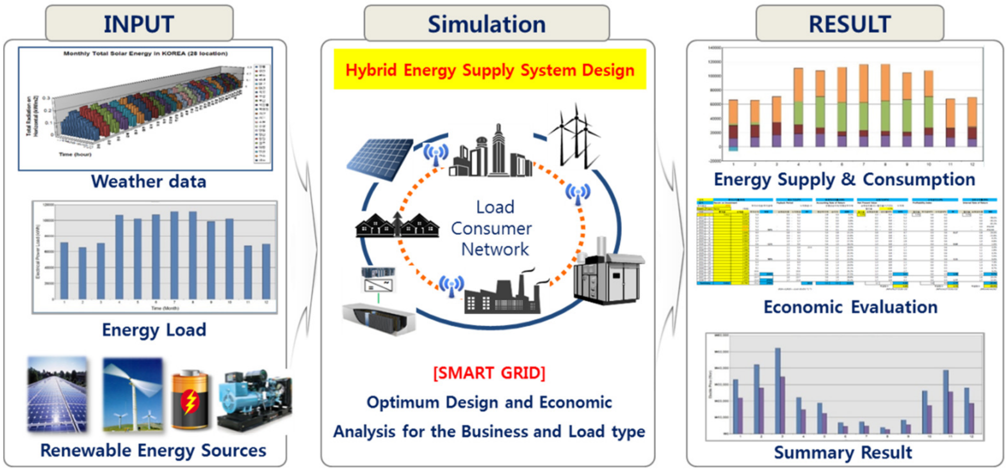


Figure 1. Overview of optimum design and economic analysis program (KePOP)

Calculation flow with user interface

To design and analyse an energy supply system that suits the demand, it is necessary to consider it as passive energy production and actively controlled energy production according to the energy production characteristics. The use of energy sources of adequate capacity to utilize renewable energy is important in securing economic efficiency. Therefore, the system should be designed so that the generated energy can be effectively utilized without waste. A passive energy source is, by nature, unilaterally supplied, such as solar and wind energy. Active energy sources include fuel cells and engine devices, which are capable of arbitrarily adjusting the timing of energy generation. When constructing a mixed renewable energy system composed of various energy sources, it is important to rationally combine a passive energy source and an active energy source to improve system efficiency and economic efficiency. The operational simulation with a basic strategy of pre-processing passive energy and injecting active energy according to the situation has been performed.

Figure 2 shows a flowchart of the program and the configuration of the graphical user interface. The first step is selecting the design target location, followed by inputting the user load value, device type, and capacity, and finally inputting values for the economic evaluation. After the operation simulation is executed, the amount of renewable energy production is calculated, and the shortfall in the required energy load consumption is calculated for when an active energy source is used or when purchasing it through an external power supply system.

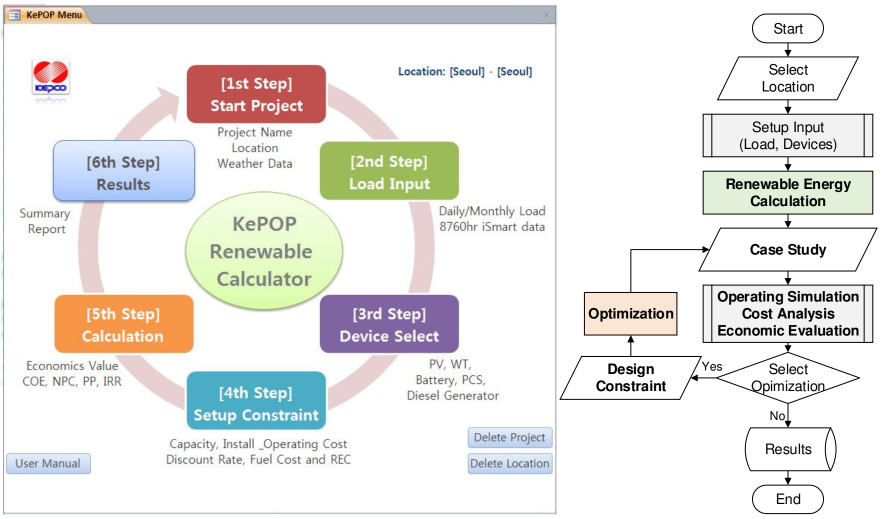


Figure 2. Main graphical user interface of KePOP with a flowchart of the program

Operating simulation

The operating simulation includes a series of processes for supplying the amount of energy required by the load through the prepared equipment. Through iterative calculations, the energy can be summed up at regular intervals to evaluate the performance and calculate the charge for energy trading volume. For example, consider a case of supplying energy with one type of solar power generation. When summing up the total amount of energy supplied for one month, there is a method of sequentially adding up the amount of generation according to time, but the result is the same, even if a distribution table for the amount of power generation for one month is made and added.

A statistical distribution table is made for one month or one year of source variables, such as solar radiation and wind speed. Calculations are performed in connection with the performance characteristics of specific equipment. This approach is appropriate because most renewable energy sources are affected by weather variables such as solar radiation and wind speed, which are represented by statistical variables. Table 1 compares the simulation and statistical analysis methods. Both methods were combined to develop the program to ensure speed and accuracy of the calculations.

Table 1. Comparison of analysis methods

Type	Simulation	Statistical approach
Coverage	Unlimited	Single type or multiple models without mutual exchange
Calculation speed	Slow computation	High speed
Application example	TRNSYS[35], MERIT[36], EnergyPlan[37], ESP-r[38]	RETscreen[39], Homer[40], fChart[41], PV fChart[42], WindPower[43]
Problem type	Specific performance evaluation Detailed optimization	Initial feasibility study Basic level optimization
Configuration	In-house development (Main-PG)	External program (Sub-PG)

DEVELOPMENT COMPONENTS

To develop the analysis program for a renewable energy system, it is necessary to define the performance analysis theory for individual equipment in the system. The following are the basic concepts for the program from previous research and operation experience with various energy supply systems, including renewable energy.

Weather data

The meteorological data are required for the analysis of the renewable energy equipment. There are 28 locations in the weather database developed by using weather information from 103 local stations provided by the Korea Meteorological Agency (KMA). The database includes latitude and longitude and 8,760 hours of temperature, solar radiation, dew point temperature, wind velocity, atmospheric pressure, and ground temperature. The weather data were prepared in a TMY2 file format, which is a standard format for renewable energy analysis. Figure 3 shows the air temperature, wind speed, solar radiation, and atmospheric pressure information for the 28 locations (Andong, Boseong, Busan, Cheongju, Chuncheon, Chupungnyeong, Daegu, Daejeon, Gangjin, Gangneung, Gimhae, Gwangju, Incheon, Jeju, Jinju, Mokpo, N. Changwon, Pohang, Seosan, Seoul, Uityeong, Wonju, Yangsan and Yeonggwang).

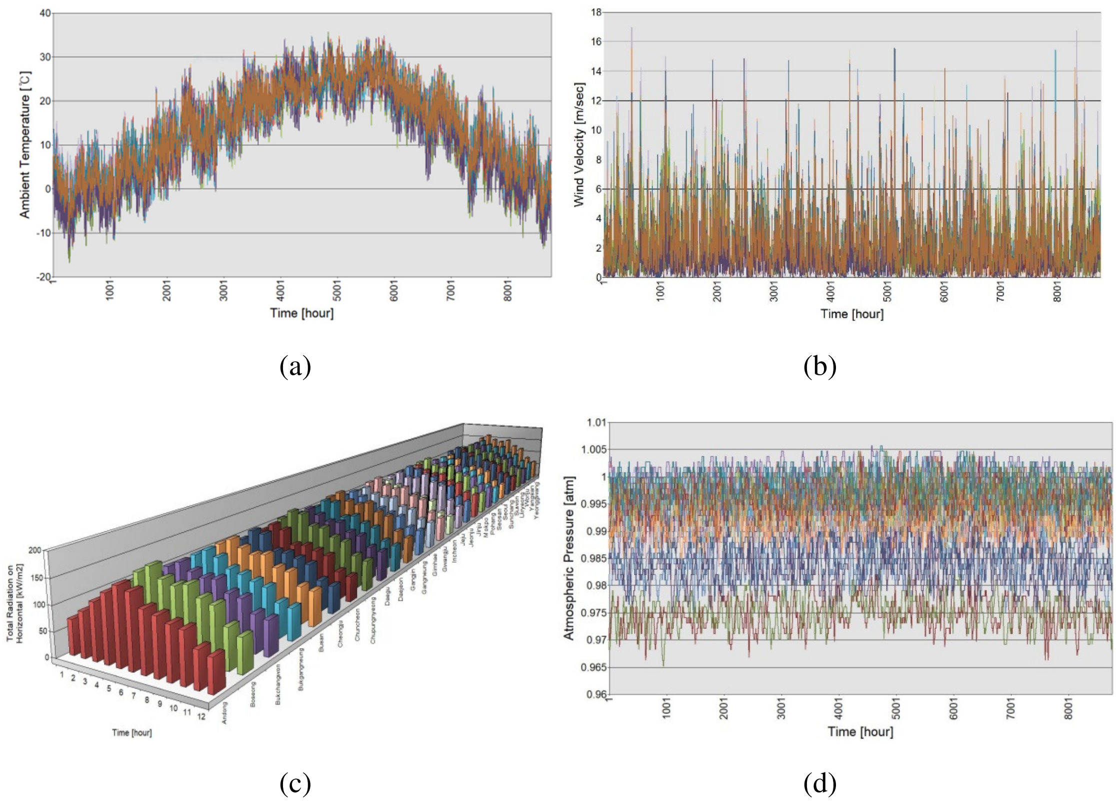


Figure 3. Specific weather data for 28 locations in Korea: ambient temperature (a); wind velocity (b); total radiation on horizontal (c) and atmospheric pressure (d)

Theoretical modelling of power generation devices

For accurate modelling analysis of each component of the system, it is necessary to perform a component test through a standardized test procedure and find out the parameters necessary for mathematically describing the behavior. Most of these tests are conducted objectively by accredited laboratories, and the manufacturer provides the information to the customer. However, it is difficult to obtain such important data for products such as batteries and fuel cells because it is not sometimes disclosed. For a system that uses these components, a mathematical model is useful, and various scenarios are analyzed through simulation instead of carrying out an empirical test, which requires much effort and cost. The Component Test System Simulation (CTSS) method has been widely used in countries such as Germany, and the TRNSYS [30] program is widely used as an analysis tool in building energy analysis.

All information of the components that have undergone performance testing through market research was used. The operation simulation was performed for the case of configuring various system combinations using renewable energy facilities. Using the results of the operation simulation, an economic analysis is performed based on the investment cost and operating cost, and the objective function for optimizing the design capacity is calculated. The simplified mathematical definition of the analytical model for each facility is described below.

Photovoltaic (PV). In the case of solar power generation from PV, the calculation result of energy production according to the input condition of each module is compared with the measured value obtained from the customer. The error of the predicted power generation was minimized by considering the effect of installation conditions such as PV farm location, inclination angle, and direction angle. PV power generation (P_{PV}) and surface temperature (T_C) can be calculated using simple eq. (1) and (2) [44, 45]:

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G}_T}{\overline{G}_{T,STC}} \right) \left[1 + \alpha_P \left(T_C - T_{C,STC} \right) \right] \tag{1}$$

$$T_C = T_a + G_T \left(\frac{T_{C,NOCT} - T_{a,NOCT} T}{G_{T,NOCT}} \right) \left(1 - \frac{\eta_{mp}}{\tau\alpha} \right) \tag{2}$$

where Y_{PV} is the rated capacity of the PV array, which is the power output under standard test conditions [kW], f_{PV} is the PV derating factor [%], $\overline{G}_T$ is the incident solar radiation on the PV array in the current time step [kW/m^2], $\overline{G}_{T,STC}$ is the incident radiation at standard test conditions [1 kW/m^2], α_P is the temperature coefficient of power [%/°C], and $T_{C,STC}$ is the PV cell temperature under standard test conditions [25 °C].

Wind Turbine (WT). Various theoretical equations are known, such as the Betz theory [46, 47] using wind turbine performance curves and the Weibull distribution model [48] using mean values and standard deviations of wind speed. However, for practical use, the correlation between the wind speed U_0 and the power generation P_{WT} is mainly used based on actual measurements and is defined in eq. (3) [44]:

$$P_{WT} = C_P \rho A_R U_0^3 \tag{3}$$

where A_R is the area of the rotor, U_0 is the free-stream velocity, and C_P is the power coefficient for a wind turbine defined as a function of the axial induction factor $4a(1 - a)^2$. The C_P values applicable for most wind turbine applications are associated with axial induction factors between 0 and 0.5. Values less than 0 are associated with propeller operation, and values above 1.0 are associated with propeller brakes. For wind turbines, values between 0.5 and 1.0 are not encountered in practice because in this region, stall-regulated turbines have lower tip-speed ratios and pitch-regulated wind turbines tend to have lower thrust coefficients. Pitching to the lower thrust coefficient achieves lower structural loads.

As with other renewable sources, it is necessary to correct the mismatch between the experimental conditions and the actual operating conditions in which the measurement data were obtained in the wind power calculation. The most important are the changes in air density and wind velocity according to height due to ground friction. Eq. (4) is used for calculating the density change according to the height of the wind turbine. Correlations based on boundary layer theory are widely used to consider vertical wind speed changes. Eq. (5) and eq. (6) show the power-law model and the log distribution equation, respectively:

$$\rho_2 = \frac{P_1}{RT}\left(1 - \frac{Bz}{T_0}\right)^{g/RB} \tag{4}$$

$$\left(\frac{U_1}{U_2}\right) = \left(\frac{Z_1}{Z_2}\right)^{\alpha} \tag{5}$$

$$U_2 = U_1 \frac{\ln\left(\frac{Z_2}{Z_0}\right)}{\ln\left(\frac{Z_1}{Z_0}\right)} \tag{6}$$

where ρ_2 is the air density at a given elevation (z), and B = 6.5 K/km of altitude.

Fuel Cell (FC) and Diesel Engine Generator (DEG). Fuel cells and diesel engine generators can be interpreted in the same way as a cogeneration model in that they produce electricity and heat using fuel. The difference is that a fuel cell relies on an electrochemical method, while a diesel engine depends on combustion. In terms of electric energy generation and heat recovery, it is convenient to perform simulations using the macroscopic indexes of heat efficiency and heat recovery efficiency. These two devices are available in either electric or thermally driven operation as required. Sometimes, it is possible to reduce the fuel cost according to the operating mode by enabling partial load operation according to the power load. For partial load operation, it is necessary to calculate the necessary fuel cell power generation load according to each hourly power load and operate with an appropriate load ratio. The partial load operation analysis is constructed using the performance function for power generation efficiency, fuel consumption rate, and calorific power according to the partial load ratio [49]. Eq. (7) and eq. (8) show the partial load rate (X) and the fuel efficiency (η_{fuel}) as functions of the fuel consumption rate ($\dot{V}_{\text{fuel}}$):

$$X = \frac{P_{\text{DEG}}}{P_{\text{DEG,max}}} = \frac{\eta_{\text{el}}\rho_{\text{fuel}}\dot{V}_{\text{fuel}}LHV_{\text{fuel}}}{P_{\text{DEG,max}}} \tag{7}$$

$$\eta_{\text{fuel}} = \frac{P_{\text{DEG}}}{\dot{V}_{\text{fuel}}} = \frac{P_{\text{DEG}}}{a + b \cdot X} \tag{8}$$

where P_{DEG} is the electrical power, $P_{\text{DEG, max}}$ is the maximum electrical power, ρ_{fuel} is fuel density, and LHV_{fuel} is lower heating value of the fuel. In the case study of the fuel cell and diesel engine generator module, calculation was performed by selecting products that can secure product performance (power generation efficiency, array efficiency, fuel consumption efficiency, etc.).

Battery Energy Storage System (BESS). The function of the energy storage system is becoming important as a countermeasure against the peak power load depending on the state of the power overload. In particular, a large-capacity battery energy storage device has advantages in that it can utilize wide energy flexibility through a function of charging surplus power and discharging it at a maximum peak load. The function of battery energy storage systems will increase steadily to maintain stable power system operation due to increases in instability and unpredictable renewable energy sources.

The battery analysis model uses the Shepherd (1965) and Hyman model (1977) [50, 51], which is based on the most traditional lead acid battery model. This model basically inputs the capacitance of the unit cell and the capacity according to the configuration of serial and parallel arrays. The relation between the charging rate of the battery, the operating current for charging or discharging, and voltage is calculated by solving a differential equation according to the characteristic curve given below for each time zone. Eq. (9) is the formula of the Shepherd and Hyman battery model:

$$V = e_x - g_x(1 - \text{SOC}) + I\, r_x \left[1 + \frac{m_x(1 - \text{SOC})}{Q_x / Q_m - (1 - \text{SOC})} \right] \tag{9}$$

where V is the voltage for charging or discharging, Q is capacity parameter, e is the open circuit voltage at full charge, g is the small-valued coefficients of State of Charge (SOC), r is the internal resistance at full charge when charging or discharging, and m is the cell type parameters. The subscript x indicates charging or discharging.

To analyse a lithium ion battery, which has recently been used in large-capacity systems, the dynamic voltage model by Tremblay [50] as in eq. (10) and the kinetic battery model [52, 53] used in HOMER as in eq. (11) to eq. (13) are adopted:

$$V = V_0 - RI + K\left(\frac{q_{\max}}{q_{\max} - \int I dt} \right) + ae^{-BIdt} \tag{10}$$

$$q_1 = q_{1,0} e^{-k\Delta t} + \frac{(qkc - I)(1 - e^{-k\Delta t}) - Ic(k\Delta t - 1 + e^{-k\Delta t})}{k} \tag{11}$$

$$q_2 = q_{2,0} e^{-k\Delta t} + q(1-c)(1 - e^{-k\Delta t}) - \frac{I(1-c)(k\Delta t - 1 + e^{-k\Delta t})}{k} \tag{12}$$

$$q = q_1 + q_2 \tag{13}$$

where V is the operating terminal voltage for charging or discharging and q is the current capacity rate for charge. The dynamic voltage model is a generic electrochemical model based on work by Jin *et al*. [54]. The model parameters are based on extracted parameters from battery datasheets. The kinetic battery model describes the interplay between bound and available capacity.

Figure 4 shows the operating concept of the Energy Management System (EMS) for a smart grid consisting of renewable energy facilities, including batteries. The EMS responds to electricity demand through power generation using new and renewable energy sources and controls the ability to sell surplus power in conjunction with the grid.

It also controls the surplus power and deficit in the smart grid using the charging/discharging flexibility of the battery.

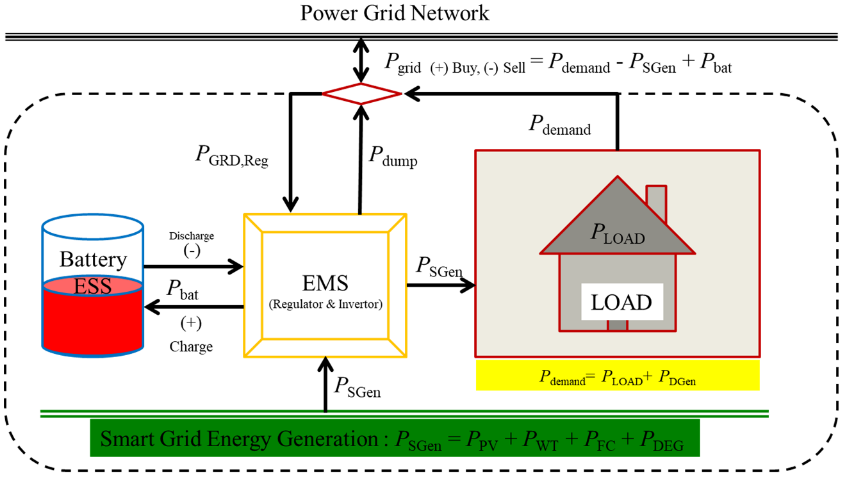


Figure 4. Energy management system of smart grid with battery energy storage system

Renewable energy density – A case study in Korea

Two power sources are considered in this study: PV and wind power. Power generation from the devices are predicted taking the effects of weather and system characteristics such as product specifications and installation details.

PV power generation. After selecting the installation site and determining the PV specifications, the predicted amount of PV power generation is determined by the solar radiation, surface temperature, and performance value of the PV product. Figure 5 shows the monthly cumulative power generation for 28 locations in Korea using a 295 W PV module sample unit (CS6X-295X, CanadianSolar).

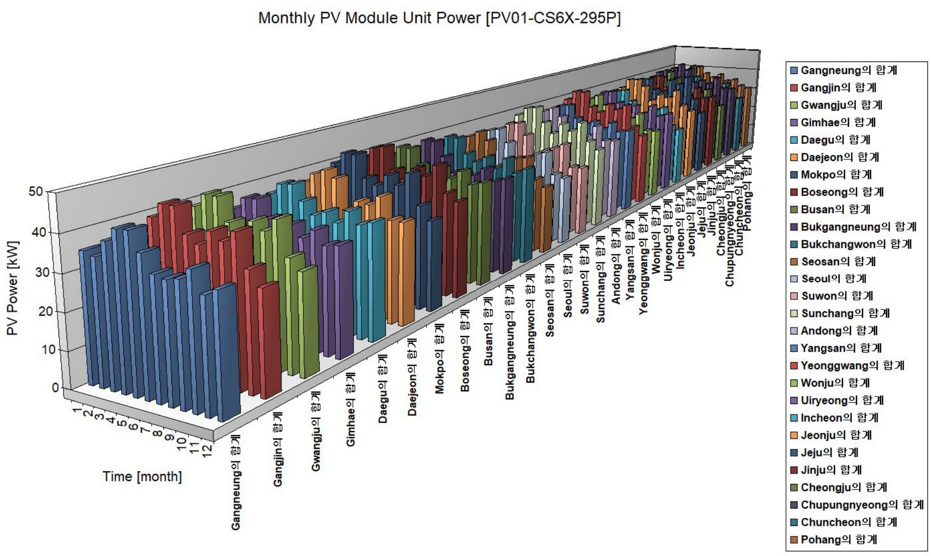


Figure 5. Monthly cumulative PV power generation for 28 locations in Korea (CS6X-295X, CanadianSolar)

Wind power generation. The wind power generators were selected from 4representative models (FD21-100-12, NPS100C-24, WES250, and DW-52-500) with different capacities, and the power output was calculated for 28 regions in Korea. After selecting the installation sites and determining the WT specifications, the predicted amount of wind power generation is determined by the wind velocity, air temperature, and the air density value at the wind farm. Figure 6 shows the monthly cumulative power generation for 28 regions in Korea using one of a 100 kW wind turbine sample unit (FD21-100-12, GHREPOWER).

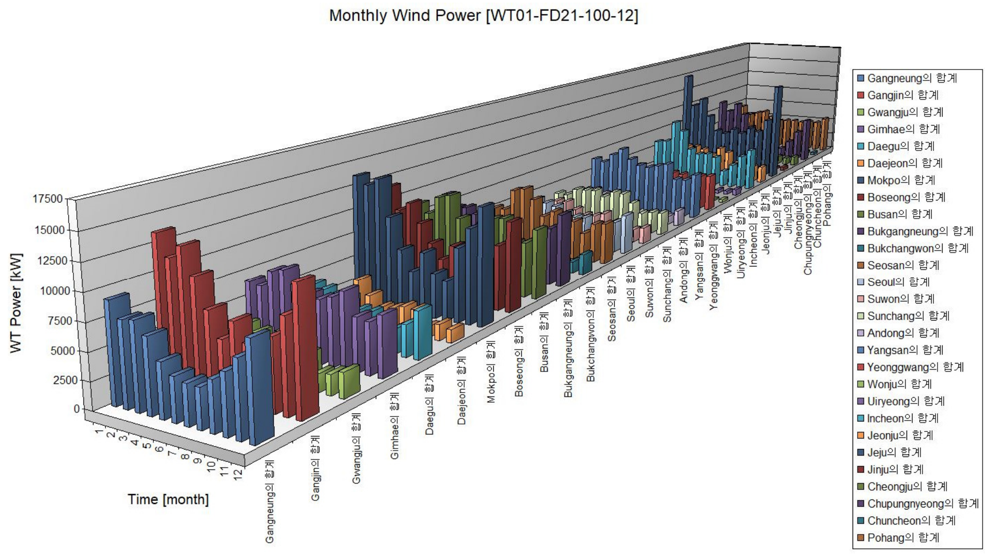


Figure 6. Monthly cumulative wind power generation for 28 locations in Korea (FD21-100-12, GHREPOWER)

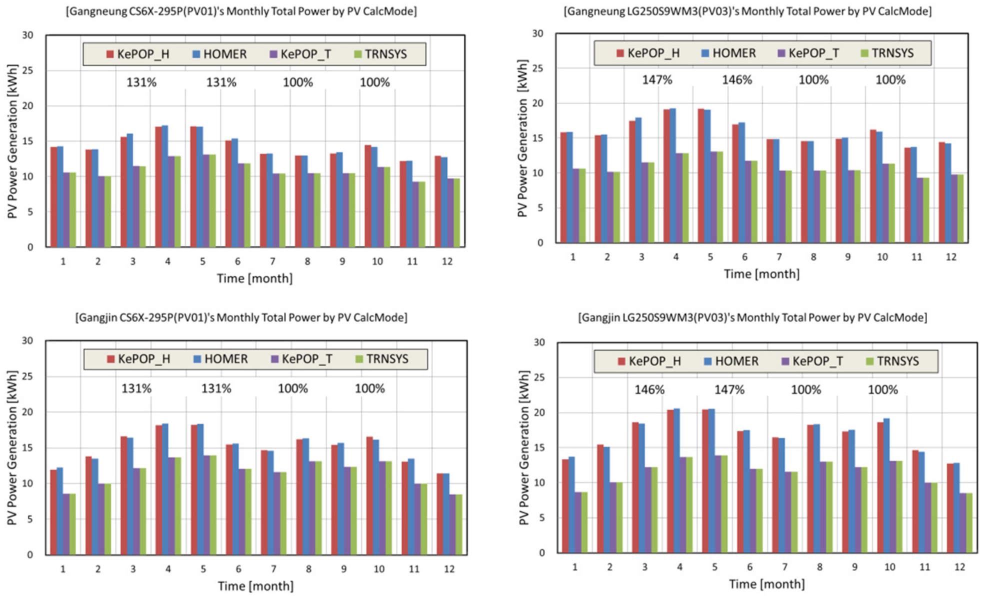
VERIFICATION CASE STUDY

To analyse the performance and economic efficiency of renewable energy facilities, the calculation results must first be verified for each module, and an integration module is needed to evaluate the results. First, the calculation process of each module was performed, and the result was compared with a standard model or a physical solution. The reliability of the developed software program was confirmed by the calculation results of renewable power generation and a sensitivity analysis for the specific region case in Korea. The following are the results from the case study.

Renewable energy generation

The developed software models were compared to verify the results of the commercial programs TRNSYS and HOMER. In the case of the PV model, the amount of power generation was predicted well based on the difference of the PV module type and the amount of solar radiation by the region. In addition, the error of the annual cumulative power generation with the target program is less than 1%. However, larger error occurs in the calculation of the power generation of TRNSYS and HOMER. In both regions, the maximum error of the cumulative annual power generation was about 47%. Figures 7 and 8 compare the calculation results and measured data from PV power plants in near the target location. As shown in Figure 8, the monthly cumulative errors were 97.8% and 75.4%, respectively. The calculation error could have occurred due to the use of different weather data in the actual PV power measurement conditions. Therefore, in future work, it is necessary to calibrate the prediction error by measuring the solar power generation together with the meteorological information, including the amount of solar radiation, and to compare the calculated results.

Figure 9 shows the results of comparing the differences in the amount of generation by product using the wind power generator calculation model. The error between the target programs is very good at 0.6%. The results are also in agreement with the calculated value of power generation by TRNSYS and HOMER.



(a) (b)

Figure 7. Monthly cumulative PV power generation from two different locations: (Gangneung and Gangjin) CS6X-295P (a) and LG250S9W-M3 (b)

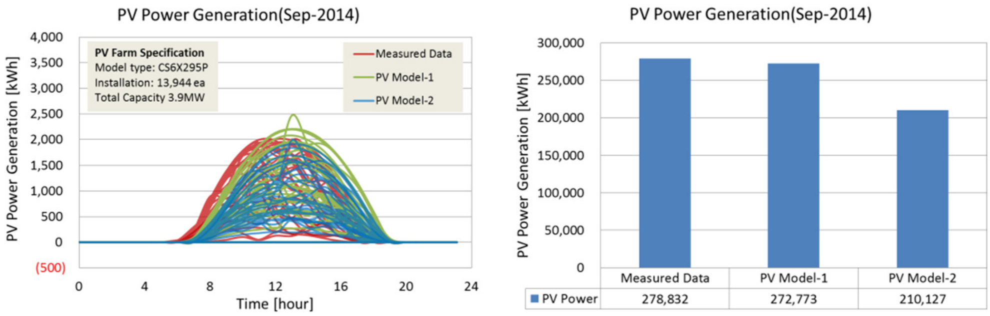


Figure 8. Verification of calculation results and measurement data from PV farm (CS6X-295P)

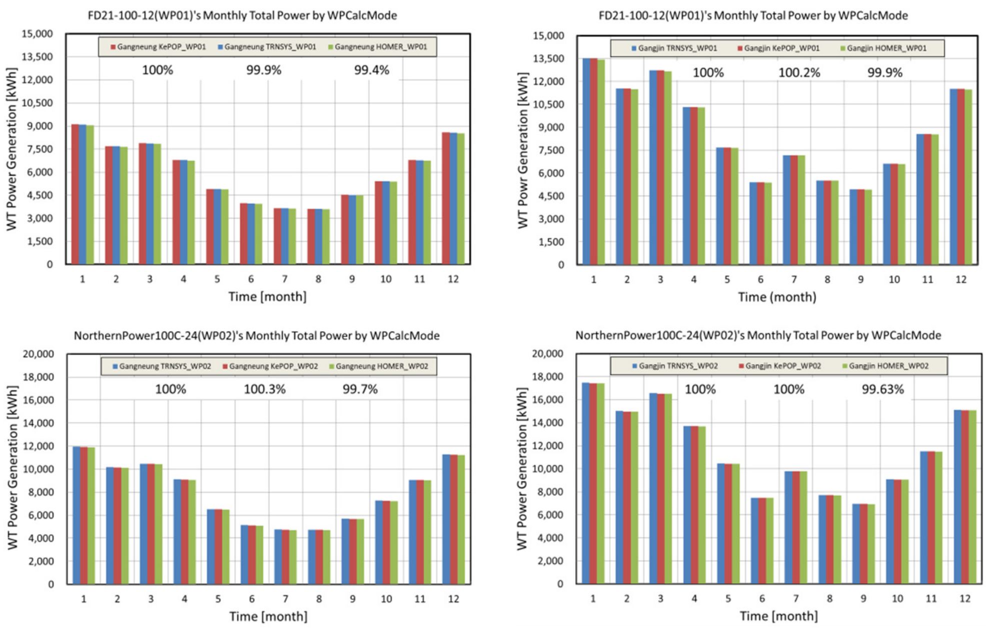


Figure 9. Monthly cumulative wind power generation for 2 regions in Korea (FD21-100-12 and NP100-24)

Sensitivity analysis

The electrical power load of a plant in a specific region was selected and analysed as shown in Figure 10. The optimum investment design condition of the renewable energy system for cost reduction through peak load reduction was calculated. The operation capacity of the renewable energy facilities was changed step by step, an operation simulation was carried out, and the results were verified. Figure 11 shows the summary results of the economic evaluation for various capacity conditions. In the sensitivity analysis, the NPV and the PP gradually increase with the total capacity and the IRR decreases. The optimum PP for the entire capacity range was 22 MW of facility investment. However, the ESS capacity was significantly influenced by the NPV compared to the FC.

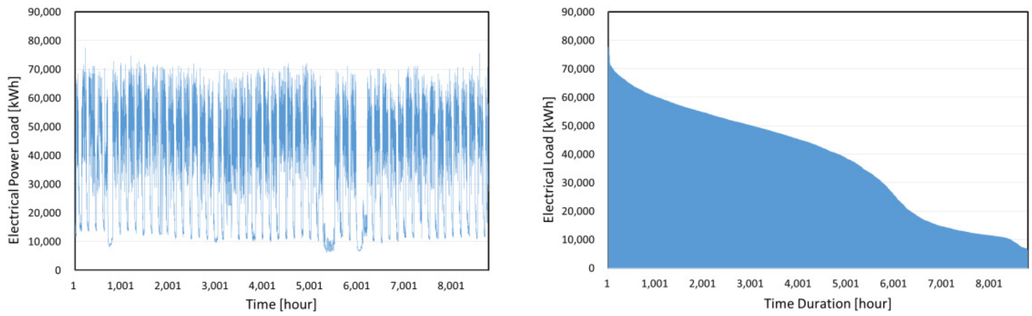


Figure 10. Electrical power load data from the grid-connected factory case study

In the calculation of the optimal design conditions for each load, the optimal capacity condition was calculated to minimize the recovery period and maximize the economic efficiency based on the NPV. There were optimal conditions of the investment payback period in the boundary area, and the optimal facility capacity and PP were calculated for each device under the optimum conditions of NPV. However, the sensitivity analysis shows that the investment effect depends on the total facility capacity, and the initial input conditions must be selected well based on the input conditions for economic analysis.

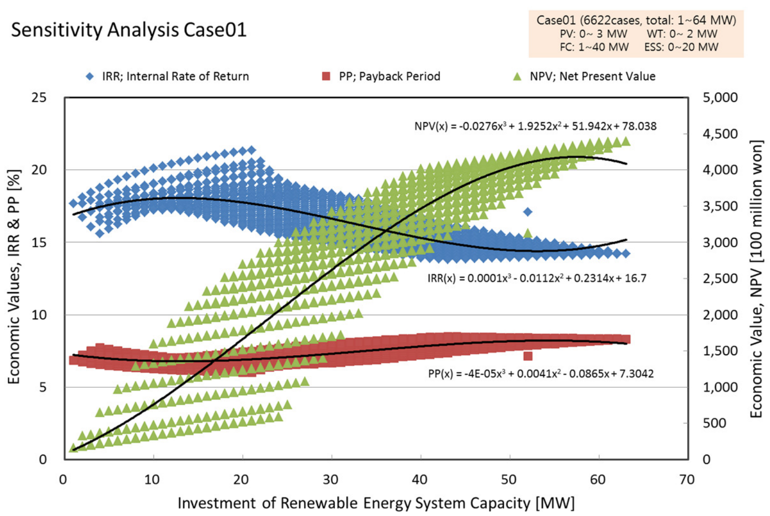


Figure 11. Economic evaluation results of the sensitivity case study

CONCLUSIONS

Power supply from renewable energy sources is increasing rapidly around the world, which is causing instability in the power grid system. It is necessary to study the optimum facility capacity design conditions, including economic efficiency analysis based on energy production, initial investment cost, and operating cost. It is valuable to obtain the optimum capacity of the renewable energy supply system that is most suitable for the specified load characteristics.

The engineering economic evaluation software KePOP was developed to find an optimum design for renewable energy systems in smart micro-grid, off-grid, and on-grid cases. The software was used to calculate the renewable energy production from PV and WT in local regions in Korea. TMY2 files were made for the renewable energy calculation based on meteorological data from 28 locations in Korea. To calculate the output of the PV and WT, a simple power generation models based on theoretical equations have been applied. Fuel cells and diesel engine generators can be selected as a base power source model, and a battery energy storage device was included for efficient energy management system. The models were compared with commercial programs such as TRNSYS and HOMER. In the case of the PV model, the amount of power generation was predicted well based on the differences in the amount of solar radiation by region. In addition, the error of the annual cumulative power generation with the target program was less than 1%. In the wind power calculation, the error between the target programs was very good at 0.6%. The results of the device model verification were in good agreement with the results under the same conditions.

Sensitivity analysis for the grid-connected factory case was performed and the optimum investment design condition of the renewable energy system for cost reduction through peak load reduction was calculated. The optimum PP for the entire capacity range was 22 MW of facility investment. It is necessary to improve the accuracy of the individual models by verifying the data with data from a demonstration complex. The developed program can provide useful information for investment decisions through the optimal design of facility capacity and economic analysis when investing in renewable energy facilities.

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