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PV Generator Performance Evaluation and Load Analysis of the PV Microgrid System in Thailand

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Abstract

Normally, the main generators of microgrid system use controllable energy resources such as fossil fuel, biomass, biogas, hydro, etc for uncomplicated control. However, it is very challenging to control the microgrid system that uses uncontrollable energy resources such as solar and wind for main generators of microgrid system because they have many advantages. From this point, the PV microgrid system is constructed and operated at School of Renewable Energy Technology (SERT), Naresuan University for research and development of the microgrid system that is supplying 50% of total electricity demand by PV main generator. By measuring the important parameters such as solar irradiance, PV array voltage, PV array current, and AC electrical power, these data were collected for a year from November 2008 to October 2009 to use in evaluation processes. The PV generator evaluation result is revealed that the average reference yield (Yr), array yield (YA), and final yield (Yf) are 5.21, 4.32, and 3.84 kWh/kWp day respectively. The average total loss of the PV generator is 26.27 % that comes from summing up the average capture losses (LC) 17.21 % and average system losses (LS) 9.06 %. The average overall PV plant efficiency (ηp) is 10.41 %, and the average performance ratio (PR) is 73.45 %. For load analysis of the microgrid, the total load is 231673 kWh/year or 635 kWh/day that the main loads of the microgrid are the real load and the battery storage loss. For the real load, it varies from 9803 to 22506 kWh/month and the average real load is 15434 kWh/month. However, the battery storage loss is really constant at 3888 kWh/month. When consider the load profile, it shows that the peak load period is 8 A.M. to 7 P.M. and the off peak load periods are 0 A.M. to 8 A.M. and 7 P.M. to 0 A.M. Moreover, the load in peak load period of working day is higher than day off but the load in off peak load period is not different. When compare the load profile with PV generator production, the load is 100% supplied by PV generator during 8 A.M. to 4 P.M. in working day and 8 A.M. to 5 P.M. in day off. Moreover, PV generator generates the surplus energy 169 kWh/day in working day and 232 kWh/day in these periods.

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Nomenclature

| Symbol | Description |
|--------|-------------|
| YA     | Array yield (h / d) |
| EA,d   | Array output energy per day (kWh) |
| P0     | Nominal power or module power at STC (kW) |
| Yf     | Final yield (h / d) |
| E_{use-PV,day} | Direct PV energy contribution to E_{use} (kWh) |
| FA     | Fraction of total system input energy contributed by PV array |
| E_{in} | Total system input energy (kWh) |
| EBU    | Energy from back-up system (kWh) |
| EFU    | Net energy from utility grid (kWh) |
| EFS    | Net energy from storage (kWh) |
| Euse   | Useful Energy supplied by the system (kWh) |
| EL     | Energy from PV to loads (kWh) |
| ETU    | Net energy to utility grid (kWh) |
| Yr     | Reference yield (h / d) |
| GI     | Global irradiance in the array plane (W/m²) |
| GSTC   | Global irradiance at standard test conditions (W/m²) |
| L_c    | Array capture losses (h / d) |
| L_s    | System losses (h / d) |
| PR     | Performance ratio |
| \eta_{A,mean} | Mean array efficiency |
| ES,A   | Total solar energy on array plane (kWh) |
| HI     | Global irradiation in the plane of the array (kWh/m²) |
| AA     | Array area (m²) |

1. Introduction

Microgrid system can be defined as a group of distributed energy resources (DER) and loads functioning as a single controllable system that reacts to central control command signals and supplies both power and heat to its regional area [1]. Moreover, it is also defined as an independent low-voltage distribution system that has a squad of DER with energy storages and microsources such as PV, wind, microturbine, CHP, fuel cell, etc. [2]. Microgrid system is not only providing power to its local area, but also exchanging power with national power grid when its power generation is insufficient or surpass its load. Normally, microgrid system has 5 main
components as follows: 1) Distributed generation or microsources 2) Loads 3) Energy storage system 4) Controller and 5) Point of common coupling. There are two common operation modes of microgrid system that are grid connected mode and island mode. Normally, just only controllable energy resources such as fossil fuel, biomass, biogas, hydro, etc. are used in primary generator because it is uncomplicated controlling with high security and stability of power generation from these energy resources. In the different way, the potential of uncontrollable energy resources is high and scattering in every part of the world. So, uncontrollable energy resources are the alternative energy resources for using as energy resources of main generator in microgrid system. Therefore, it is very interesting to study how to manage these problems in operating of microgrid systems that have uncontrollable energy resources for major generator. This is the origin of the research on of microgrid system that use PV for major generator with the energy fraction over 50% by the cooperation of School of Renewable Energy Technology, Naresuan university (SERT), New Energy and Industrial Technology Development Organization (NEDO), and Shikoku Electric Power co., inc. (YONDEN) in The International Cooperative Demonstration Project for Stabilized and Advanced Grid-Connection Photovoltaic Systems Demonstrative Research Project on Micro Grid Stabilization. The PV microgrid system is constructed and operated at SERT in Thailand. The main devices and schematic diagram of PV microgrid system are presented in Fig. 1. From the PV microgrid concept, PV generator and load are the vital components that play the serious role to achieve the electricity supply fraction goal. The performance evaluation of the PV generator and load analysis are the important activities that is not only designating the efficiency and performance but also exploring the imperfect and unusual of the generator and load. The evaluation results can be used as the database in adjustment and maintenance PV generator to keep the highest efficiency and performance. The performance evaluation of the PV system is a common action that is usually executed in many part of the world. In Japan, 30 kWp bifacial PV systems that installed in the microgrid system in Aichi airport-site demonstrative research plant for new energy power generation was evaluated. The result shows that the energy generation of bifacial PV in vertical installation is about 90% of single-facial PV faced to south with 30° tilt [3]. In addition, various configurations of PV roof top systems are evaluated and the result is presented that south-oriented systems have about 22% higher reference yield [4]. In Thailand, 500 kWp PV power plant at Mea Hong Son province was evaluated. The result was displayed that the final yield is in 2.91–3.98 range and performance ratio is in 0.7–0.9 range [5]. Moreover, 5 kWp PV system at Rajamangala University of Technology Suvarnabhumi was evaluated by using data from data monitor system and standard instrument (IV Checker) and the result was showed that the both data give the different of average array efficiency about 1% [6]. For the objective of this research, PV generator performance and load of PV microgrid system that installed at SERT is evaluated and analyzed for 1 year.

2. Data collection and performance evaluation procedure

2.1. Data collection

In this evaluation, PV microgrid system is assigned to operate in grid connected mode and every major device is regularly working for highest efficiency and performance of PV generator. The data collection system in PV microgrid controlling system collects the important parameters such as solar irradiance, ambient temperature, module temperature, PV output, PV inverter output, exchanged power between grid and PV microgrid system, diesel generator output, battery inverter input/output, and load are collected from the sensors that installed in PV microgrid system. The data collection system collects these significant parameters every minute during PV microgrid system operation. The collected data is transferred to graphic operation terminal (GOT) 1000 for displaying and storing in its compact flash memory. The data that stored in the compact flash memory is downloaded to the computer every week for using in performance evaluation of PV generator. For the instrument, solar irradiance is measured by EKO MS-602 ISO second class pyranometer, all temperature is
measured by type T thermocouple, and all electric power is measured by Toyo keiki WGM-04A watt/watt hour transducer set.

Fig. 1. The main device and schematic diagram of PV microgrid at SERT

In this evaluation, the vital parameters are measured and collected for a year from November 2008 to October 2009.

2.2. Performance evaluation procedure

The technical analysis processes of International Energy Agency Photovoltaic Power Systems (IEA PVPS) Task 2 – Performance, Reliability and Analysis of Photovoltaic Systems that based on EU guidelines and IEC 61724 standard [7,8,9,10] are used to evaluate the efficiency and performance of PV generator in this evaluation. The important parameters and equations for analysis are presented as follows:

\[
Y_A = \frac{E_{A,d}}{P_0} \quad (1)
\]

\[
Y_f = \frac{E_{use,PV,day}}{P_0} \quad (2)
\]

\[
E_{use,PV,day} = F_A \times E_{use} \quad (3)
\]

\[
F_A = \frac{E_A}{E_{in}} \quad (4)
\]

\[
E_{in} = E_A + E_{BU} + E_{FU} + E_{FS} \quad (5)
\]

\[
E_{use} = E_L + E_{TU} \quad (6)
\]

\[
Y_r = \frac{\int G t \ dt}{G_{STC}} \quad (7)
\]

\[
L_c = Y_r - Y_A \quad (8)
\]

\[
L_s = Y_A - Y_f \quad (9)
\]
3. Evaluation results

3.1. Solar radiation and ambient temperature analysis

The daily average solar radiation in each month range from 4.50 to 5.93 kWh/m²day and can be classified into 2 groups. First, high solar radiation group that available from November 2008 to May 2009 in winter and summer of Thailand has the daily average solar radiation about 5.50 kWh/m²day. Second, low solar radiation group that available from June 2009 to October 2009 in rainy season of Thailand has the daily average solar radiation about 4.81 kWh/m²day. For the annual daily average solar radiation, it is approximately 5.21 kWh/m² day that is a little bit higher than the annual daily average solar radiation of Thailand, 5.05 kWh/m²day given by DEDE. For daily average ambient temperatures in each month, it ranges from 29 to 35 Cº that can be categorized into 3 groups following the seasons. The daily average ambient temperature of winter, summer, and rainy season are 31, 32, and 33 Cº respectively. Annual daily average ambient temperature is 33 Cº. The daily average solar radiation and ambient temperature in each month is presented in Fig. 2.

3.2. Overall PV generator

The daily average PV generator output is in 394 – 530 kWh/day range in each month and 461 kWh/day for annual. When evaluate over all PV generator follow EU guidelines and IEC 61724 standard, daily average reference yield, array yield and final yield in each month is showed in Fig. 3 (a). In winter and summer, these parameters value is higher than rainy season. When consider the daily average total energy in PV generator that is equivalent to daily average reference yield, it consist of daily average final yield, capture loss, and system loss in each month with the ratio that presented in Fig. 3 (b). From the figure, it reveals that the daily average reference yield and final yield in winter and summer are higher than those in rainy season. Moreover, the daily average capture loss, and system loss in winter and summer are lower than those in rainy season. For the annual daily average final yield, capture losses, and system losses, they are 3.84 h or 73.6%, 0.90
h or 17.3% and 0.47 h or 9.1% respectively that displayed in Fig 4(a). The daily average performance ratio and overall PV plant efficiency in each month are as showed in Fig. 4 (b). From the figure, the annual daily average performance ratio and overall PV plant efficiency are 73.6% and 10.41% and these parameter values in winter and summer are higher than those in rainy season.

Fig. 3. (a) The daily average reference yield, array yield and final yield in each month (b) The ratio of daily average final yield, capture loss, and system loss in each month

Fig. 4. (a) The annual daily average final yield, capture loss, and system loss (b) The daily average performance ratio and overall PV plant efficiency in each month

3.3. Load analysis

From the load data that collected from the PV microgrid, the total load is 231673 kWh/year or 635 kWh/day and in 13970 – 27004 kWh/month in each month that classified into 2 main loads. First, real load is 185212 kWh/year or 507 kWh/day and in 9803 - 22506 kWh/month in each month with average real load at 15434 kWh/month. Second, battery storage loss is 46658 kWh/year or 507 kWh/day and about 3888 kWh/month in each month. Fig. 5 is displayed total load, real load, and battery storage loss in each month. When calculate the PV generator supplying ratio, it is 73% that achieve the PV generator supplying
target. For the load profile, the peak load period is 8 A.M. to 7 P.M. and the off peak load periods are 0 A.M. to 8 A.M. and 7 P.M. to 0 A.M. In addition, the load in peak period of working day is about 35 kW and the highest peak period is 1 P.M. to 5 P.M. while day off is about 25 kW. However, the loads in off peak periods are about 15 kW that is not different. When compare the load profile with PV generator production, the load is 100% supplied by PV generator during 8 A.M. to 4 P.M. in working day and 8 A.M. to 5 P.M. in day off. Moreover, PV generator generates the surplus energy 169 kWh/day in working day and 232 kWh/day in these periods. For the surplus energy, it is used to charge battery and exported to the external grid. Fig. 6 showed working day load profile, day off load profile, and PV generator power.

![Graph showing load profile and PV generator power](image)

Fig. 5. Total load, real load, and battery storage loss in each month

![Graph showing average load and PV generator power](image)

Fig. 6. Working day load profile, day off load profile, and PV generator power

4. Conclusion

The performance and efficiency of PV generator in PV microgrid system is really good. The annual daily average performance ratio and overall PV plant efficiency are 73.6% and 10.41% respectively. The annual daily average reference yield, array yield and final yield are 5.21, 4.32 and 3.84 h respectively. These parameters have higher values in winter and summer than in rainy season. The total loss in PV generator is 26.27% that consists of capture loss (17.3%) and system loss about (9.1%). Both capture loss and system loss are
higher in rainy season than in winter and summer. For the cause of higher losses in rainy season, it is due to the fluctuation of solar irradiance in this season that makes the power generation of PV array unstable and PV inverter has to change MPP point very often. For load analysis of the microgrid, the total load is 231673 kWh/year or 635 kWh/day that the main loads of the microgrid are the real load and the battery storage loss. For the real load, it varies from 9803 to 22506 kWh/month and the average real load is 15434 kWh/month. However, the battery storage loss is really constant at 3888 kWh/month. In addition, PV generator supplying ratio is 73% that achieve the PV generator supplying target of PV microgrid. When consider the load profile, it shows that the peak load period is 8 A.M. to 7 P.M. and the off peak load periods are 0 A.M. to 8 A.M. and 7 P.M. to 0 A.M. Moreover, the load in peak load period of working day is about 35 kW that is higher than the load in peak load period of day off about 10 kW but the load in off peak load periods are about 15 kW that is not different. When compare the load profile with PV generator production, all load is supplied by PV generator during 8 A.M. to 4 P.M. in working day and 8 A.M. to 5 P.M. in day off. Moreover, PV generator generates the surplus energy 169 kWh/day in working day and 232 kWh/day in these periods. The surplus energy is used to charge battery and exported to the external grid.

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