

Operation strategy of microgrid for rural area of northern Thailand

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Abstract

This paper presents operation strategy and energy management for a grid connected microgrid, which is consisted of the micro hydropower plant, photovoltaic system (PV), battery energy storage system (BESS) and the main grid. The main objective is to minimize the energy flow of the system as a lot of power is imported from the main grid. All actual data profiles are collected from a real microgrid site. The microgrid model uses a microgrid controller to control BESS, PV generation, and load consumption, which focuses on energy management system (EMS), is based on the peak shaving. The EMS can perform smoothly when used with BESS. The experimental results have shown that a system is able to reduce energy consumption and peak demand period from the grid.

Keywords: BESS, energy management system, microgrid, operation, peak shaving

1. Introduction

Recent increases in the development of energy and renewable energy technology has produced more opportunities to use renewable sources. One of the main challenges is the integration of renewable energy sources (RESs) into distribution networks in environmentally friendly ways. A microgrid plays an important role to solving outage problems and energy management in the distribution network. However, the PV system may bring about a fluctuation problem to grids periodically.

In addition, the PV generation produces a lot of power but the load in this region is mostly day time lighting. At this time there is a large amount of power flows back to the grid. Peak demand occurs during early morning and night time when a lot of power is drawn from the grid. The BESS plays a major role in balancing energy between the microgrid and grids. Therefore, the Provincial Electricity Authority (PEA), in cooperation with Chiang Mai University (CMU), has installed the first pilot smart microgrid system to Khun Pae to resolve those issues [1]. The optimal energy management system (EMS) has been proposed in [2], for the minimum of cash flow to optimize the schedule of sources is used to find by Dynamic programming technique, including the import/export power with the main grid. In [3], [4], the optimal energy management for a grid-connected with PV/battery and a vehicular electric power system is addressed by using the quadratic programming (QP). A matrix real-coded genetic algorithm (MRC-GA) optimization module is used to search for the optimal generation schedule in [5]. In [8], [9], the aim effort is to decrease costs by reducing the amount of energy and to shave the maximum of load using the simulation model. The optimization models using Mixed Integer Linear Programming (MILP) for the EMS, and the operation will be tested in microgrid experiments with commercial loads, taking into account the payback period. Papers [10], [11] presented the best energy management system for PV and

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BESS. The hardware of microgrid experimental with battery, and load for improved the management of energy storage is verified by pseudo SOC concept. The performance test and results were created using MATLAB/Simulink for simulation [12], [13].

In this paper presents the operation strategies to reduced peak load and minimize a lot of energy from the main grid. Section 1 describes the introduction of microgrid, Section 2 describes the system components and operation strategies in microgrid of this site. Section 3 discusses the methodology and section 4 explains the experimental results in microgrid system. The conclusion is described in section 5.

2. System Components

2.1. Microgrid components

Microgrid (MG) is a combination of load, distributed generation, storage, and associated conditioning of power units that operate as single controllable and provides power load. The microgrid experimental model can be of benefit to the operators of utilities, distributed generation owners and consumers in terms of reliable power supply, efficient power distribution, reduced throughput of distribution line and increased efficiency of renewable energy.

Khun Pae microgrid is comprised of a 100kW small hydropower plant, solar PV at 100 kWp, battery energy storage (BESS) at 100 kWh, 100kW capacity converter, and the main grid. The system used in this study is a microgrid system connected to main grid 22 kV, as shown in Fig. 1. The microgrid controller used is the PCS9617 from NR Electric, China. The main objective of the research is to reduce energy import from the main grid and peak demand by optimizing energy storage scheduling and shaving the peak demand.

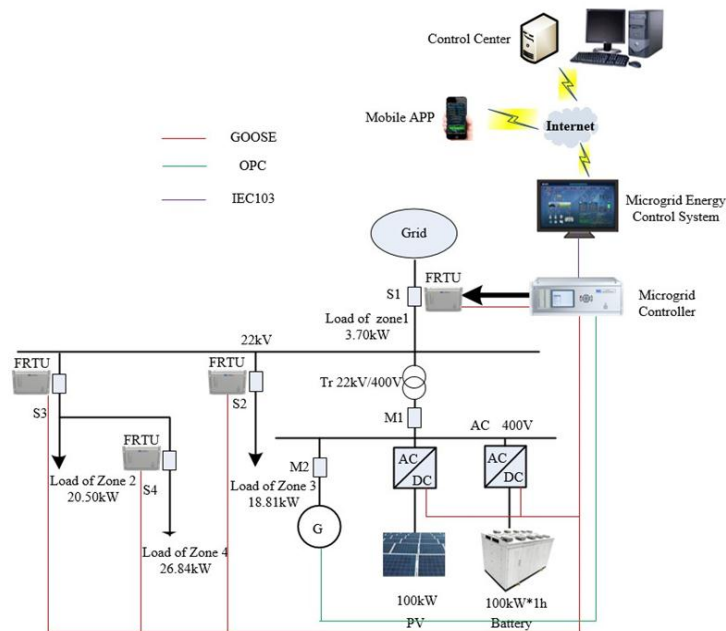


Fig. 1. Khun Pae smart microgrid system.

2.2. Load profile

As a result of the load data collected from the FRTU S1 shown in Fig.1, the load profile data is based on daily load curve, as shown in Fig. 2. The peak load in the morning between 5:45-7:45 am at 113.62 kW and another peak load is between 17:00-21:00 pm at 98.71 kW.

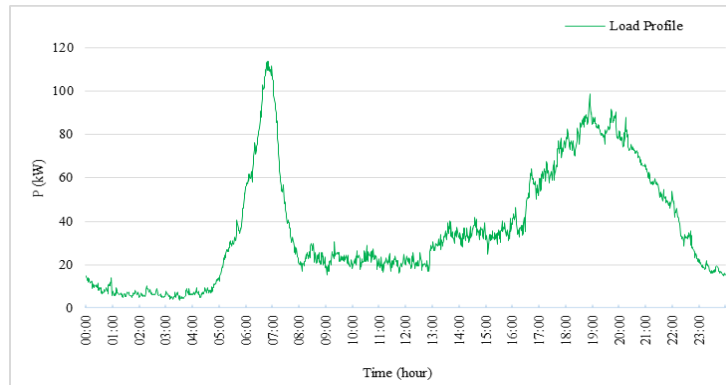


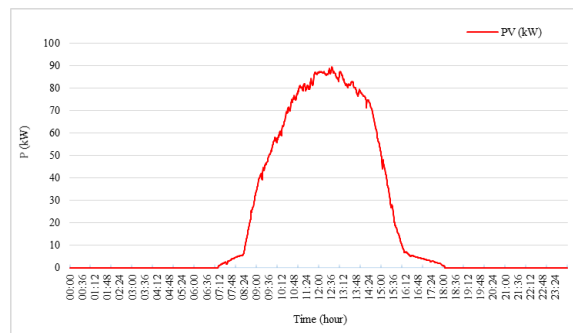
Fig. 2. The daily load curve (10 February 2018).

2.3. Generation profile

- a) Solar PV: The 100 kW photovoltaic power system has been installed as shown in Fig. 3 (a). The PV profile obtained by the light intensity and temperature data collected in February 2018 is as shown in Fig. 3 (b). Seven hours of operation has been found. Photovoltaic systems produce up to 89.4kW at approximately noon.



(a)



(b)

Fig. 3. (a) Solar PV 100 kW and (b) The PV system production of site with hourly data.

- b) Micro hydro: The micro hydro has a maximum output of 55.57 kW and average output amount of 36.35 kW [1]. The water flow of small hydro in the area is such that that the amount of water is very high during the rainy season, from June to November. As such, the small hydropower can generate electricity for the project area well. However, during the dry season, it is unable to produce electricity efficiently because of the lack of water. In addition, some of the water needs to be used in agriculture for the community.
- c) Battery Energy Storage System (BESS): A lithium-ion Battery Energy Storage System (BESS) with a rated power of 100kW and a capacity of 100kWh is designed for this microgrid system to enhance the system operation reliability and stability. The Lithium battery uses advanced LiFePO₄ technology which has the advantage of high energy density (small volume, light weight), high charge & discharge rate (applicable for fast charge and discharge, long cycle life, adaptability to various environments, suitability to high power short time backup applications). To fulfill a sufficient performance of above 100kW@1h, the design energy capacity of the battery energy storage system is 107.52kWh, which is installed in the container, as shown in Fig. 4.



Fig. 4. 100 kW/100 kWh BESS at Khun Pae.

3. Methodology

This section discusses the management and operation of the grid connected microgrid. The first section described a typical application of microgrid controller, secondly, the energy management and algorithm of peak shaving. Finally, the constraints is described.

3.1. Microgrid controller

A microgrid controller is a device that has the ability to control various pieces of equipment in the area of Khun Pae; micro-hydro, solar PV, BESS, load break switch (LBS) and the communication system. It can be connected to the main grid (grid-connected mode) and independent power supply modes (islanded mode), including black start, load shifting or peak shaving, PV smoothing and SOC control function. There is a real-time monitoring system, measuring voltage, current, frequency, active power, reactive power and power factor electrically generated circuit breaker [6],[7]. A typical application of this device is carried out by the equipment of NR Electric Co., Ltd as shown in Fig. 5.

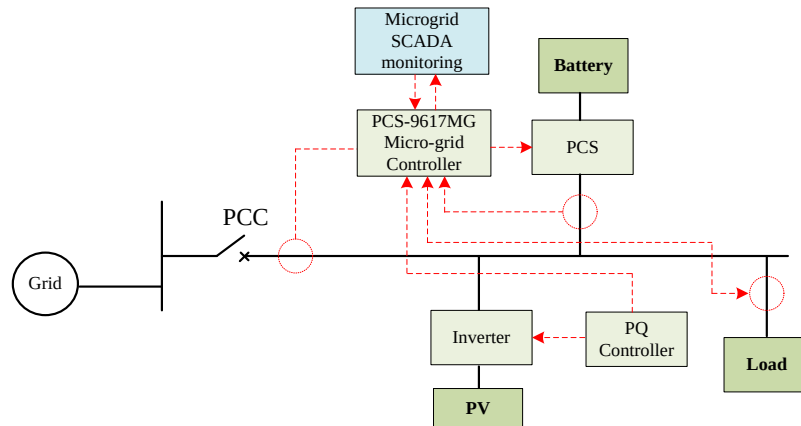


Fig. 5. A typical application of PCS-9617MG.

3.2. Microgrid Energy Management System (EMS)

The main source is solar PV used for energy management system, but maximum shaving with PV cannot be guaranteed because of the variation. Thus, the solution of peak shaving is used by BESS coupled with solar PV. The best use of BESS is the time-scheduling with planned curve and amount of charge and discharge via the power supply and solar energy. The Time of Use (TOU) is received from the grid. The typical EMS is shown in Fig. 6.

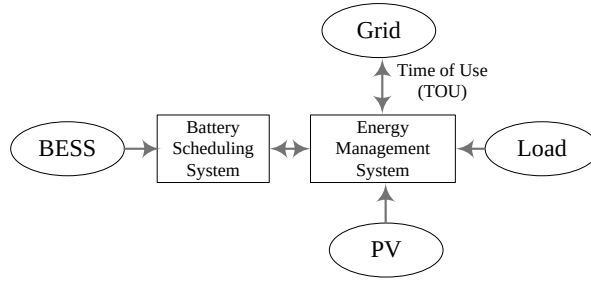


Fig. 6. The Energy Management System (EMS).

3.3. Peak shaving algorithm

The EMS is used to manage energy in a way that reduces energy imported from the grid and loss in the distribution line. Because the system calculates the energy consumption of the micro-grids compared to the load that occurs, the peak shaving step is required to reduce the demand and time, decreasing the maximum energy provided by the proposed algorithm by considering the energy contained within the BESS. The peak shaving process modified is summarized in the following main steps, as shown in Fig. 7.

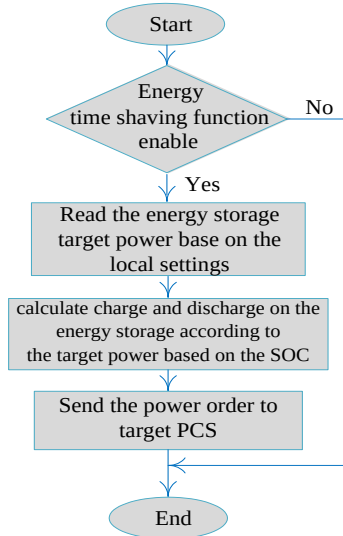


Fig. 7. Peak shaving algorithm.

3.4. Constraints

- Power balance constraint:

$$P_{Load}(t) = P_{PV}(t) + P_{BESS}(t) + P_{Grid}(t) \quad (1)$$

- Grid power constraint:

$$P_{grid}^{min} \leq P_{grid}(t) \leq P_{grid}^{max} \quad (2)$$

To reduce energy import from the main grid, the P_{grid}^{max} value is limited as follows:

$$0 \leq P_{grid}^{max} \leq P_{peak\ load} \quad (3)$$

$$P_{\text{grid}}^{\min} = -P_{\text{grid}}^{\max} \quad (4)$$

- Stabilize Fluctuation of PV:

The fluctuation control is divided into first order filtering control method and average filter control method according to the algorithm. First order filtering control based on the formula:

$$P_0 = \frac{1}{1+T_f s} P_{\text{DG}} \quad (5)$$

$$P_0 = \frac{1}{n} \sum_{i=1}^n P_{\text{DG}i} \quad (6)$$

$$P_{\text{bess}} = P_0 - P_{\text{DG}} \quad (7)$$

where: “ P_0 ” is the target power output value; “ P_{DG} ” is the actual output power value of distributed power supply; “ P_{bess} ” is the energy storage target output value; “ T_f ” is the time constraint for first-order filter and “ $P_{\text{DG}i}$ ” is the history output power value of distributed power supply.

- The constraint of BESS:

BESS state of charge constraint:

$$\text{SOC}_{\min} \leq \text{SOC}_{(t)} \leq \text{SOC}_{\max} \quad (8)$$

BESS power output:

$$P_{\text{BESS}}^{\min} \leq P_{\text{BESS}}(t) \leq P_{\text{BESS}}^{\max} \quad (9)$$

where $\text{SOC}_{(t)}$ is state of charge, $\text{SOC}_{\min}$ is lowest SOC, which is equal to DOD Depth of Discharge, $\text{SOC}_{\max}$ is maximum SOC which is an upper bound of battery capacity. In this study, DOD is 70%, $\text{SOC}_{\max}$ is 90% and $\text{SOC}_{\min}$ is 20%.

4. Experimental Results

BESS will charge and discharge power in accordance with the planned curve value set by micro-grid controller. When $\text{SOC} > 0.9$ (90%), BESS can't charge the battery. But on the other hand, when $\text{SOC} < 0.20$ (20%), BESS can't discharge the battery. Enable energy time shaving function, set parameters for power planned curve, start BESS and then compare the active output power of BESS with settings. In the setting items, there are 5 groups for charging and discharging. When the microgrid is working in remote status, BESS will charge & discharge according to the target power planned by SCADA, as follows in Fig. 8 and setting in Table I.

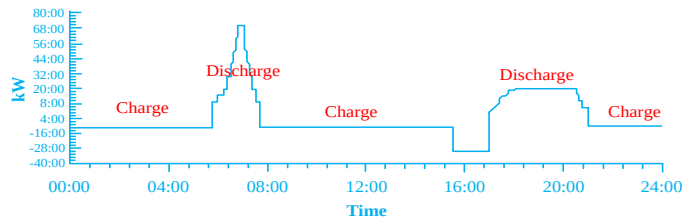


Fig. 8. Remote control power planned curve (RCC).

From the load profile as illustrated in Fig. 2, the concept is to use a control system with a battery to manage energy in the area and trying to reduce the energy consumption of the main grid. Peak shaving is

used during from 5:45 am to 7:45 am and from 17:00 pm to 21:00 pm. Another time period charges the battery to save energy from 7:45 am to 17:00 and 21:00 pm to 5:45 am. The management function is shown in Fig. 8 and Table I.

Table 1. Time of use operation

Time	Operate function
05:45am-07:45am	Peak shaving
07:45am -17:00pm	Charge battery
17:00pm -21:00am	Peak shaving
21:00am -05:45am	Charge battery

As shown in Fig. 9, from the concept of remote control power planned curve (RCC), the peak shaving function SOC setting which the energy consumption from the main grid at that time decreases. In the morning, peak decreases from 113.62 kW to 73.37 kW, and in the evening decreases from 98.71 kW to 78.87 kW, while the daytime load is negative at -67.25 kW. This means that the microgrid is sending power back to the main grid by solar PV system.

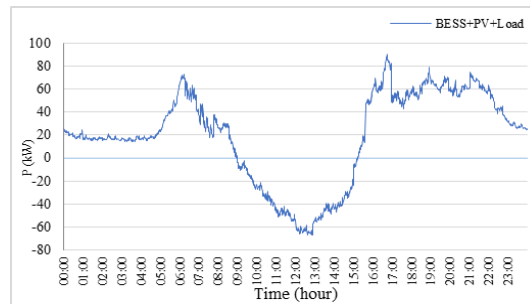


Fig. 9. Daily power output of PV and BESS curve.

As shown in Fig. 3. (b), microgrid generated power from PV panels was higher than the load with 89.4 kW maximum. PV generation is used to the load in local area. At the same time, the microgrid managed by sending excess energy back to the main grid which is a positive effect on the electrical system.

As shown in Fig. 10. (a), the SOC level is in the range of 20% - 90%. When the value of the SOC begins to increase the battery charges, storing energy from the grid. In addition, the battery is set to discharge to the load in the morning. After that, the battery is set to charge from solar PV in the afternoon. On a cloudy day, the PV power output is affected by light intensity and has fluctuating characteristics. Especially in the grid-connected state, changing of light intensity has a great influence on the PV output. The SOC value starts decreasing from 17:00 pm until 21:00 pm with battery supplied energy to the load. Then, battery power charged from the main grid to reserve to use in the morning for the load. The fast charging and discharging characteristics of the energy storage battery can be used to stabilize the fluctuation of PV output (PV smoothing) from 11:00 am to 15:00 pm as shown in Fig. 10. (b).

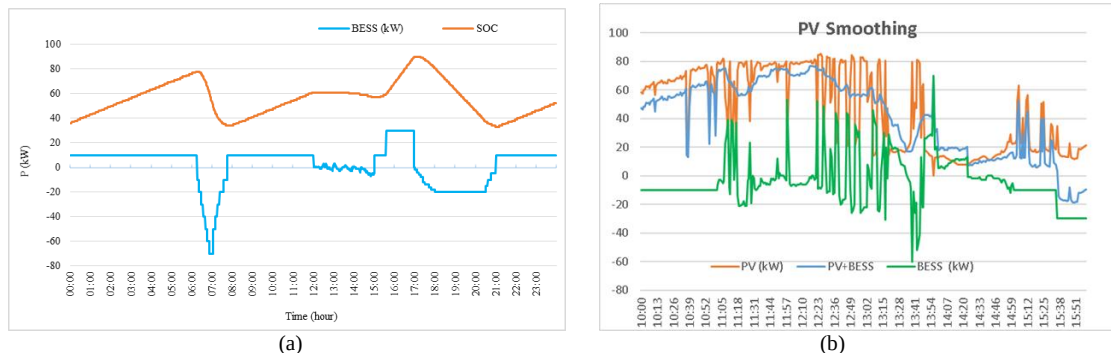


Fig. 10. (a) Battery energy storage system (BESS) and (b) The PV smoothing is average filtering control.

As shown in Fig. 11, the microgrid uses the battery energy storage system to manage the energy in the area well. Load before shaving (green line) with no onsite PV and battery, all electricity load consumption is supplied from the main grid at 52,484 kWh/day. Load after shaving (blue line) with both the battery storage and PV, all electricity load consumption is supplied with energy from the battery to peak period and sends back to the main grid by solar PV in a daytime at -14,578 kWh/day. The comparison plot graphs above are calculated for microgrid experiments, which can be found in Fig.11. It is able to reduce power consumption from the main grid by 27.78%.

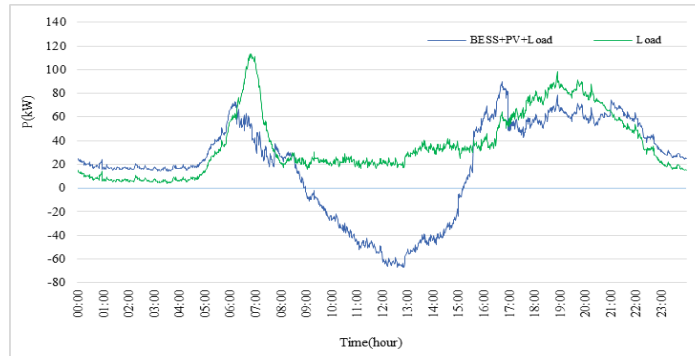


Fig. 11. The daily power output of PV, BESS and load curves.

5. Conclusions

This paper has focused on improving management for increasing grid power quality in power operation, which can use the battery to control power flow and peak load consumption. The energy storage system discharges power for use during times of high electricity load, including add power to respond the PV output variability and charges power storage in light load. The energy has sent back to the main grid by PV generation, which could be reduced by 27.78% or 14,578 kWh/day.

Finally, the operation strategy of a first pilot smart microgrid applies this experimental result to other projects and case studies in Thailand. The microgrid system is targeted to shave the peak load and produce a power generation that is a beneficial solution for the distribution system of PEA. It can be of great benefit and is able to reduce peak demand from the main grid.

Conflict of Interest

Currently, the fund promotes energy conservation provides to support the renewable energy association for sustainable development runs a project to improve the quality of life of remote rural communities in accordance with the sufficiency economy initiative. By installing the microgrid prototype system and laying out the community electricity grid according to the usage potential in each area by allowing the community to participate in this regard, the use of photovoltaic power generation technology together with high-efficiency energy storage systems is used. As well as installing a solar water pumping system for consumption and for agriculture, it helps reduce the burden on farmers and helps improve the quality of life for the community. In order to improve the quality of life for the communities in that area. Therefore, the author declares that in this paper no conflict of interest.

Author Contributions

In order to qualify for authorship, all authors have engaged in research and preparation as follows. This study was designed, directed, and coordinated as the principal inspectors, providing conceptual and technical advice for all aspects of this project by Assoc. Prof. Dr. Suttichai Premrudeepreechacharn. Performed and supported the experimental data by Provincial Electricity Authority (PEA) as Tirapong

Kasirawat, Channarong Sorndit, Thongchai Meenual. Discussed and commented on by Kohji Higuchi. Finally, summary and wrote the paper by Ketsavanh Solaphom.

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