Analysis of a Vanadium Redox Flow Battery for Energy Storage from Solar Rooftop

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Abstract: This paper presents an analysis of a vanadium redox flow battery (VRFB) for energy storage system of solar rooftop. VRFB was charged by a solar power supply system which supplies electricity to residential loads. The residential load had a total periodic change in energy of use for 11.26 kWh/day. The yearly solar radiation profile from Pathum Thani province was used to analyze and evaluate the efficiency and ability of the energy storage system. The simulation results showed that the unmet electrical load value was 0 kWh/yr and excess electricity was 1,337 kWh/yr. These results indicated that the efficiency of the system and the performance of vanadium redox flow batteries energy storage system were stable and reliable. The PV system with VRFB can continuously be discharged to the loads.

***Keywords* — Redox Flow Battery, Battery Backup Energy Storage, Energy Storage, Vanadium Redox Flow Battery.**

I. INTRODUCTION

Nowadays, there is more renewable energy to produce electricity such as wind power and solar power. However, the electricity generation from these energy sources is not continuous. In this case, the system needs to have an energy storage system to reserve enough energy to meet the demand load. As a result, these renewable energy sources are not as popular. Therefore, if we want the system can produce electricity from renewable energy sources to distribute the load continuously, we must have an energy storage. The energy storage supplied energy when the main power generation system was unable to supply energy continuously. The system will have the good quality of electrical energy supply and system reliability. Therefore, energy storage systems have an increased role and to reduce the problem of discontinuity. One of the things is that good energy storage systems must have a long service life or cycle, safe, and no impact on the environment. The energy storage devices that store the electric surplus production of renewable energy. [1], [2], [3]. We have presented an electrical energy storage system that is a vanadium redox flow battery to ensure its quality use. Therefore, it's necessary to test the properties of energy supply and energy storage. So that it can be used effectively We offer electric energy storage systems based on vanadium redox flow batteries to ensure high quality applications. Therefore, it is necessary to test the performance of energy supply and energy storage. So that, it can be used effectively.

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II. MATERIALS AND METHOD

A. Energy Storage Methods

An energy storage system (ES) is a system of storage energy for later use. The remaining energy from use was stored in various possible forms of energy, which can be classified into 6 types of energy storage, as shown in Fig. 1. Each type has different roles and purposes. It is very necessary to study the performance of each type of energy storage system before using it. To guarantee that it can be used correctly and efficiently.

Fig. 1. Typical of energy storage methods [4]

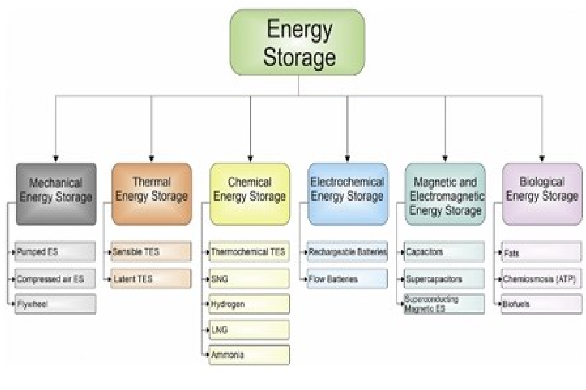

Fig. 2. Typical of energy storage methods [4]

These energy storage systems (ES) have different advantages and disadvantages. It depends on the use of stored energy. Each type of energy storage (ES) has many different subtypes. They can be classified according to the generation of energy and the materials used to store them as shown in Fig. 1. The classification of ES systems is done by grouping the techniques that store energy in the following ways: Mechanical, Thermal, Chemical, electrochemistry, magnetism, electromagnetism, and biology. These many ES techniques are still being developed and improved. As shown in Fig. 2.

B. Flow Batteries

Flow batteries are a type of electrochemical energy storage system (EESS). Two chemical components that dissolve in liquids separated by a membrane. Flow batteries charging and discharging occur through the transfer of ions from one component to another across the membrane. The advantage of flow batteries is that they can store large amounts of energy. The trend of interest in developing flow batteries has increased significantly along with the increasing demand for energy storage from renewable sources. Due to the high-capacity flow battery, there will be a large electrolyte tank to store large amounts of electrical energy. The main problem with flow batteries is the high cost of internal assembly materials. Such as vanadium, membranes etc. The use of flow batteries in the storage of renewable energy can be shown in Fig. 3. The electrical energy is stored in an electrolyte tank. Initially, the electrolyte is pumped through the electrodes by a pump. During the charging state, solar panels, wind turbines or grid inputs provide electricity for charging the electrolyte and stored in a tank. During the discharge period, liquid electrolyte is pumped through electrodes to separate the electrons and distribute electricity to the electrical load.

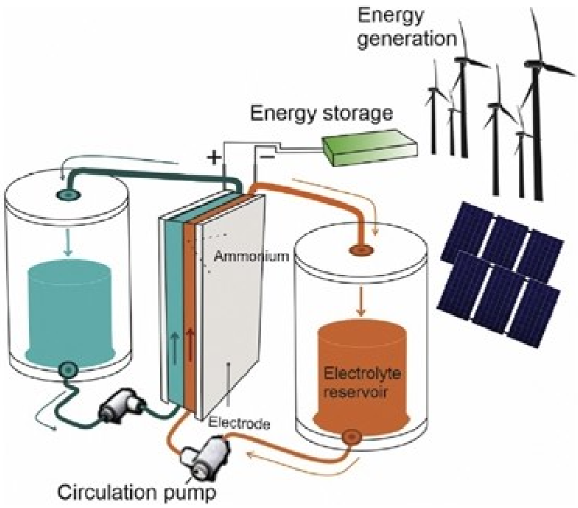

Fig. 3. Schematic view of flow batteries [5]

There are currently a variety of electrolyte pairings of redox flow batteries (RFBs) used on the electrolyte composition. Such as iron/chromium [6], [7], [8], iron/cadmium [9], quinone/bromide [10], vanadium/bromine [11] and all vanadium [12], [13], etc. The all-vanadium redox flow batteries (VRFBs) [14] have received considerable attention because of the advantages associated with using metal electrochemistry in both parts of the same electrolyte. This reduces the loss of efficiency, due to contamination of the membrane, where is the species crossover between the electrolyte components and an electrochemical cell. The electrolyte used in the negative battery is V2+/V3+, while the positive battery is V2+/V3+. V4+/V5+(VO2+/VO2+).

C. Vanadium redox flow batteries

The vanadium redox flow batteries (VRFBs) are the most commercially available flow batteries today. Because it has many advantages over other battery chemistries. Even though, it has limited energy and energy density. The use of vanadium on both electrodes prevents cross-contamination. However, the limited solubility of vanadium salts compensates for this advantage in practice. The most important for VRFB's commercial success is the near-perfect matching of the voltage window of the carbon acid/water interface with the operating voltage range of the vanadium redox couple. This guarantees the durability of the low-cost carbon electrode and low impact from side reactions. Such as H2 and O2 evolution, resulting in a record-long service life (several years) and cycle life (15,000–20,000 cycles). This has consequences, at a low cost of energy (LCOE, i.e. system cost divided by available power, cycle life and round-trip efficiency). The flow battery's long service life allows it to offset relatively high distribution costs. (minimizes the cost of vanadium, carbon felt, bipolar plates and membranes.) Total energy costs are about twenty to thirty dollars or euros per kWh, which is much lower than solid-state batteries and not far from the targets of approximately 0.05 dollars and 0.05 euros stated by the United States and EC government agencies in [15].

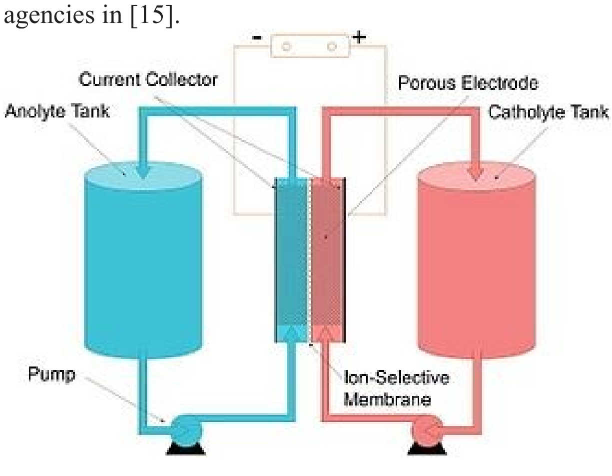

Fig. 4. A vanadium redox flow battery [15]

D. Resident load used for analysis

Fig. 5 and Fig. 6 show the demand for electrical energy at different times throughout the day, which has an energy demand throughout the day of about 11.26 kWh/day, 4,109.12 kWh/yr. and peak demand of about 2.09 kW. Therefore, a good electric power distribution system must be able to meet the demand of the load throughout the period. However, electricity production from solar energy alone cannot supply the load shown in Fig. , which still must receive electrical energy from other sources to distribute electrical energy during periods, when solar energy cannot supply it. Therefore, the energy sources have been experimented with and other technologies. They have been to be joined into the system to keep the system stable and reliable. Here, we will talk about vanadium redox flow batteries, which are batteries for backing up electrical energy, during periods when the production exceeds without distribution needed to the electrical load. It is stored in a vanadium flow battery. Then electrical energy is distributed when the main system is unable to supply electrical energy.

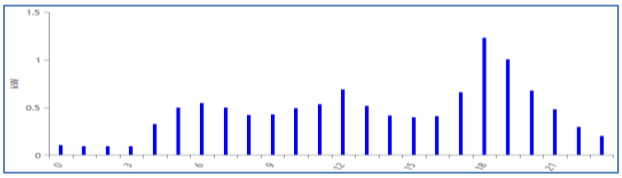

Fig. 5 Daily resident load profile

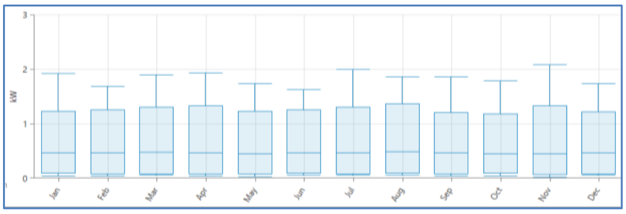

Fig. 6 Yearly resident load profile

III. RESULTS

The performance model system analysis includes solar panels, VRFB, energy receiving and distribution controllers, and a residential load of 4,109 kWh/yr., as shown in Fig. 7 by setup in the Homer Pro application is obtained, we input the value of yearly resident load profile and value of solar irradiation into the system, as shown in Fig. 5, Fig. 6 and Fig. 8. The profiles can be considered representative of general conditions. Therefore, it is used in this work as a general circuit model of solar irradiation to evaluate the charge of VRFB to compare the response of VRFB under intermittent power supply of solar panels. Therefore, two different charging modes are to be compared. First is a direct charge from photovoltaic energy of about 4 kW and Vanadium redox flow batteries (VRFBs) consisting of a Cell Stack of about 2.5kW and an electrolyte of 40kWh. This system is shown in table 1. The second is a direct charge from photovoltaic energy of about 4 kW and Vanadium redox flow batteries (VRFBs) consisting of a Cell Stack of 2.5kW and an Electrolyte of 60kWh. This system is shown in table 1. Both systems are similar in producing electrical energy. Since the size of the solar cell is 4 kWh. As shown in Fig. 9, it shows details of the energy produced each month. But they are different in the energy stored in the battery flow. This is a difference of about 1 kilowatt hour. This causes a lack of response to the load of 0.62 kilowatts of 2.5kW/40kWh VRFB system and causes a difference in excess energy of 1 kWh. From this experiment, it was seen that different capacity of flow batteries affects the amount of energy stored. Battery energy flows vary in energy input, energy output, capacity shortage, and energy supplied to the system by approximately 1 kWh/yr. But storage depletion is approximately 8.14 kWh/yr. The comparison of things that the system can produce can be seen in Table 1.

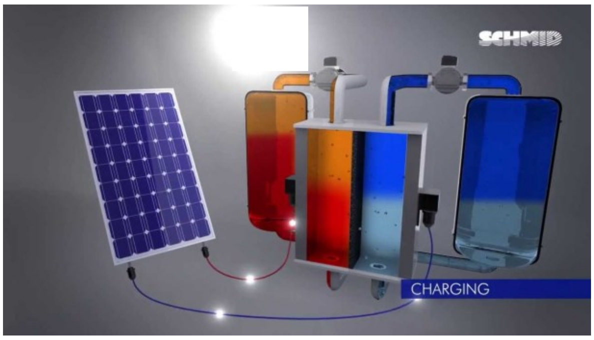

Fig. 7 Diagram of a vanadium redox flow battery for the storage of electricity produced by photovoltaic solar panels

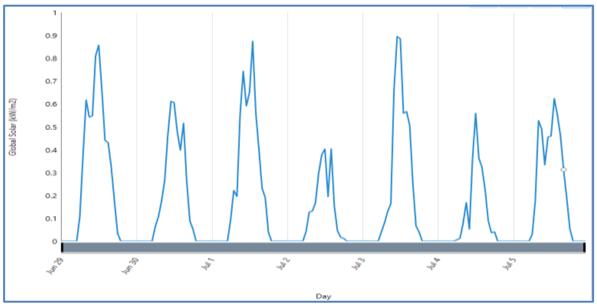

Fig. 8 Solar irradiation in June 29 – July 5

Table 1 Comparison of two difference mode.

Pv	Stack cell	Electrolyte	Excess electricity	Unmet electric load	AC primary load	Generic PV	Battery System				
							Ennergy In	Energy Out	Capacity Shortage	Storage Depletion	Annual Throughput
(kW)	(kW)	(kWh)	(kWh/yr)	(kWh/yr)	(kWh/yr)	(kWh/yr)	(kWh/yr)	(kWh/yr)	(kWh/yr)	(kWh/yr)	(kWh/yr)
4.00	2.50	40.00	1,338.00	0.62	4,109.00	6,238.00	2,912.00	2,337.00	1.62	8.14	2,613.00
4.00	2.50	60.00	1,337.00	0.00	4,109.00	6,238.00	2,913.00	2,338.00	0.13	8.14	2,614.00

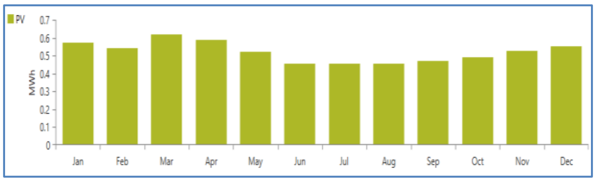

Fig. 9 PV generic power electric each month on year

The VRFB's charge cycle depends on the solar radiation, while the VRFB's charge cycle depends on the load profile. As shown in Fig. 10 (PV state=4kW and VRFB=2.5kW/40kWh) and Fig. 14 (PV state=4kW and VRFB=2.5kW/60kWh), in the case of a large amount of solar radiation causing VRFB can store a lot of energy, If VRFB is full of stored energy, it cannot store more energy, causing excess energy in the system in the amount of 1,338 kWh/yr. as shown in Table 1. From comparing the energy values that VRFB can store and to be collected. They can be indicated in Fig. 11 and Fig. 15, respectively, which have different accumulated energy values. The accumulated energy with a large amount of energy will be a VRFB system with a size of 2.5kW/60kWh. The increased amount of electrolyte results in increased energy storage. Although, the increase in electrolytes causes the energy work to increase as well. It will cause the cost of the system to increase accordingly. Therefore, allowing some periods of lack of load response will reduce costs. But it must be according to the purpose of the design.

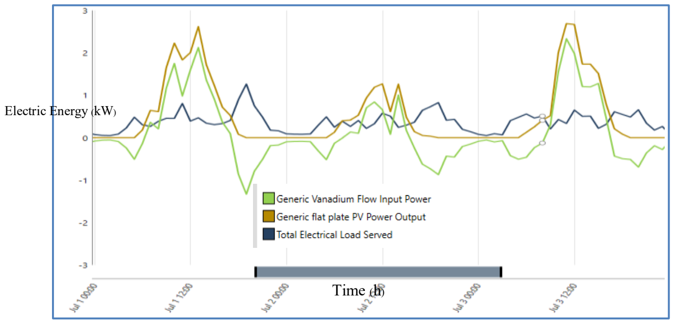

Fig. 10 Status of production, distribution, and storage of electrical energy of the system in each data. (PV=4kW, VRFB = 2.5kW/40kWh)

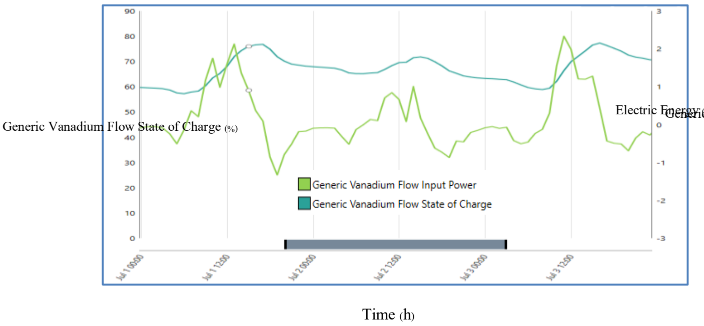

Fig. 11 Charging and discharging status of the vanadium redox flow battery at some periods (PV=4kW, VRFB = 2.5kW/40kWh)

The state of charge (SOC) of a battery over a year, as shown in Fig. 13 and Fig. 17, shows the state of energy stored in the electrolyte of a vanadium redox flow battery. The state shown in blue means the power level in VRFB is different at show 2.5kW/40kWh about 20% with 2.5kW/60kWh about 30%. The state shown in orange means the power level in VRFB is same around 100%. Therefore, a range of states in which SOC is low indicates that stores enough energy. It came through only a little or maybe it was because it used a lot of energy. As shown in Fig. 12 and Fig. 16, the status values of different SOCs are shown. A system using a 2.5kW/60kWh VRFB will have a higher monthly SOC value than a system using a 2.5kW/40kWh VRFB. This shows that increasing the amount of electrolyte results in better performance. This is a smaller investment than scaling up other energy storage methods.

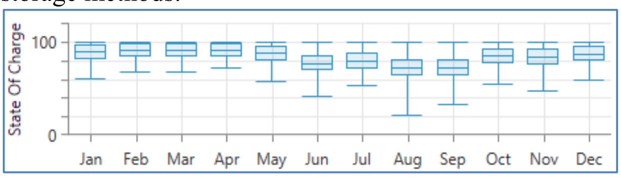

Fig. 12 State of charge of power electric each month (PV=4kW, VRFB = 2.5kW/40kWh)

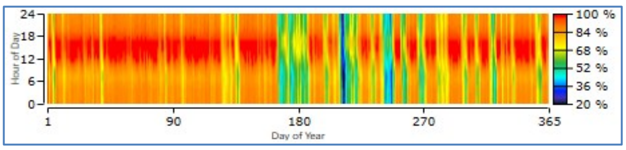

Fig. 13 State of Charge of a vanadium redox flow batteries (PV=4kW, VRFB = 2.5kW/40kWh)

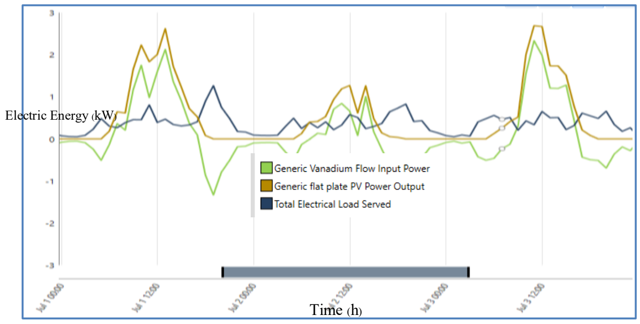

Fig. 14 Status of production, distribution, and storage of electrical energy of the system in each data. (PV=4kW, VRFB = 2.5kW/60kWh)

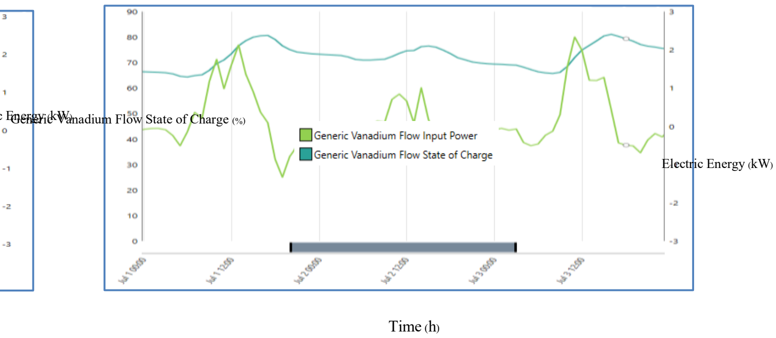

Fig. 15 State of charge and discharge of the vanadium redox flow battery at some periods (PV=4kW, VRFB = 2.5kW/60kWh)

The performance analysis of energy storage system in the form of electrochemical reaction by vanadium redox flow battery (VRFB). Each step presents all performance and efficiency characteristics such as power level, state of charge, and discharge (SOC), the energy level stored as electrons within the electrolyte. The comparison of system performance and efficiency when the electrolyte amount is changed. As a result, the efficiency of the system changes. This has been explained in Fig. 13 and Fig. 17 respectively. The case of monthly accumulated energy, as shown in Fig. 12 and Fig. 16, indicates the status of the accumulated energy level in the vanadium redox flow battery (VRFB). During August, there will be a minimum energy level of 20% (2.5kW/40kWh) and 30% (2.5kW/60kWh), which is a critical energy period resulting in a lack of energy to supply the load.

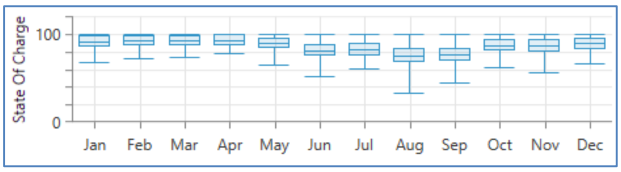

Fig. 16 State of charge of power electric each month (PV=4kW, VRFB = 2.5kW/60kWh)

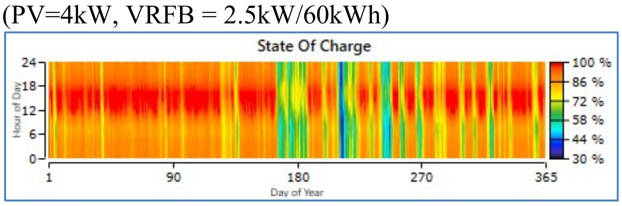

Fig. 17 State of Charge of a vanadium redox flow batteries (PV=4kW, VRFB = 2.5kW/60kWh)

IV. CONCLUSION

The experiments indicated that the good performance power supply system must be able to support 100**%** of the load demand**.** The proposed vanadium redox flow battery **(**VRFB**)** is proper for energy storage system**.** The first result showed the performance and efficiency of energy storage, the vanadium flow battery **(**VRFB**)** had better performance and efficiency that improved the power supply of the system**.** The advantage of VRFB is that it can increase the amount of energy by increasing the amount of electrolyte**.** It is able to support load demands by increasing the size of the cell stack to provide more power**.** However, the supply of electric power to the load and the storage of electric power will depend on the solar power generation capacity and the VRFB capacity**.** In the case of solar producing a lot of energy remaining in the system, but the vanadium flow battery has a small capacity, it will not be able to store energy as well**.** Therefore, system sizing design must take into account the size and fit to the performance of various components as well**.** The performance and efficiency of VRFB depend on the efficiency and quantity of the electrolyte in collecting electrons**.** The results of this study confirmed that the vanadium redox flow batteries are suitable for the backup energy storage of renewable energy by solar power generation systems**.** Further work is to take these promising results to the laboratory for long**-**term investigation and capture the influence of other parameters**.** However, if the use of redox flow batteries is promoted and developed more applications, it is necessary to develop standards for redox flow batteries to ensure safety for use**.**

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