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RELATIONSHIP BETWEEN CURRENT DISCHARGE TO STATIC AND DYNAMIC LEAD ACID BATTERY PERFORMANCE

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ABSTRACT

The performance of the battery depends on electrode material, electrolytes and input energy. Current is an energy input during the process charging and discharging. In this study, a dynamic lead acid battery is used with the features of Pb and PbO_2 as the electrode, 30% H_2SO_4 as electrolyte and constant current charging at 1.5 A for 4 hours. The dynamic battery was compared with conventional lead acid battery and the effect of different discharge current at 0.5 A; 1.0 A; 1.5 A; and 2.0 A on the dynamic battery was investigated. Comparison both type of battery showed that the voltage of dynamic battery always lower than conventional battery before reaching 2.4 V during charging process while the opposite result occurs during discharging process. The dynamic battery with 1 A discharge current has the highest capacity. After 30 cycles charge-discharge test for single cell battery has shown that the middle voltage of the battery decrease about 2% from 2.02 V to 1.99 V and still held the capacity of 3100 mAh.

Keywords: Battery, Dynamic Battery, Lead Acid, Capacity, Energy

1. INTRODUCTION

The growing electricity demand is not compensated by the availability of the electricity source. According to Enerdata (2018), the increasing of electricity consumption is faster than other energy vectors. The electricity consumption of 2017 is 22.016 TWh, increases up to 2.16 % from the electricity consumption of 2016 [1].

Coal is the biggest world electricity source, which its availability predicted by BP Statistical Review of World Energy (2017) will remain until 153 years with the same consumption rate of 2016 [2]. This leads to the using of renewable energy (electricity)

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source to lessen the using of the non-renewable electricity source. Renewable energy such as the solar cell or wind energy requires an energy storage system to maintain the energy supply [3]. A battery is an energy storage which store the produced electricity to be used when it is needed, as renewable energy depends on the weather condition [4,5].

A large scale and rechargeable battery are required as one of the components in the renewable energy source system. Redox flow battery (dynamic battery) is a new type of battery that is being hugely developed for its ability to store a great amount of electricity [6,7]. The dynamic battery has high efficiency, long cycle life and flexible design [8]. The active materials of the dynamic battery are stored in a separated container. The electrolyte is stored in the chamber and pumped through the battery cell, where the electrodes are stored [9]. Therefore, the dynamic battery has the ability to separate the battery capacity and power. Modification of the battery can be done just by modifying one component, chamber or cell. For the same cell size dynamic battery, a greater capacity can be obtained by increasing the volume of the electrolyte (which means also increase the size of the chamber) [10].

The dynamic battery can be classified into double electrolyte and single electrolyte dynamic battery. The double electrolyte dynamic battery uses two different types of electrolyte that are stored in two separated chamber, while the single electrolyte dynamic battery uses only one type of electrolyte. The using of only one electrolyte reduces the costs of the battery as we can cut the needs of an ion-separator and the second pump [11,12]. Lead acid is a battery that can be developed as a single electrolyte dynamic battery [12]. Lead acid battery is a rechargeable battery with a high capacity, long life cycle and high efficiency. The investigation of a soluble lead acid flow battery by Zhang, et all (2011) presents that the battery has a similar energy efficiency to a static lead acid battery, while the charge (current) efficiency is higher. A different applied current density can affect the battery performance. A higher current density can decrease the battery energy and charge density. The soluble lead acid dynamic battery has energy efficiency of 21-69 % according to the applied current density [13]. The single cell lead acid RFB with electrode size 22.5 x 7.5 cm^2 and 30% of sulfuric acid electrolyte show that the avarage capacity always bigger about 800 mAh than conventioanl lead acid [14] and the duration of discharging process for lead acid RFB always longer than conventional lead acid batterry in the [15].

In this work, the effects of different load current on the lead acid dynamic battery are investigated. The aim is to determine the most effective load current of the battery based on the highest battery capacity.

2. METHOD

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Lead acid battery works based on Pb electrode reactions in acidic electrolytes, such as H_2SO_4. When the battery is being discharged, negative-sulfate ions (SO_4^{2-}) react with the lead plate (Pb) at the anode. The reaction produce lead (II) sulfate ($PbSO_4$) by releasing 2 electrons. At the cathode, negative-sulfate ions (SO_4^{2-}) bind to lead dioxide plate (PbO_2) and produce lead sulfate ($PbSO_4$) by absorbing 2 electrons. PbO_2 also binds to hydrogen ions (H^+) to form water (H_2O). The electron release and electron capture in this chemical process causes an electrical potential difference between the positive and negative plates in the battery [16].

The chemical reaction of lead acid battery is a reversible reaction, that can be written as :

$$Pb + H_2SO_4 \longleftrightarrow PbSO_4 + 2H^+ + 2e \quad \text{(Anode)}$$

$$PbO_2 + 2H^+ + H_2SO_4 + 2e \longleftrightarrow PbSO_4 + 2H_2O \quad \text{(Catode)}$$

$$\overline{\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad} +$$

$$Pb + PbO_2 + 2H_2SO_4 \longleftrightarrow 2PbSO_4 + 2H_2O \; [17].$$

The electrolyte of the battery in this experiment is 450 ml 30% sulfuric acid (H_2SO_4) and the electrodes are 13.5 cm x 7.5 cm of lead (Pb) and lead dioxide (PbO_2). The electrodes are arranged as 1 cell. Because the battery electrolyte and electrodes are stored in a different container, a pump and pipe are needed to flow the electrolyte through the battery cell. A 1.95 watt peristaltic pump is used with a 3 volt adaptor as a power source of the pump, which produces a 9-10 ml/minutes electrolyte flow rate. The battery cell, chamber and pipe are transparent to make it easier to control the flow of the electrolyte. The battery cell is made of acrylic and the chamber is made of 600 ml plastic container.

The battery charge-discharge test was completed using a battery management system, Turnigy Accucell-6 that was connected to the battery positive and negative terminals. The obtained data was recorded by a software "ChargeMaster2.02" installed on PC that was also connected to the Turnigy Accucell-6. The charge current was set to be 1.5 A with the charge time of 4 hours for both static and dynamic battery. Both batteries were also discharged at the same applied current of 1.5 A. The batteries operate at the voltage of its open circuit voltage up to 2.41 V at the charging state. While at the discharging state, the batteries operate at voltage of its open circuit voltage down to 1.8 V (the battery voltage decreased while it was being discharged). The dynamic battery was also tested for different discharge currents of 2 A, 1.5 A, 1 A and 0.5 A. The test was also done for 10 charge-discharge cycles at the most effective discharge current known from the experimental data (1 A).

3. RESULTS AND DISCUSSIONS

3.1 Charge and Discharge Characteristic of Lead Acid Static and Dynamic Battery

The single cell lead acid static and dynamic batteries were charged for 4 hours with a 1.5 A load current set on Turnigy. Fig. 1 shows

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the cell voltage vs time and current vs time graphs for the first charge of the lead acid static and dynamic battery. As shown at fig. 1, the cell voltage and current of both static and dynamic batteries have similar behavior. The charge used a constant current followed by constant voltage method [18]. The cell voltage during charge increases from its initial charge voltage up to 2.4 V, then constant for the rest of charge process. Meanwhile, the current is constant at 1.5 A at the beginning, and then begin to decreases at the time the battery voltage reaches 2.4 V to keep the battery charge voltage constant until the battery fully charged.

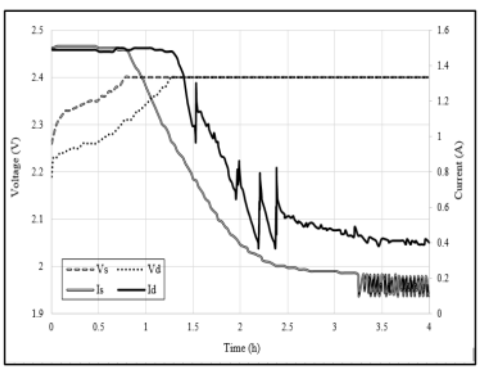

Figure 1: Voltage and Current relation during charging mode for static and dynamic batteries.

The dynamic battery initial charge voltage is ±0.08 V lower than the static battery initial charge voltage. With the same trend of the graph, the dynamic battery takes the longer time to reach the cell voltage at 2.4 V. The time difference between static and dynamic batteries to reaches 2.4 V is 0.5 hours. The longer it takes for the battery to reaches 2.4 V, the longer the battery holds its constant current at 1.5 A and more electric charge can be stored in the battery. At the decreasing part, the dynamic battery charge current looks like a jagged line which is caused by an unstable flow rate of the electrolyte. Overall, the charge graph of both static and dynamic battery have a similar trend. The static battery charge current decreases until 0.1 A, while the dynamic battery charge current decreases only until 0.4 A. This means the charge of the static battery has completed, while the charge of the dynamic battery has not. With the same charge duration of 4 hours, the dynamic battery is not fully charged, yet still produce a higher charge capacity than the static battery.

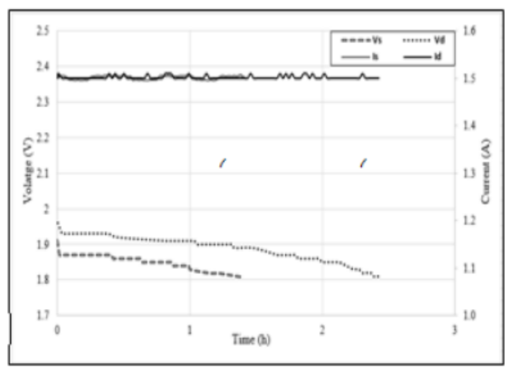

Figure 2: Voltage and Current relation during discharging mode for static and dynamic batteries.

The battery discharge voltage for both static and dynamic battery, as shown at fig. 2, decreases until 1.8 V. Meanwhile, the

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discharge current is constant at 1.5 A for both batteries. The dynamic battery has a higher initial discharge voltage and takes longer discharge time than the static battery. This means the dynamic battery has higher capacity. The 0.5 V difference in the initial discharge voltage between static and dynamic battery is resulting in 1 hour difference in discharge time or 1000 mAh difference in capacity.

3.2 Characteristic of Dynamic Battery with Different Discharge Current

The battery discharge characteristic can be affected by the current load to the battery. The same battery will show a different characteristic when it's discharged at different discharge current (load). In order to find the most suitable discharge current, the dynamic battery was charged and discharged for 4 cycles, which the charge current is 1.5 A for all cycles and the discharge currents are 2 A, 1.5 A, 1 A, and 0.5 A accordingly from the 1st cycle up to 4th cycle.

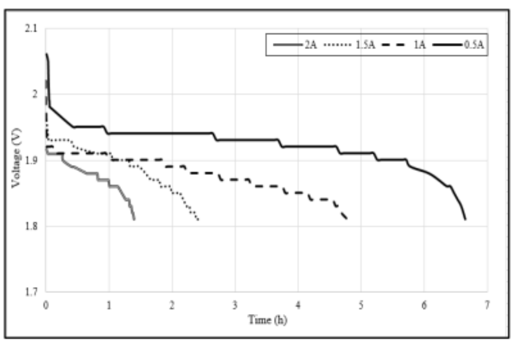

Figure 3: Comparison of voltage on dynamic batteries with different load current.

Fig. 3 presents the voltage vs time graph for 4 discharge cycles with different discharge current. The battery discharge time increases along with the decreasing of the discharge current. The battery discharge time for each cycle (1st up to 4th) are 1.4 hours, 2.42 hours, 4.78 hours and 6.65 hours accordingly. Since electric current is the amount of charge per second that past a point, the smaller the amount of charge given by the battery per second, the longer it takes for all charges to past the point. The dynamic battery with lower discharge current has more stable cell voltage. At lower current density, the battery over-potential is smaller or the discharge of the battery begins at a higher discharge voltage [13,19].

The dynamic battery capacity is affected by the different discharge current. The capacity for each cycles are 2798 mAh at 2 A discharge current, 3641 mAh at 1.5 A discharge current, 4780 mAh at 1 A discharge current, and 4435 mAh at 0.5 A discharge current. This shows that 1 A is the most suitable discharge current which results in the highest battery capacity. This also shows that high discharge current can cause more energy loss, which causing in a decreasing of the battery capacity.

3.3 Dynamic Battery Performance for the First 30 Cycles

The dynamic battery was tested for 30 charge-discharge cycles at 1 A current of

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charge and discharge. Fig. 4 presents the battery voltage vs time graph for the first 10 cycles. It can be seen that the cycling time at the 6th up to 10th cycles decreases significantly. The decreasing of battery cycling time will affect the battery capacity. The 1st cycle (initial) charge capacity is 4931 mAh, and then decreases every ±100 mAh for the next cycles. The decreasing of charge capacity for the 9th cycle is 1527 mAh, which is a large decrease.

Because of the large decrease, the 9th cycle charge capacity become 57% of the initial charge capacity. This happens due to a condition of the battery that begins to drop in performance. Conventional lead acid batteries would fail if a large value of the charge capacity drops to 70-80% of the initial battery charge capacity [20]. After 30 cycle, the dynamic battery still recorded 3100 mAh of it capacity but with more fast duration of charging and discharging.

The performance drop on the battery can be noticed by the decrease in capacity or the load that can be stored by the battery. This performance drop lasts until a failure in the battery system occurs due to a not completed reduction of lead dioxide into lead (II) ions. The gradual growth of lead dioxide at both electrodes occurs. Pb^{2+} concentration decreases and the proton concentration increases as the some of the active particle lead (II) fell from the electrode and some transformed into lead dioxide deposit that cannot dissolve into Pb^{2+}. This phenomenon causes the battery failure due to the lack of lead (II) content in the electrolyte or short circuit in both electrodes [21]. The other aspects that could reduce the battery performance, such as the electrode grid corrosion, the entry of oxygen into the battery cell, the reduction of the active materials adhesion, the loss of water in electrolyte, etc [22].

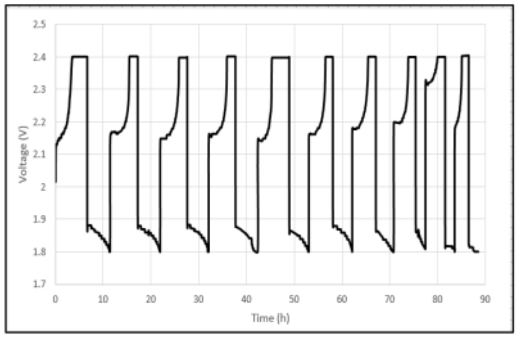

Figure 4: The life cycle test of dynamic battery with 1 A of load current for first 10 cycles.

4. CONCLUSION

The lead acid dynamic battery is a rechargeable battery which has higher voltage and capacity compared to the conventional (static) battery. The most suitable discharged current for the dynamic battery based on the experimental results is 1 A, which produces the highest battery capacity at 4780 mAh. The dynamic battery with 1 A charge and discharge current has an initial capacity at 4931 mAh, and the performance drop begins at the 9th cycle.

A further development on the battery setting is needed in order to achieved a high

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capacity lead acid dynamic battery with a longer life cycle which also consider the battery efficiency.

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