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AGV Battery Life Prediction using Voltage Depth of Discharge Method

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ABSTRACT

AGV (Automatic Guided Vehicle) is a mobile robot that distributes components or products from one production line to another without a crew by following certain navigation lines. The battery is the main power source for the AGV. Batteries can become damaged or short-lived due to: over-voltage, over-charging, and over-discharging. This research examines the estimation of battery life using the average percentage level of the battery's Depth of Discharge (DOD) voltage and the number of daily cycles used by the battery. The battery tested was the Valve Regulated Lead-Acid (VRLA) type with a nominal voltage capacity of 24 Volts obtained from 2 batteries with a voltage of 12V each and a capacity of 65Ah arranged in series. The research was carried out by measuring the battery voltage after each AGV operational cycle. The results of data acquisition and calculations show a percentage level of Depth of Discharge (DOD) of 10% with an average discharge voltage of 1 volt. The estimated remaining life of a Valve Regulated Lead-Acid (VRLA) battery is 693 battery cycles or the equivalent of 1 year, 10 months, and 28 days.

Keywords: AGV, battery, depth of discharge, life cycle

1. Introduction

One of the key processes for smooth production in the manufacturing industry is material handling, especially in the horizontal distribution of goods from one location to the next. AGV is an option when the transmission distance is far enough to be reached by a handling robot or conveyor. AGV is a mobile robot vehicle that moves without a crew which generally follows a pre-planned path. These paths can be in lines on the floor with certain colors or magnetic tape. AGV offers high streaming because the travel path can be changed accordingly and high efficiency because it can operate independently without an operator. The AGV's ability to follow a predetermined path is very dependent on the drive control module which consists of an electric motor, sensors, and a control system that generally uses a programmable logic controller (PLC) [1].

The main source of electricity for an AGV comes from the battery, so the battery plays an important role in the smooth operation of the AGV. Therefore, sufficient battery capacity is very important to support AGV operational time. Research on battery development to find out the best way to maintain the battery's ideal condition or imagine the battery's lifespan.

Research on battery charging strategies was carried out by Zhan et al using the automatic charging station method which was distributed at several points on the AGV work route. By placing a charging station close to the AGV's travel route, whenever the AGV needs to charge its battery, it can easily reach it. The next step is to set the battery charging time. The state of charge (SoC) and depth of discharge (DoD) of the battery are often used as references for battery capacity to determine the optimal charging duration so that the AGV can return to work immediately after its ideal capacity is met [2]. SoC means the percentage of remaining battery capacity and the full capacity of the

SoC. SoC is usually expressed in percentage (%) where if the SoC value is 0% it indicates the battery capacity is empty, and conversely, 100% indicates the battery capacity is full. DoD which is the inverse of SoC refers to the percentage of battery discharge and its full capacity.

Batteries can be degraded due to incorrect treatment in the process of charging and using the battery. This degradation causes the battery to gradually become unusable. In other research, the way the battery is charged is studied so that it can be seen to what extent it will affect reducing its capacity. The research was carried out by reviewing the DoD on the battery to find out how much DoD variation occurred. The larger the DoD, the more the battery capacity will decrease. The next step is to compare the effectiveness of Constant Voltage Charging (CVC) with the pulse charging method. As a result, the comparison between CVC and pulse charging methods indicates that the pulse charging method has a more significant performance in terms of battery capacity reduction [3].

Estimating the decline in capacity of a battery or general things related to the battery aging process is very useful in planning battery use. So, it can help increase the efficiency and reliability of the AGV energy system. However, this estimate is technically difficult because the battery aging process is influenced by many factors, including physical and chemical reactions that occur when the battery is stored until the battery is used, where this process is quite complex and non-linear, storage temperature and when the battery is used, SoC, DoD, charging and discharging currents, and the charging method. A simple step that can be taken to find out the battery aging model is to carry out experiments directly over several days, months, or even years [4].

The type of battery most widely used in AGVs is Valve Regulated Lead Acid (VRLA). Research on VRLA batteries was carried out by Rifqa Al Hadi et al by estimating the SoC on the battery using the open circuit voltage method. OCV (Open Circuit Voltage) is a power supply voltage value when not connected to the load. This method is considered quite precise with two experiments that only differ by 3.77% [5]. Specifically, batteries can have dynamic behavior in responding to the repeated charge-discharge process. Through the stages of modeling the battery cell, carrying out calculations from the battery model, and carrying out battery testing, an estimate of the state of health (SoH) of the battery can be obtained so that we can get an idea of how quickly and how much battery replacement or battery backup is needed [6]. Used batteries with low SoH have low energy storage capacity, so they generally require a short charging time. Meanwhile, batteries with high SoH have a high energy storage capacity with a longer charging time [7].

This paper presents predictions of the remaining life of AGV batteries with the VRLA type using the DoD method. This method was chosen because it can provide an overview of the remaining capacity value that the battery can still store. Section 2 contains a description of the methods used in the research. Section 3 contains data obtained in measurements and data processing results. Section 4 contains research conclusions.

2. Material and Methods

This research was conducted on an AGV unit at the car manufacturing company, PT.ADM. The AGV operates using 2 Panasonic LC-P1265NA, VRLA batteries with a voltage of 12V and a current capacity of 65 Ah. AGV operates 8 hours a day from 8 to 5 pm. At the end of every working hour, the AGV battery is charged until it is full and used again the next day.

VRLA batteries can be damaged due to overcharging, undercharging, or over-discharge. The significant formation of lead sulfate ($PbSO_4$) can increase the DoD value. This battery is not recommended for use at more than 80% of its capacity [8]. This battery has no caps/valves, no access to electrolytes, and is sealed. Thus, this type of battery does not require maintenance. This type of battery can last for approximately 10 years with good capacity planning and maintenance. The explanation of the parameters can be seen in Table 1.

Table 1: Characteristics of lead-acid based on standard [9]

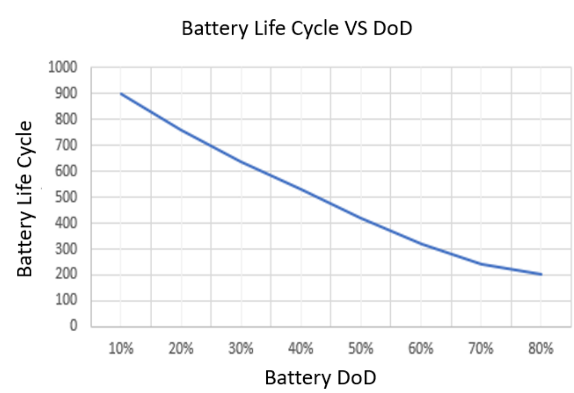
CHARACTERISTICS	LEAD ACID
Specific energy (Wh/kg)	30-50
Internal resistance (mΩ)	Very low
Life cycle (80% discharge)	200-300
Fast-charge Time	8-16 hour
Self-discharge/month	5%
Cell voltage (nominal)	2V
Cut-off Charge Voltage (V/cell)	2.4 float 2.25
Cut-off Discharge Voltage (V/cell, IC)	1.75
Charge temperature	-20 up to 50°C
Discharge temperature	-20 up to 50°C
Maintenance	3-6 month

The research stages were carried out as follows:

1. Data collection on DoD's relationship to battery cycles
2. Measurement of battery open circuit voltage when the battery is fully charged and when the battery is empty
3. Average battery discharge every hour
4. Calculate the DoD value from the average hourly discharge
5. Determine the equation for reducing the battery life cycle relative to DoD
6. Substitute the DoD value in the equation to get the life cycle value

Figure 1 shows a graph of the battery life cycle against the DoD used in the battery. The battery has a life cycle of 900 times if used at a DoD of 5% and a life cycle of 200 times if used at a DoD of 75%. AGV uses 2 batteries with an effective voltage of 12V connected in series to form a battery with an effective voltage of 24V. Measuring the voltage on the battery gets the maximum power condition when it is fully charged at 30V and when the battery is empty it is 20V. Thus the battery has a voltage span of 10V which describes a total capacity usage value of between 0-100%. The results of this measurement will get the average battery discharge voltage every hour. DoD is obtained by comparing the hourly discharge voltage to the total discharge capacity (10V) [10].

$$DoD = \frac{Average\ Discharge}{Total\ capacity}\ x\ 100\%$$



Source: (Battery Panasonic VRLA Handbook Professional, 2023)
Figure 1: Battery Life Cycle Vs Battery DoD

The equation for decreasing the life cycle to the DoD value as shown in Figure 1 is obtained using linear regression, assuming battery DoD as the X axis and Battery Life Cycle as the Y axis. By entering the DoD value in this equation it will produce the number of Battery Life Cycles.

3. Results and Discussions

Table 2 is the results of hourly measurements of battery voltage in open circuit conditions. The DoD percentage is obtained by comparing the average discharge to the total capacity.

$$DoD = \frac{1}{10}\ x\ 100\%$$
$$DoD = 10\%$$

Table 2: Voltage Discharge per hour

HOUR	OCV (VOLT)	DISCHARGE (VOLT)
0	29,2	0
1	27,8	1,4
2	25,4	2,4
3	24,8	0,6
4	24,3	0,5
5	23,8	0,5
6	23	0,8
7	22,7	0,3
8	21,5	1,2
Average Discharge/hour		1

The linear regression results are shown in Figure 2 below.

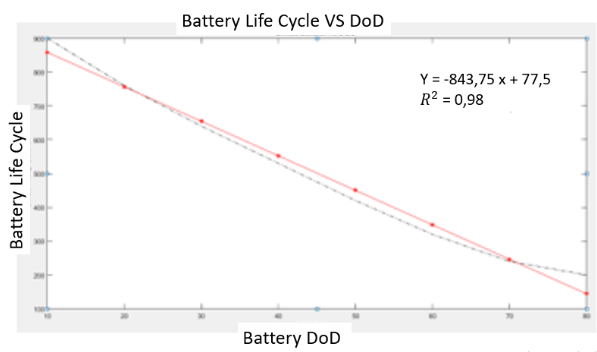


Figure 2: Equation for Battery Life Cycle Vs Battery DoD

The equation for linear regression is:

$$Y = -843.75(X) + 777{,}5$$

Where X is the DoD value. The DoD value is then included in the battery life cycle graph to find out how many charge and discharge cycles can be carried out until the battery cannot be used again. So:

$$Y = -843.75(10\%) + 777{,}5$$
$$Y = 693.125$$

With the number of charging and battery usage cycles being 1 time per day, the value of 693.125 life cycles can represent the predicted number of days in which the AGV battery can still be used, namely 693 days. Or the equivalent of 1 year, 10 months and 28 days.

4. Conclusion

Based on measurements, calculations and data analysis, the following conclusions are obtained:

1. The nominal voltage capacity of each battery is 12 Volts and the total of 2 batteries is 24V.
2. The effective voltage of 2 batteries when fully charged is 30V and when empty is 20V.
3. The battery has an average discharge voltage of 1 Volt per hour, with a DoD value of 10V
4. With a DoD of 10%, the predicted number of cycles is 693,125.
5. With 1 charging and discharging process per day, the battery is predicted to last for 1 year, 10 months, and 28 days.

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