Life Estimation Method for super capacitors Used in Wind Turbine Pitch

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Abstract. At present, various wind farms in the industry have not established a service life based on the actual situation of super capacitors used in the wind turbine pitch system, a new method for estimating the life of super capacitors is proposed. The first step is to collect the charging voltage value and the annual temperature data value of the capacitor cabinet of a wind turbine, and then calculate the actual operation time of the super capacitor at each temperature point. Secondly, we use the life estimation formula to calculate the estimated operating life of the super capacitor at each temperature point. Finally, we use the method of life conversion to convert the actual operation time of super capacitor at each temperature point into the operation time of super capacitor at a specific temperature point in a year, and then the estimated life value of super capacitor is calculated. This new method for estimating the life of super capacitors takes into account the differences in the local environment of wind farms across the country, as well as the influence of the actual operating environment difference of each wind turbine on the life of super capacitor. The proposed method plays an important role in the regular maintenance and replacement of the super capacitor used in the wind turbine pitch system.

1. Introduction

At present, the pitch backup power sources used in domestic and foreign wind farms are mainly lithium batteries, lead-acid batteries and super capacitors[1-3]. Super capacitors have the advantages of fast charging speed, long cycle life, and strong discharge capacity. In recent years, super capacitors have gradually been used in wind farms and gradually replaced lithium batteries and lead-acid batteries[2]. The main factors affecting the service life of super capacitors are the charging voltage and the temperature of the use environment. Considering that China has a vast area, the environmental differences in various regions are large, and the aging degree of super capacitors in the charging system of the variable pitch cabinet of each wind turbine is different. As a result, there is certain deviation in the charging voltage value, so it is impossible to formulate a uniform service life value of the super capacitor for the wind turbine pitch. NB/T 31149-2018 "Technical Specifications for super
capacitors for Wind Turbine Pitch System\textsuperscript{a} has not stipulated the replacement period of super capacitors. It is generally believed in the industry that when the super capacitor capacity decays to 80% of the nominal value or the internal resistance ESR increases to 200% of the nominal value is defined as the failure of the super capacitor function, which has reached the end of its life and needs to be replaced. After sampling inspection and analysis of key parameters such as internal resistance, capacity, and withstand voltage insulation of super capacitors used in wind farms in different regions, combined with operation and maintenance experience, then the wind turbine manufacturer agreed that the current imported super capacitor replacement cycle is 10 years. Therefore, in the actual use process, when the service life of the super capacitor is close to 10 years or the feathering requirements cannot be met, replacement measures are taken, which may easily lead to unexpected safety accidents. How to calculate the estimated life value of super capacitor according to the actual operation of each wind turbine in each wind farm plays a very important reference role in the regular maintenance and replacement of super capacitor.

2. Factors affecting the life of super capacitors

The operating voltage and operating temperature are the main factors that cause the deterioration of the super capacitor electrode and the decomposition rate of the electrolyte. The decomposition voltage of the electrolyte restricts the maximum working voltage of the super capacitor. On the contrary, the working voltage affects the parameters related to the stability of the super capacitor electrolyte, such as current density and temperature. In the range of temperature, high temperature increases the activity of the electrolyte, resulting in accelerated aging. Its accelerated thermal decomposition and electrochemical reactions that lead to a decrease in the ion concentration of the electrolyte, the decomposition products block the separator, and reduce the accessibility of the electrode to the pores.

The estimated life of the super capacitor at each charging voltage point at each temperature time is calculated by the following life estimation formula:\textsuperscript{[4]}

\[
MSL(U_x,T_x) = MSL(U_0,T_0)(\frac{U_x}{U_0})^{-a}e^{-(E_a/k)((1/T_x)-(1/T_0))}e^{-m(U_x/U_0)\beta(T_x/T_0)\beta}
\]

Among them, \(U\) and \(T\) respectively represent the charging voltage value and temperature value of the pitch capacitor cabinet; \(MSL(U_0,T_0)\) represents the estimated life of the super capacitor when the voltage is \(U_0\) and the temperature is \(T_0\). \(n=0.6\), the power-law index of voltage; \(E_a=0.3\)eV, the activation energy of a typical electrochemical capacitor; \(K=862e^{-5}\) Ev/K, boltzmann constant; \(m=0.023\), the Gain; \(\alpha=16\), the power law exponent of voltage factor; \(\beta=17\), the power factor of temperature factor;

Substituting the above parameters into formula (1), the life estimation result of super capacitor is shown in Figure 1 below.

Figure 1. Predicted life of super capacitors at different charging voltages at different temperatures

As can be seen from the figure above, the predicted service life of super capacitors is longer at lower ambient temperatures and lower charging voltages. Under actual use conditions, in order to ensure the charging speed of the super capacitor, the charging voltage of the super capacitor charging device generally used is set to 2.5V.
3. super capacitor life estimation method
A method for estimating the life of a super capacitor for a wind turbine pitch includes the following steps, as shown in Figure 2.

(1) Collect the charging voltage of the capacitor cabinet of a certain wind farm and the temperature data of 10 minutes throughout the year, and calculate the actual operating time of the super capacitor at each temperature point. The so-called 10min temperature data value means that the SCADA system of the wind turbine records the average temperature value of the pitch capacitor cabinet within 10min every 10min. The range of the temperature data value should be between 0 and $T_{\text{max}}$°C is the lowest temperature value of the pitch capacitor cabinet after the unit starts normally.

(2) Using the above life estimation formula (1), the estimated operating life of the super capacitor at each temperature point is calculated.

(3) Divide the estimated operating life of a super capacitor at a specific temperature by the estimated operating life at each temperature instant to obtain a life conversion coefficient curve.

(4) Combined with the life conversion coefficient curve, the actual operating time of the super capacitor at each temperature point in a year is converted into the converted operating time of the super capacitor at a specific temperature point. The converted operating time is equal to the product of the actual operating time and the life conversion coefficient curve.

(5) Sum the converted operating time of the super capacitor in one year, and the sum value is the actual total operating time of the super capacitor at each temperature point in one year, which is equivalent to the total operating time at a specific temperature point. Finally, divide the summation value by the estimated operating life at a specific temperature point to obtain the estimated life of the super capacitor for the wind turbine's pitch.

4. Example analysis and field verification
Taking a wind farm in Hainan Province as an example to calculate the estimated life of a super capacitor, the realization process is as follows.

The temperature data of the capacitor cabinet and the charging voltage value of the pitch capacitor cabinet of a wind farm in Hainan in 2018 were extracted. The SCAD system recorded the temperature...
values of the pitch capacitor cabinet of 3 pitch blades of a wind turbine every 10 minutes. A total of 52560 data points are collected in 365 days of the year, as shown in Figure 3 below.

![Temperature data collected at 10min temperature throughout the year](image)

Figure 3. Data collected at 10min temperature throughout the year

It can be seen from Figure 3 that the temperature values of the pitch capacitor cabinets of the blades 2 and 3 are basically close to each other, and the temperature value of the pitch capacitor cabinet 1 has a large deviation. After investigation, it is found that this is due to the existence of the cooling fan in the pitch capacitor cabinet Aging, jamming scene, resulting in poor heat dissipation.

The charging voltage of the pitch capacitor cabinet is generally maintained at about 2.5V. To simplify the subsequent calculation process, each temperature data value is rounded to an integer, and the actual operating time of the super capacitor at each temperature point is calculated, as shown in Figure 4 (a).

The conversion coefficient is shown in Figure 4 (b), and 25°C is selected as the reference point for conversion. The ratio of the predicted life of the super capacitor at this temperature to the predicted life of the super capacitor at each temperature point.

Multiplying the actual running time of the capacitors at each temperature point in Figure 4 (a) by the corresponding conversion factor in Figure 4 (b), the conversion running time when the conversion shown in Figure 4 (c) is 25°C is obtained.

![Conversion running time](image)

Figure 4. The actual operating time at various temperatures is converted to the converted operating time at 25°C
Known from Figure 4 above, for example, the corresponding conversion factor of wind turbine blade 1 at 44°C is 2.1. Under this conversion factor, the service life of the super capacitor at 25°C is about 2.1 times the service life of the super capacitor at 44°C. At this moment, the actual operating time of the super capacitor is 283.8 hours, which is equivalent to about 596 hours at 25°C.

All temperatures are converted to the operating time at 25°C, and the sum of the three blades is 1.76 years, 1.5 years and 1.48 years, respectively. That is to say, the super capacitors in the three capacitor cabinets can run for 1.76, 1.5 and 1.48 years respectively under the actual operation of the wind farm for one year in 25°C.

According to formula (1), the predicted life time of super capacitors at 25°C is 17.1233 years. From this, the lifespans of the three capacitors under actual operating conditions are 17.1233/1.76 = 9.7 years and 17.1233/1.5 = 11.4 years, 17.1233 years/1.48 = 11.57 years, thus the estimated life of the super capacitors in the three capacitor cabinets of the unit are 9.7 years, 11.4 years, and 11.57 years respectively.

A large number of super capacitor modules replaced after 10 years of operation of the wind farm were disassembled. It was found that some super capacitor modules swelled and leaked, the electrodes and the casing broke through the arc, which was no longer satisfactory. Paddle requirements are shown in Figure 5 below. It can be seen from this that the estimated life of the super capacitor in this paper is very close to the actual field service life and has certain credibility.

Figure 5. Damaged pitch super capacitor

5. Conclusion
This paper proposes a method that estimating the life of super capacitors for variable pitch, which reduces the waste of resources caused by unreasonable super capacitor replacement cycles, frequent labor costs and environmental pollution. It can make a scientific and economic replacement standard according to the actual operating environment of each wind farm, this is of great significance to the regular replacement and maintenance of super capacitors.

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