FAILURE DETECTION OF THE CAPACITOR BANK OF THE THREE PHASE DIODE RECTIFIER

Tamer Kamel, Student Member, IEEE, Yevgen Biletskiy, Member, IEEE, Liuchen Chang, Senior Member, IEEE

University of New Brunswick, Fredericton, New Brunswick, Canada
{tamer.kamel, biletski, lchang} AT unb.ca

ABSTRACT

This paper provides new methods to detect and investigate the failure in the DC filter of the power rectifier. The proposed diagnoses techniques are interested in two types of capacitor faults; capacitor aging and capacitor open circuit O.C. faults. The required inputs for the methods are the ripple of the DC voltage of the capacitors as well as the loading and the supply conditions.

Index terms-Capacitor Aging, 3 Phases Rectifier, Open Circuit Fault, and Discrete Fourier Transform DFT.

1. INTRODUCTION

Dc bus electrolytic capacitors have a short lifetime, which is often shorter than that of the power semiconductors. Moreover, these Capacitors are responsible for more than half of the breakdowns in power converters [1]. So, there is a big need to include them into the diagnosis. Dc bus capacitor failures can be subdivided into total breakdowns, Capacitor aging and Open Circuit fault. In the case of a total breakdown, which corresponds to a blown fuse of the capacitor, the converter will usually be shut down because of an insufficient smoothing effect in the dc link. In the other two cases a certain limits should be defined and a preventive maintenance is necessary to avoid further growing of their effects and following total breakdown.

This research uses electrolytic DC capacitor of 250V-1000uF for the rectifier. This capacitor has ESR “internal series resistance” at normal condition equals nearly 200 m$\Omega$ [2]. It contains three paralleled capacitors in series with other three paralleled capacitors. Therefore, at normal condition:

$$C = 1000 \times \frac{3}{2} = 1500uF \quad ESR = 200 \times \frac{2}{3} = 133.33m\Omega$$  (1)

2. FAULT DETECTION TECHNIQUES

1. Capacitor Aging:

The main aging mechanism is the evaporation of the electrolyte which increases with high currents ripple and temperature. The consequences are the increase of internal resistance and a decrease of capacitance. Many authors and some manufactures define the end-life limit of a capacitor when ESR doubles or C changes 20%, when compared with their initial values [1-3]. Aluminum electrolytic capacitors have a liquid electrolyte that has proprieties like conductivity and viscosity. Both proprieties change with temperature. For instance, conductivity increases with temperature which explains the ESR decreasing with temperature. However, in this research we assumed that the environmental temperature is kept constant during all the operation period of the equipment, so we will focus on the alteration of the ESR due to only the internal variations inside the equipment.

There are previous researches investigate the measure of ESR using the ripple of the output DC voltage “Vdc” of the capacitor, the current flowing through the capacitor, and the case temperature of the capacitor [1,4,5,6,7]. However, due to the available sensors in the system under study, the output DC voltage of the capacitor is only accessible to detect the change of the ESR. The ripple of the Vdc is not affected by the ESR variations only, but also it alternates with the supply and the load variations. Therefore, in order to detect the capacitor aging using ESR, the Vdc of the capacitor should undergo several processing operations so that the result signal could indicate the change in ESR independent of the statuses of the load and the supply.

A DFT is performed to estimate “V1” the 6$^{th}$ harmonic component of the ripple of the output DC voltage of the rectifier “VR”. So that we can deduce the effective values of the ripple voltages that efficiently vary with ESR of the capacitor bank after eliminating any effect of noise or distortion. Figure 1 shows V1 at the normal case at different load and supply variations. Form this figure, any value of V1 for another load and supply conditions can be estimated by using the linear interpolation. This figure was evaluated at the normal condition, as mentioned before, where C1=1500uF, ESR1=133.333m$\Omega$. Furthermore, the same figure can be deduced at any case during the aging period of the capacitor bank where C1 and ESR1 will be changed depending on the aging factor. Therefore, we can calculate the V1 at the rated supply condition “150 V” for certain load and aging condition, if we measure the actual supply voltage Vs and the actual value of V1 at the same load using also the linear interpolation as follows:
\[ V_{150} \text{ (at aging)} = \frac{V_{1V} \text{ (at aging)} \times V_{150} \text{ (at normal)}}{V_{1V} \text{ (at normal)}} \]  

Where;

- \( V_{150} \text{(aging)} \) is the required voltage \( V_1 \) at the aging case at the rated supply voltage 150V. We will denote it as \( V_1^* \)
- \( V_{1V} \text{(aging)} \) is the measured voltage \( V_1 \) at the aging case at the present supply voltage \( V_S \).
- \( V_{1V} \text{(normal)} \) is the calculated voltage \( V_1 \) at the normal case at the present supply voltage \( V_S \). It is calculated from the set of curves of Fig. 1.
- \( V_{150} \text{(normal)} \) is the calculated voltage \( V_1 \) at the normal case at the rated supply voltage 150V. It is calculated also from the set of curves of Fig. 1.

Figure 1: \( V_1 \) Versus The Supply Voltage at different load conditions

As mentioned before, the end-life limit of the capacitor can be detected if its ESR doubles and its capacitance decreases by 20% of its normal value. Therefore, in order to investigate the aging process of the capacitor bank, Equation 3 demonstrates the relationships between the load and end-life states of \( V_1^* \).

\[ V_1^* = -0.027 \times L^2 + 0.46 \times L + 9.3 \]  

(3)

After the previous discussion, an on line fault diagnosis algorithm can be effectively established to detect the aging of the capacitor bank of the system under the study. The final proposed algorithm for capacitor aging diagnosis is illustrated in Figure 2.

2. Capacitor Open Circuit Fault:

The capacitor open circuit fault means that one capacitor or more disconnects from its bank. This fault will affect the equivalent capacitance and the ESR of the whole bank. It causes the decrease of its capacitance and increase of its ESR as same as the effect of the capacitor aging but with different rate depending on the number of capacitors disconnect from the bank at the same time. It is worth to mention that the significant difference between the capacitor aging and capacitor open circuit fault is the rate of change of \( V_1^* \) during the two conditions. The rate of change of \( V_1^* \) during the capacitor aging is very slow due to the sluggish variation of the capacitance during the aging. On the other hand, the sudden detachment of number of capacitors from the capacitor bank at the same instant causes a rapid variation of the bank capacitance which leads to a fast rate of change in \( V_1^* \) during the capacitor open circuit fault.

Equation 4 illustrates the relationship between the load and the voltage difference “\( \Delta V_1 \)” between the \( V_1^* \) at normal condition and \( V_1^* \) at one disconnected capacitor for the capacitor bank.

\[ \Delta V_1 = -0.071 \times L + 0.86 \]  

(4)

From the above discussion, a proposed technique can be evaluated for the open circuit fault diagnosis of the capacitors dependant on the difference between the present and the old values of \( V_1 \), as shown in Figure 3. So, if this difference is equal or greater than the \( \Delta V_1 \) which is calculated from equation (4) then an alarm will be triggered indicating a capacitor open circuit fault. If two or more capacitors are disconnected from the capacitor bank, the difference will exceed and the alarm will be triggered too.

On the other hand, during the capacitor aging phenomenon, the rate of change of \( V_1 \) is very slow, so the measured
difference will be small and won’t trigger the above suggested algorithm as required.

Figure 3: The Proposed Algorithm for Capacitor Open Circuit Fault Diagnosis

3. EVALUATION OF THE PROPOSED TECHNIQUES

1. Testing of Capacitor Aging Diagnoses:

Figures 4 illustrates several testing cases for the capacitor aging diagnoses for the rectifier capacitor bank. The threshold curve, which is evaluated before in Equation (3), is indicated to differentiate between the fault and non-fault conditions.

The testing situations are as follows:
1- The load is 2 kW, the supply voltage is 150V, C is reduced by 10% and ESR is increased by 50% → “Non Fault Condition”.
2- The load is 2 kW, the supply voltage is 150V, C is reduced by 50% and ESR is increased by 250% → “Fault Condition”.
3- The load is 8 kW, the supply voltage is 160V, C is reduced by 10% and ESR is increased by 50% → “Non Fault Condition”.
4- The load is 8 kW, the supply voltage is 160V, C is reduced by 40% and ESR is increased by 200% → “Fault Condition”.

Figure 4: Some Testing points for the Capacitor Aging Diagnoses.

From the previous figure; it is shown that all the fault conditions in the capacitor bank are occurred beyond the estimated threshold values. Besides, the non-fault cases take place below the threshold value.

2. Testing of Capacitor O.C Fault Diagnoses:

Figures 5 represents several testing situations for the capacitor open circuit fault diagnoses. The threshold line, which is evaluated before in Equation (4), is given in the figure. The testing fault conditions are as follows:
1- The load is 5 kW, the supply voltage is 140 V, and two parallel capacitors are disconnected from the capacitor bank.
2- The load is 5 kW, the supply voltage is 140 V, and two parallel capacitors with other series capacitor are disconnected from the capacitor bank.
3- The load is 10 kW, the supply voltage is 185 V, and two series capacitors are disconnected from the capacitor bank.
4- The load is 10 kW, the supply voltage is 185 V, and two parallel capacitors with other series capacitor are disconnected from the capacitor bank.

4. CONCLUSION

From the previous evolution section, it is demonstrated that the insinuated failure detection techniques accomplish correct decisions and classification for the rectifier capacitor bank faults. The proposed algorithms use only the capacitor bank voltage with the knowledge of the load and supply conditions without introducing any additional sensors for temperature or current as used in the other researches.
5. REFERENCES


