The Journal of CPRI,
Vol. 10, No. 2, June 2014 pp. 373-378

Analysis of DC Link Capacitor Performance and Capacitor Life In Back to Back Converters With Respect to Converter Switching

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Back to Back converters are commonly used converters in many ac to ac conversion applications. Even though Converters without intermediate energy storage element are developed, Those with DC link capacitors still continue to be most popular due to the inherent advantages. The performance of such converters is affected by the operation of DC link capacitors used. This paper gives a detailed study of various types of back to back converters and considerations in DC link capacitor design and selection. A MATLAB program is also developed to analyze the effect of RMS (Root mean Square) ripple current and consequent effect on the life of the DC link capacitors in Voltage link back to back converters.

Keywords: *Back to back converters; matrix converter, DC link capacitors.*

1.0 INTRODUCTION

Back to back converters are used in many AC and DC applications. Basically it consists of a force-commutated rectifier and a force-commutated inverter connected together. The output converter can be operated to get sinusoidal currents, for which the dc-link voltage must be higher than the peak main voltage. Inorder to overcome the disadvantages of DC link energy storage elements, matrix converters were developed which can converter ac to ac in one single stage.

Back to back converters are used conversion of uncontrolled ac to regulated ac for power systems applications and for obtaining variable voltage variable frequency ac from ac mains for machine applications. Another application is in power feed back converters in traction breaking. The same principle is utilized in regenerative load emulators for testing of power equipments utilizing the possibility of fast control of the power flow. The current drawn by the rectifier can be regulated without affecting inverter performance. A suitable back to back converter configuration can be designed so as to draw the required load profile from the equipment and to regenerate it as sinusoidal ac instead of wasting the energy in passive load components [1-2].

A comprehensive explanation and comparison of various types of back to back converters is given in section II out of which converters with DC link capacitor is of prime focus. A detailed explanation of DC link capacitors in given section III followed by analysis of capacitor life based on the RMS current and electrical stress on electrolytic capacitors. The life span and performance of DC link capacitors are affected by many factors like temperature, atmospheric conditions, electrical parameters operating frequency, material properties etc. All these factors together contribute to the performance degradation for which a proper analysis technique

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is not yet devised. Here the effect on the capacitor life based on the stess due to RMS current and ripples is analyzed

2.0 TYPES OF BACK TO BACK CONVERTERS

The back to back converter configurations can be broadly classified in to those with DC link energy storage and without DC link energy storage. In first case, an energy storage element can be either capacitor or inductor. The converters with energy storage device were the earliest developed and most popular model of back to back converters. Later on Matrix converters were developed to overcome certain disadvantages, but are more complex in architecture and control [3].

2.1 Converters with DC link energy storage

In Capacitor-supported systems, multiple power converters are interconnected by a dc link. The dc-link voltage is maintained by a capacitor bank. It minimizes the voltage variation on the dc link by absorbing instantaneous power difference between the input source and output load. It also provides sufficient energy when required.

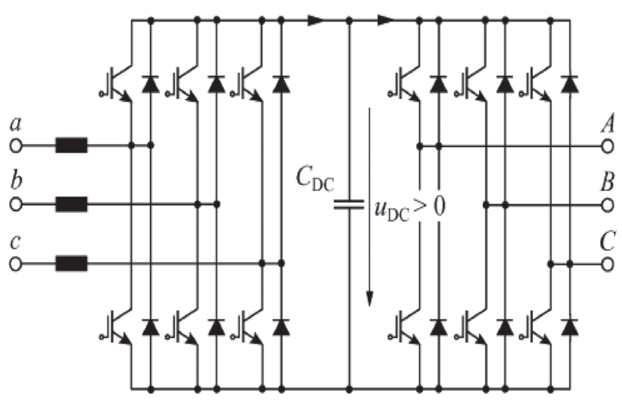

FIG. 1 TYPICAL BACK TO BACK CONVERTER WITH DC LINK CAPACITOR

Instead of capacitor element, some converters use inductors as the DC link Energy storage element, which makes the inverter part current sourced. But due to the sluggishness in operation, this is used only in very few applications. Voltage source DC link back to back converter is shown in Figure 1.

2.2 Converters without DC link energy storage

Matrix Converters are forced commutated ac-ac converter topologies without any intermediate energy storage. Their operating principle is based on the constant power flow in a symmetrical three-phase voltage–current system. Figure 2 shows typical matrix converter topology [4].

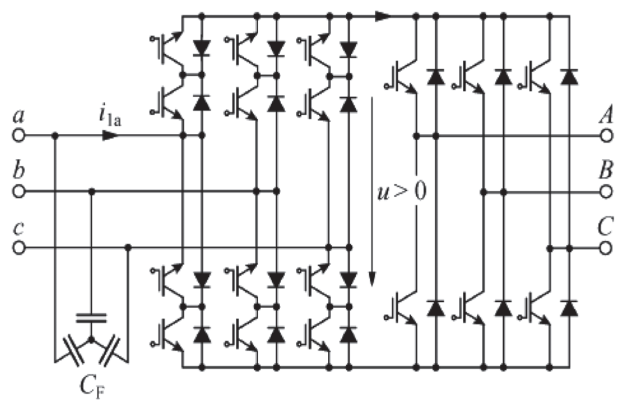

FIG. 2 MATRIX CONVERTER CONFIGURATION

Various topologies of matrix converters are also developed out of which convensional model provides conversion in a single step. Indirect matrix converters do this in two steps over coming the disavantage of single step conversion without using energy storage element. Matrix converters can provide simultaneous amplitude and frequency transformation of three-phase voltage–current systems [5] .

2.3 Comparison

Many researchers have performed comprehensive comparisons of various back to back topologies. (Table 1) Many of them are based on the losses in switching since there is considerable difference in the number of switches in DC link type and matrix type converters.

Another comparison is based on the performance degradation since capacitor is a sensitive part of DC link model. Even though matrix converters overcome the disadvantages of DC link energy storage element, they are not very commonly used due to the higher number of switches and consequent complexities. They require impressed voltages at the input and impressed currents at the output.

TABLE 1

COMPARISON BETWEEN CONVERTER WITH DC LINK AND MATRIX CONVERTER

Parameter	**Back to back converter with Capacitor DC link**	**Matrix Converter**
No. of switches	12	18
Isolated gate driver supplies	8	9
Max output voltage	>U	0.86 U
Additional protection circuit	No	Yes
Min. no. of Voltage/ Current sensor	4/4	3/2

3.0 DC LINK CAPACITORS

Voltage DC-link inverters are usually fed via uncontrolled rectifier bridges from the single-phase or the three-phase mains, as shown in Figure 1. There, in the DC link, aluminium electrolytic capacitors are usually used. The main advantages of using DC link capacitors are [6],

- It supplies the input current of the inverter with pulse frequency
- It supplies transient power peaks
- It helps in compensating for the difference between instantaneous power requirement of inverter and instatneous power supplied by rectifier.
- Dissipation of magnetizing energy
- Reduce harmonics
- Protection of inverter.

3.1 Capacitor Selection

Large varieties of capacitors are available commercially which are chosen depending upon the application. For DC link application, Aluminum electrolytic capacitors are the most popular choice because of their high volumetric efficiency and low cost. But some of the disadvantages are, high equivalent series resistance, low ripple current capability, relatively short lifetime and requirement of maintenance work. Advances in power film capacitor technology are emerging for dc-link filtering.

The component characteristics and ratings of different manufacturers are very similar. The volume per capacitance scales with the rated voltage U_C and the surge voltage capability [7] [8]. If V_c is the volume of capacitor, C is the capacitance and U_c is the rated voltage, then

For a given rated voltage

$$V_c \propto C \qquad ....(1)$$

For a given Capacitance

$$V_c \propto U_c^2 \qquad ....(2)$$

DC-link capacitors are chosen with higher voltage rating than the required DC link voltage for providing a margin for transient voltage variations. For 700 V DC link voltage usually capacitor rating of 800 V is chosen providing a margin of 100 V. Another factor affecting the selection of DC link capacitor is the ripple voltage. The variation of capacitor value with ripple voltage is shown in Figure 3.

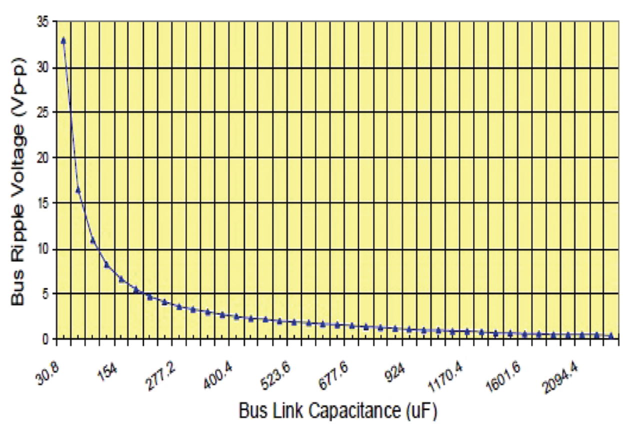

FIG. 3 THE VARIATION OF DC LINK CAPACITOR VALUE WITH RESPECT TO BUS RIPPLE VOLTAGE

3.2 Capacitor life

The working life of electrolytic capacitors is largely dependent on the operating voltage and the working temperature. For example, failure rate is reduced to 60 % if the capacitor is operated at 0.9 x rated voltage. Similarly when working temperature is reduced, capacitor life is increased. This is because, at lower temperature the diffusion of gaseous particles and hence the drying is reduced. Thus proper thermal design is a very important factor affecting the life of capacitor. Figure 4 shows the variation of capacitor life with change in temperature for three different ratings [9].

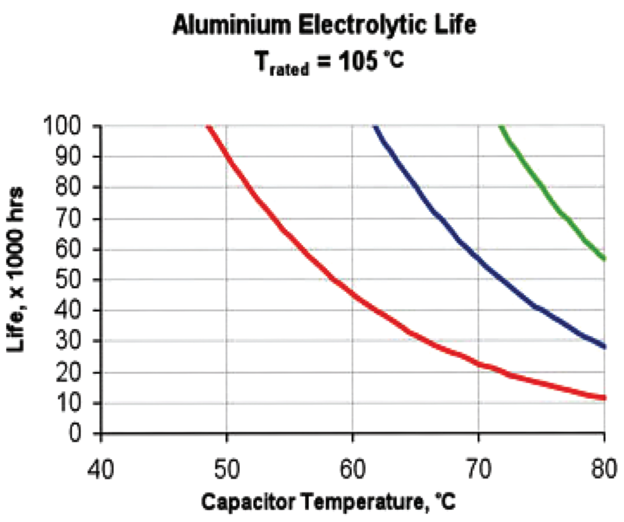

FIG. 4 CAPACITOR LIFE WITH RESPECT TO RISE IN TEMEPERATURE FOR INCREASING RATING

4.0 ANALYSIS OF CAPACITOR PERFORMANCE AND LIFE WITH RESPECT TO SWITCHING

The working life of the capacitor is dependent mainly on the can temperature T_c. Its is determined from the ambient temperature Ta and the power dissipation in the capacitor, as caused by the capacitor RMS current. Expression is shown in equation 3 where R_{ESR} is the equivalent series resistance. It includes the contribution of dielectric, electrolyte foils, terminals etc. R_{th} is the thermal resistance

$$T_c = T_a + I_{C,rms}^2 R_{ESR} R_{th} \quad ....(3)$$

So, for a correct thermal design of the capacitor and there by improving the life, the RMS value of the DC- link-capacitor current is important [10]. Many methods have been developed to obtain this value. Here an analytical method is presented with the support of digital simulation.

4.1 RMS Current stress

It is assumed that the inverter is space vector modulated and rectifier is uncontrolled 3 phase. Evaluation is done over a period from π/3 to 2π/3. The DC-link capacitor current is obtained by the difference of out put current of rectifier i_L and input current of inverter i.

$$i_C = i_L + i \quad ....(4)$$

i and i_L can be divided in to DC and AC components as shown in equations (5) and (6).

$$i = I_{avg} + i_{ac} \quad ....(5)$$

$$i_L = I_{L,avg} + i_{L,ac} \quad ....(6)$$

Therefore equation (4) becomes,

$$i_C = I_{L,ac} + i_{ac} \quad ....(7)$$

I_{avg} can be assumed to be supplied directly by the rectifier bridge. We have, steady state value of square of RMS current is,

$$I_{C,rms}^2 = \frac{3}{2} \int_{\frac{\pi}{3}}^{\frac{2\pi}{3}} i_C^2 d\phi \quad ....(8)$$

Substituting for i_C, we get RMS value of dc link capacitor current.

$$I_{C,rms}^2 = I_{ac,rms}^2 + \frac{6}{\pi} \int_{\frac{\pi}{3}}^{\frac{2\pi}{3}} i_{ac} i_{L,ac} d\phi + I_{L,ac,rms}^2 \quad ....(9)$$

Inorder to simplify the integral operation, it is assumed that currents i_L and $i_{L,ac}$ do not contain harmonics in same frequency range. Then,

$$\frac{6}{\pi}\int_{\frac{\pi}{3}}^{\frac{2\pi}{3}} i_{ac} i_{L,ac} \, d\phi = 0 \qquad ....(10)$$

Thus equation (9) can be simplified as below.

$$I_{C,rms}^2 = I_{ac,rms}^2 + I_{L,ac,rms}^2 \qquad ....(11)$$

Thus it RMS contains two components, one from rectifier and one from inverter. It is the superposition of harmonics of DC link input and output currents. The maximum current stress on the DC-link-capacitor current, which occurs for the worst-case is,

$$I_{C,rms,\max} = I_{ac,rms} + I_{L,ac,rms} \qquad ....(12)$$

The dependency of life of capacitance on the switching of converters is thus derived by obtaining the relation between RMS current and the inverter operating parameters modulation index and power factor. The width of the segment of phase current I_N depends on the modulation index M. The relation obtained for a space vector modulated inverter [11]

$$I_{C,rms} = I_{N,rms}\sqrt{\left[2M\left\{\frac{\sqrt{3}}{4\pi} + \cos^2\phi\left(\frac{\sqrt{3}}{\pi} - \frac{9}{16}M\right)\right\}\right]} \qquad ....(13)$$

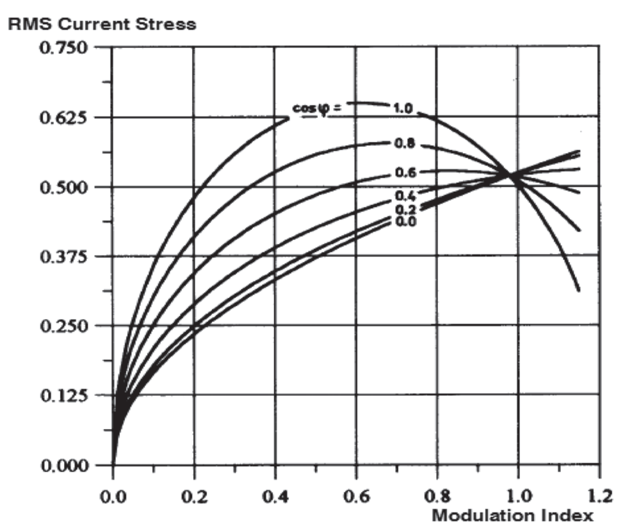

FIG 5 RELATION BETWEEN MODULATION INDEX AND RMS CURRENT SRESS ON CAPACITOR

Using equation 13, the plot between Modulation index and RMS current stress is plotted as shown in Figure 5. It is shown for different values of cos φ. Maximum RMS current stress is when cos φ = 1.

4.2 Method for improvement

From the relations obtained from equations (4) to (13) it can be seen that the current stress on the DC-link capacitor is highly dependent the amplitudes and the phase relationships of the harmonics of equal ordinal number. These harmonics cause higher or lower amplitude of the respective harmonics in the DC-link-capacitor current. This will in turn increase the capacitor RMS current there by affecting the life. Thus the RMS current stress can be reduced by appropriate coupling and control of rectifier and inverter sides. The harmonics should be taken in to consideration while designing the converter there by reducing the current stress on converter [12][13].

5.0 CONCLUSIONS

The DC Link Capacitor is the most important part of a back to back converter. Even though matrix converters with out DC link energy storage element are also designed, most of the application still utilize the inherent advantages of Voltage link back to back converters. The voltage stability of the input of inverter is dependent on the DC link capacitor design. The overall performance of the converter is also dependent upon the life of capacitor. The capacitor life with respect to the RMS current value is evaluated which depends on the switching of converters. Proper design of converter switching and modulation index should be done to minimize the RMS current stress on capacitor.

ACKNOWLEDGEMENT

The work is supported by Central Power Research Institute (CPRI), Bangalore, India. The studies were carries out in the solar PV and inverter testing laboratory of Energy Efficiency and Renewable Energy Division, CPRI Bangalore and the works are done with the guidance of the experts from the Organization.

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