Online Capacitance Estimation of DC-Link Capacitors using AC Voltage Injection in AC/DC/AC PWM Converters

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ABSTRACT

A novel online capacitance estimation method for a DC-link capacitor in a three-phase AC/DC/AC PWM converter is proposed. A controlled AC voltage with a lower frequency than the line frequency is injected into the DC-link voltage, which then causes AC power ripples at the DC output side. By extracting the AC voltage and power components on the DC output side using digital filters, the capacitance can then be calculated using the recursive least squares method. The proposed method can be simply implemented with only software and no additional hardware. Experimental results confirm that the estimation error is less than 0.2%.

1. Introduction

A great number of power electronic systems are made up of three-phase AC/DC/AC PWM converters such as mill drives, elevators, UPS, and so on. The converters have matured in both the structure of the power circuits and the control strategy. Electrolytic capacitors are commonly used in all of these equipments as smoothening element of the converters because it has high capacitance for its size and low price [1].

The electrolytic capacitor usually has the shortest span of life in the power circuit, and then determines the system lifetime. Therefore, a deterioration diagnosis of the electrolytic capacitor is needed for preventive maintenance of the circuit [2].

In wind power generation systems, the AC/DC/AC PWM converters are located offshore or on high towers, making it difficult to measure the capacitance without detaching the capacitors. It is necessary to find an accurate algorithm to estimate the capacitance value instead of measurement [3], [4].

In this paper a novel online capacitance estimation method for the AC/DC/AC PWM converter systems is proposed. To determine the degree of deterioration, the capacitance of the capacitor is periodically estimated using an input voltage injection and the Recursive least square (RLS) method. A particular ac voltage component with a lower frequency than the power line frequency is injected into the DC link voltage reference. The injected AC voltage into the DC side causes an AC voltage ripple that can be easily extracted from the measured voltage by using bandpass filters. Meanwhile, the DC-side power can be calculated from the AC input converter power and AC inverter output power. As a result of balance power of the both DC side, the power balance equation can be used to calculate the capacitance based on the RLS method.

The capacitor is estimated periodically by injecting AC voltage component and applying RLS method. Compared with the capacitance value measured by the RLC meter, the estimation error is less than 0.2%. The experimental result verifies the effectiveness of the proposed algorithm.

2. Estimation of Capacitance of DC-link Capacitor

2.1 AC voltage injection

In steady-state, the DC-link voltage of the AC/DC/AC PWM converters is constant except switching frequency related ripple components. For the purpose of parameter estimation, it is difficult to get effective information of the system from the constant voltage signal. So, it is necessary to inject some exciting signal into the system. In this case, a low frequency AC voltage component is injected into the constant DC-link voltage as

$$v^*_{dc,ripple} = V_{ac} \sin \omega_{inj} t \quad (1)$$

where =10[V] and $\omega_{inj} = 2\pi f = 2\pi.30$[rad/s].

2.2 Voltage controller

Since the precision of the capacitance estimation depends on the control performance of the injected AC voltage, the DC-link voltage should be controlled precisely. For this purpose, the DC voltage controller needs the feed-forward compensation term together with the feedback controller.

From the power balance of both sides of the DC-link,

$$P_{input} - P_{out} = \frac{C}{2}\frac{dv_{dc}^2}{dt} \quad (2)$$

where P_{input} is the input power of the front-end converter and P_{out} is the output power of the inverter. So,

$$P_{input} = \frac{3}{2}(v_d^e i_d^e + v_q^e i_q^e) \quad (3)$$

If $i_d^{e*} = i_d^e = 0$ for unity power factor control of the source side, then

$$P_{input} = \frac{3}{2} v_q^e i_q^e \quad (4)$$

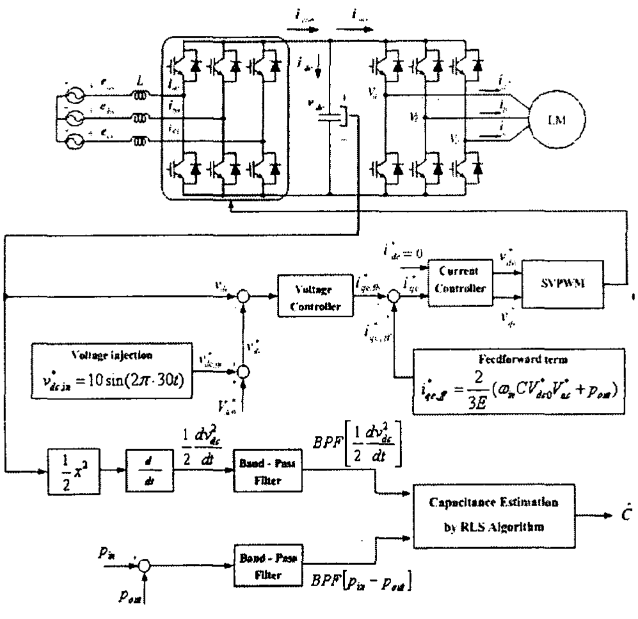

Fig. 1 Control block diagram of AC/DC/AC PWM converters for capacitance estimation

In steady state, $P_{input} = \frac{3}{2} E i_q^e$, where E is the magnitude of the source voltage.

For the load side,

$$P_{out} = \frac{3}{2}(\nu_{ds}^e i_{ds}^e + \nu_{qs}^e i_{qs}^e) \quad (5)$$

From the above equations, the q-axis current reference for feed-forward compensation is obtained as

$$i_{qe,ff}^* = \frac{2}{3E}\left(\frac{C}{2}\frac{d\nu_{dc}^2}{dt} + P_{out}\right) \quad (6)$$

The DC-link voltage reference with an injected term is

$$\begin{aligned} v_{dc}^* &= V_{dc0}^* + v_{dc,ripple}^* \\ &= V_{dc0}^* + V_{ac}\sin\omega_{inj}t \end{aligned} \quad (7)$$

Differentiating (7) and assuming $V_{dc0}^* \gg V_{ac}$, then

$$\frac{d\nu_{dc}^{*2}}{dt} = 2\omega_{inj} V_{dc0}^* V_{ac}\cos\omega_{inj}t \quad (8)$$

Thus, from (6), a feed-forward compensation term is expressed as

$$i_{qe,ff}^* = \frac{2}{3E}\left(\omega_{inj} C V_{dc0}^* V_{ac}\cos\omega_{inj}t + P_{out}\right) (9)$$

The detailed block diagram for capacitance estimation is shown in Fig. 1.

2.3 RLS (Recursive least-square) algorithm.

The capacitance can be estimated by the well-known RLS method. To extract the injected-frequency component, the second-order band-pass filters are used [5], of which transfer function is as

$$H_{BS}(s) = \frac{K_{BS}(s^2 + \omega_{BS}^2)}{s^2 + (\omega_{BS}/Q_{BS})s + \omega_{BS}^2} \quad (10)$$

where,

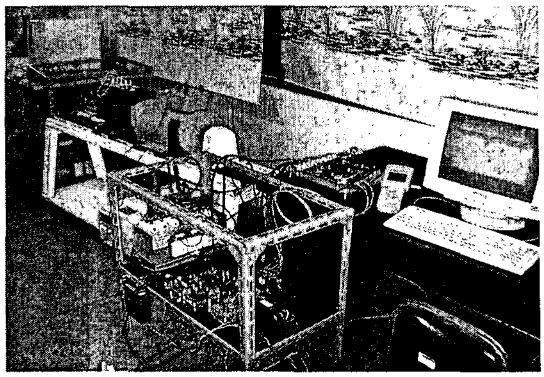

Fig. 2 Experimental setup

$K_{BS} = 1$, $Q_{BS} = 2$, $f_{BS} = 30[Hz]$ and $\omega_{BS} = 2\pi f_{BS}$.

Applying the band-pass filter to the both sides of (2),

$$BPF(P_{input} - P_{out}) = C.BPF\left[\frac{1}{2}\frac{d\nu_{dc}^2}{dt}\right] \quad (11)$$

where $BPF[\cdot]$ means the band-pass filtered quantity.

The RLS update of the parameter to be estimated, $\hat{C}[n]$, can be written by

$$\hat{C}[n+1] = \hat{C}[n] + \gamma[n] BPF\left[\frac{1}{2}\frac{d\nu_{dc}^2}{dt}\right] \left\{ \begin{array}{l} BPF[P_{input} - P_{out}][n] - \\ \hat{C}[n] BPF\left[\frac{1}{2}\frac{d\nu_{dc}^2}{dt}\right][n] \end{array} \right\} \quad (12)$$

where $\gamma[n]$ is an adjustment gain, which was selected by a trial and error method. The initial value of $\hat{C}[0]$ can be set either the estimated capacitance from the last capacitor diagnosis or the nominal value of the capacitor bank.

3. Experimental results

To verify the effectiveness of the proposed scheme, experiments were carried out using the experimental setup shown in Fig. 2. The TMS320C31 DSP chip operating at 33.3MHz is used as a main processor and the power capacity of the AC/DC/AC PWM converter using IGBT modules is 3 kVA. The measured capacitances values are lower than the nominal values due to the aging effect of the capacitor at the laboratory.

Figure 3 shows the total DC-link and the injected AC components of the reference voltage and real values. The frequency of the AC component is 30[Hz] with 10 [V] amplitude with DC-link voltage value of 340 [V]. The total voltage is well controlled as shown in Fig. 3.

The derivative of DC-link voltage and the AC power component are extracted as shown in Fig. 4(a) and (b). To use the aforementioned values, a band-pass filter with 30[Hz] cut-off frequency is used to extract the filtered values as shown in Fig. 4(c) and (d). The corresponding harmonic spectra before and after filtering are shown in Fig. 5. It noticeable that the unfiltered quantities contains a series of low order frequency components while the filtered quantities have only 30[Hz] components.

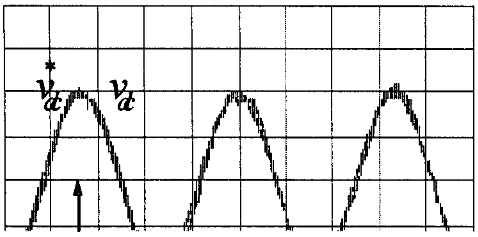

Fig. 3 DC link voltage with injected AC component

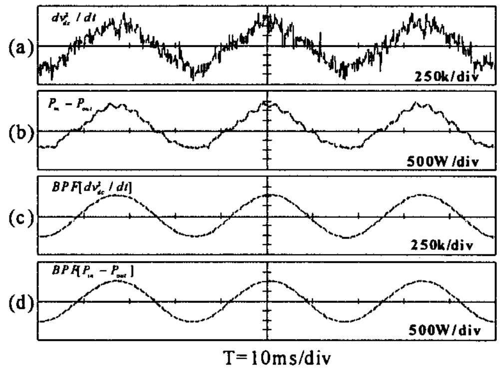

Fig. 4 Measured data for RLS algorithm

Figure 6 shows the variation in the filtered DC-link ripple voltage, AC power component and estimated capacitance values at abrupt change of capacitance. Initially, two branches of capacitors are connected in parallel with nominal capacitance 1,950[μF](in series of two capacitors of 3,900[μF]) and 500[μF]. The measured values are 1,918[μF] and 466[μF] for each branch. Using the proposed algorithm, the estimated capacitance for this capacitor bank is 2,389[μF], which has only +0.013% estimation error. When the 466[μF] capacitor is disconnected abruptly, the estimated capacitance value for a measured 1,918 [μF] is 1,920 [μF], which has only +0.104% estimation error. It is noticeable that the capacitance is well estimated even though the capacitance value changes abruptly as shown in Fig. 6(c).

4. Conclusions

A new method for deterioration diagnosis of the electrolytic capacitor has been proposed for the three phase AC/DC/AC converters. Voltage injection method is simpler than current injection one since the former does not require calculation of the DC-link current. The proposed scheme can be implemented only by software, based on injecting an AC voltage, processing the power and voltage signals with digital filters, and using the RLS method. Experimental results confirmed that the capacitance estimation error was less than 0.2%, making the proposed algorithm effective for diagnosing the deterioration of DC electrolytic capacitor banks in the AC/DC/AC PWM converter system.

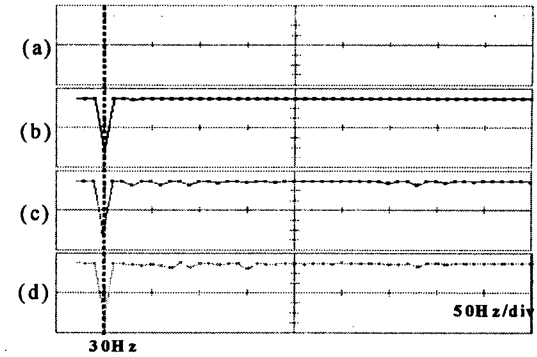

Fig. 5 Harmonic spectrum corresponding to Fig. 5

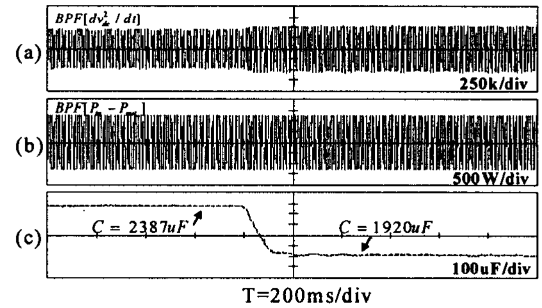

Fig. 6 Capacitance estimation at abrupt variation of C

Table 1 Per unit values of the system parameters

Nominal value	Measured	Estimated	Estimation error%
C1= 2450[μF]	2384[μF]	2387[μF]	+0.013%
C2=1950 [μF]	1918 [μF]	1920 [μF]	+0.104%

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References

[1] Yang Ye. M. Kazerani, and V. H. Quintana. "Realization of a smart electrolytic capacitor circuit", IEEE Trans. power Elect, Vol. 18, No. 3, pp. 857-864, 2003, May.

[2] K. Harada, A. Katuski, and M Fujiw, "Use of ESR for deterioration diagnosis of electrolytic capacitors", IEEE Trans. on Power Elect., Vol. 8, No. 4, pp. 1199-1207, 1993, Oct.

[3] D.-C. Lee and H.-J. Kim, "Life estimation of electrolytic capacitors for inverters", Trans. of KIEE, Vol. 50B, No. 7, pp. 338_346, 2001, July.

[4] K.-J. Lee, D.-C. Lee, and J.-Ki Seok, "Capacitance estimation of dc-link capacitors of three-phase ac/dc/ac PWM converters using input current injection", Trans. of KIPE, Vol. 8, No. 2, pp. 173-179, 2003. April.

[5] R. Chassaing, Digital signal processing, John Wiely & Sons Inc. 1999.