§20. R&D of Arbitrary Waveform, Arbitrary Power Factor and Fast-response Matrix Converter

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Fig. 2: Quaternion of output voltage. The inner circle is that of AV method and the outer curve is that of optimum AV method.

Fast-response power supply is indispensable for feedback stabilization of vertical position instability of spherical tokamak plasma. By introducing quaternion concept as an extension of hypercomplex numbers, Alesina-Venturini method is discussed with emphasis on duty cycle space vector. The similarity is shown, though the quaternion rotates on the three-dimensional plane. The quaternion concept is applied also to optimum Alesina-Venturini method and discussed.

Here, quaternion concept is introduced as an extension of complex $\alpha\beta$ coordinate system. The quaternion is defined by vector part and scalar part as follows:

$$q = iq_1 + jq_2 + kq_3 + q_4 \qquad (1)$$

where $\{i, j, k\}$ are the hypercomplex numbers satisfying the following equations.

$$i^2 = j^2 = k^2 = -1 \qquad (2)$$

$$ij = -ji = k, jk = -kj = i, ki = -ik = j \qquad (3)$$

Three-phase AC input voltage is expressed with quaternion as follows:

$$v_i = \sqrt{2}V_{ie}[i\cos(\omega_i t - 0\pi/3) + j\cos(\omega_i t - 2\pi/3) + k\cos(\omega_i t - 4\pi/3)] \qquad (4)$$

Namely, quaternion has a property of vector, where i, j, k behave as if they are unit base vectors, but they have also a property of hypercomplex number. The quaternion of v_i is transformed to polar form as follows:

$$v_i = \sqrt{2}V_{ie}[(+i - j1/2 - k1/2)\exp(+n\alpha_i)] \qquad (5)$$
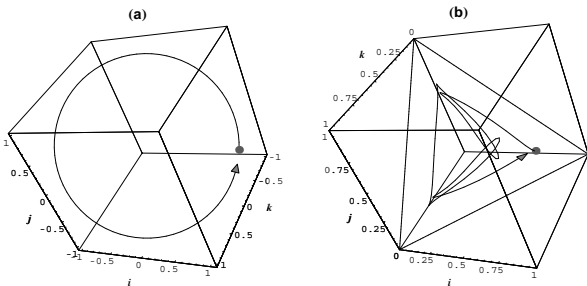

Fig. 1: Quaternion of input voltage and duty cycle space vector in optimum AV method: $q = 0.5, \omega_i = 2\omega_o$
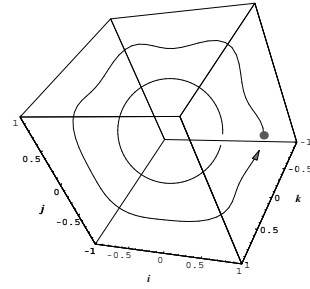
$$n = (+i + j + k)/\sqrt{3} \qquad (6)$$

where $(+i - j1/2 - k1/2)$ is the initial vector, n is the normal vector of the rotating phasor plane, and α_i is the phase angle of the input voltage, $\omega_i t$. Namely, the quaternion v_i rotates from the initial vector around normal vector n on the phasor plane as shown in Fig. 1a.

The second term of the first row of the switching matrix of optimum Alesina-Venturini method is expressed with quaternion directly as follows:

$$m_i = 2q/3[i\cos(\omega_i t - 0\pi/3)\{\cos(\omega_o t - 0\pi/3)$$
$$- 1/6\cos(3\omega_o t) + 1/2\sqrt{3}\cos(3\omega_i t)\}$$
$$- i1/3\sqrt{3}\{\cos(4\omega_i t - 0\pi/3) - \cos(2\omega_i t + 0\pi/3)\}$$
$$+ j... + k...] \qquad (7)$$

This quaternion corresponds to duty cycle space vector defined in 1), and is shown in Fig. 1b. The quaternion of output phase voltage is shown in Fig. 2. Though the voltage transfer ratio is larger than that in case of Alesina-Venturini method, the quaternion does not draw a circle. The space vector draw a circle in $\alpha\beta$ coordinate system, of course, and the quaternion of the output line-to-line voltage draw a circle in three-dimensional space.

Though eddy current in the conducting vacuum chamber or stabilizing shell around the tokamak plasma decelerates the growing speed of vertical position instability, it may shield the stabilizing horizontal magnetic field into the chamber or the shell. So, high-voltage power supply is necessary for the forcing in addition to the above mentioned characteristics. As for the application of the matrix converter, computer and circuit simulations are necessary, since the switching frequency cannot be much higher than the modulation frequency in the real power supply. And the confirmation about the arbitrary output current waveform and the input power factor is necessary, since the output frequency cannot be negligible and the output waveform may be controlled to arbitrary waveform (not DC) according to the external command.

1) D. Casadei, et al.: IEEE Transactions on Industrial Electronics **49** (2002) 370.