Torque Harmonic Analysis of Permanent Magnet Synchronous Machine According to Current Harmonic Order

Abstract

When motor operating, many harmonic components are included. There are spatial harmonics and current harmonics, and from combination of them torque ripple is generated. Torque ripple causes noise and vibration and has influence on stability of operation system, so torque analysis is important part. If back-EMF and current is ideal sinusoidal wave, torque is constant. However, back-EMF and current is not ideal sinusoidal, and torque ripple is generated by interaction of the back-EMF harmonics and current harmonics. According to order of current harmonic components, torque ripple is shown differently when time harmonic components are coupled with spatial harmonic components, some of harmonic components are canceled out, as others are intensified due to interaction.

In this paper, effect of current harmonic order on torque characteristic is studied. 3rd, 5th, 7th and 9th harmonic components are considered, and FEA is carried out for torque characteristic analysis according to ratio of each harmonic order.

Torque Mechanism

Back EMF and current with harmonic components can be expressed,

\[ E = E_1 \cos(\omega t) + \sum E_{n} \cos(n \omega t - \phi_{n}) \]

\[ i = I_1 \cos(\omega t - \phi_1) + \sum I_{n} \cos(n \omega t - \phi_{n}) \]

Electromagnetic torque is expressed as,

\[ T_{em} = \frac{E_1 I_1 \cos(\phi_1)}{2\pi} + \frac{\sum E_n I_n \cos[(n-1)\omega t + \phi_1]}{2\pi} \]

Harmonic Distribution of back EMF

Harmonic including ratio[\%]

<table>
<thead>
<tr>
<th>Voltage</th>
<th>10</th>
<th>30</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque ripple [%]</td>
<td>29.11</td>
<td>31.11</td>
<td>33.11</td>
</tr>
</tbody>
</table>

Harmonic Including ratio[\%]

<table>
<thead>
<tr>
<th>Voltage</th>
<th>10</th>
<th>30</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque ripple [%]</td>
<td>31.83</td>
<td>39.58</td>
<td>47.44</td>
</tr>
</tbody>
</table>

Electromagnetic Torque Characteristics with Current Harmonics

Current Harmonic

In this paper, we assume that only 1 kind of harmonic order is included in input current. And the cases of different included ratio is analyzed.

 conclusions

- Electromagnetic torque harmonic is generated from both EMF harmonics and current harmonics
- Torque harmonic components is intensified or cancelled out according to interaction between two types of harmonics.
- This paper studies about effect of current harmonic order and included ratio to torque harmonic, and 3rd, 5th, 7th and 9th current harmonic components are considered.
- FEA results show that both current harmonic order and amplitude have influence on torque characteristics.
- With combination of current harmonic components, torque harmonic components could be reduced.

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