SELECTION OF SYNCHRONOUS REACTIVE FREQUENCY CONVERTER’S SECONDARY WINDINGS PARAMETERS AND OPTIMIZATION OF ROTORS GEOMETRICAL DIMENSIONS TO ENSURE HIGHEST INCREASED FREQUENCY EMF INDUCTION

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Finite element method; QuickField; frequency converter.

ABSTRACT
In many spheres of human activities devices that work on increased frequency current are widely applied. 50 Hz current can be converted into increased frequency (100-400 Hz) current using synchronous reactive converters, which are based on exude and usage of higher harmonics.

The goal of this paper is to determine which circumstances must be taken into account to ensure highest increased frequency EMF induction in a secondary winding. To solve this problem the optimization of rotor geometrical shape must be applied. As a result rotor’s optimal shape which ensures highest EMF induction is obtained.

INTRODUCTION
While using modern alternative current (AC) network with 50 Hz frequency it is not expedient to apply autonomous power sources with increased frequency. Economically more beneficial is to convert 50 Hz AC into AC with increased frequency.

Increased frequency current usage in hand tools can give significant economical effect. For example, increased frequency hand tools are lighter (in comparison with pneumatic), in addition they have higher technical-economical coefficient, increased frequency tool’s actual cost is 8-10 times smaller than pneumatic hand tools, operation costs are 7-8 times smaller (Таращанский 1962).

To fulfil frequency increasing task the synchronous reactive frequency converter (SRFC) can be used. SRFC is synchronous reactive machine, which uses magnetic field’s higher harmonics. In slots of SRFC two windings are placed: primary, which is connected to industrial frequency AC network and secondary, which is used to receive higher frequency. It is possible to note, that synchronous reactive frequency converter is one-machine aggregate, in which the synchronous reactive motor (stator’s primary winding – salient pole rotor) and inductor generator (salient pole rotor – secondary winding) are combined.

Primary winding is consuming magnetizing current, which produces rotating magnetic field in the air gap. From induction’s distribution curve the necessary higher harmonic is used due to specific form rotor magnetic system and to accordingly selected air gap’s width.

This harmonic induces increased frequency EMF in secondary winding. To achieve this secondary winding’s step must be equal to necessary field’s higher harmonic pole pitch (or almost equal). Power with help of magnetic field is transferred from primary winding to secondary winding by means of specific transformation. In this case link between primary and secondary winding isn’t provided by mutual induction flux, but by part of it – higher harmonic exuded flux. Power transfer is depending on geometrical shape of a converter. Having one stator (core, stator windings, slot number, etc.), but different rotors a very different EMF value can be received. So it is necessary to determine optimal shape of rotor to receive highest secondary winding’s EMF induction.

SELECTION OF SRFC’S CONSTRUCTIVE ELEMENTS AND PARAMETERS

Stator’s secondary winding
Salient pole synchronous machines magnetic induction’s distribution in air gap is not sinusoidal. Than means, that magnetic induction curve contains not only fundamental harmonic, but also higher harmonics. Higher k harmonic’s magnetic field in synchronous machines rotates with synchronous rotation frequency and its pole number \(2p_k\) is \(k\)-times bigger than fundamental harmonic’s pole number \(2p\) (Zviedris 1984). So, to use k harmonic’s energy in synchronous machines slots secondary winding with pole number
\[ 2p_k = 2kp \]  
and winding pitch
\[ y_k \approx \frac{\tau_s}{k} = \frac{Z_k}{2kp}, \]  
where \( \tau_s \) – fundamental harmonics pole pitch; \( Z_k \) – for secondary winding used slots number, must be inserted.

To use \( k \) harmonic’s energy more efficiently it is important to choose secondary winding shame and parameters correctly. Constructively it is efficient to insert secondary winding in the same slots in which primary winding is placed. If secondary winding is organized as two lair loop winding, it will occupy all \( Z \) armature slots. Generally secondary winding can be organized with different phase number \( k_m \) (Zviedris 1984).

**Possible variants of rotors shapes for different \( f_2/f_1 \) ratio (2:1, 3:1, 4:1)**

For SRFC it is important to exude defined magnetic field’s higher harmonic so it will have biggest value. To achieve this rotor’s magnetic system’s shape and air gap must be chosen that in magnetic field necessary harmonic will be exuded, but all other higher harmonics whenever possible are equal to zero. Rotor’s constructive variants for different harmonic exude are presented on table 1.

**Table 1: Simplified rotor’s constructions**

<table>
<thead>
<tr>
<th>Exuded harmonic</th>
<th>( k = 2 )</th>
<th>( k = 3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Even</td>
<td>( \Theta )</td>
<td>( \Theta )</td>
</tr>
<tr>
<td>Odd</td>
<td>( \Theta )</td>
<td>( \Theta )</td>
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- ferromagnetic part of a rotor,
- non-ferromagnetic part of a rotor (aluminum, plastic).

**SRFC’S CALCULATION EXAMPLE**

Finite element method (FEM) is chosen as magnetic field’s research method which is realized in QuickField software (QuickField 2009). For research is chosen commercial asynchronous machine’s magnetic system, in which slots primary and secondary windings are placed. To clarify SRFC’s magnetic system modeling questions and to asses received characteristics the frequency doubler is selected. The aim of research is to determine in stator’s primary and secondary winding induced EMF fundamental harmonics effective values dependence from SRFC rotor’s geometrical parameters, rotor’s ferromagnetic parts filling angle \( \beta \) (see Fig. 1.) and from armature current.

Figures 1. SRFC rotor’s designs (with gray the ferromagnetic part is shown)
Calculations are made for idle running, when secondary winding’s current $I_2 = 0$.

Conducting magnetic field’s mathematical modeling the following magnetic field’s picture is received for different rotor’s filling angles $\beta$.

In primary and secondary winding induced EMF fundamental harmonics values are received (for secondary winding the fundamental harmonic is magnetic field’s distribution higher harmonic, in this case 100 Hz) for number of variants:

1. $\beta = 180^\circ$ and $I_a = 16, 30, 44, 58, 72$ A;
2. $\beta = 90^\circ, 180^\circ, 270^\circ$ and $I_a = 16, 44, 58, 72$ A.

Using first variant data results are presented on figures 3 and 4.

**Figures 3.** In primary winding induced (direct-axis with index $d$, quadrature-axis with index $q$) EMF effective values dependence form armature current for $\beta = 180^\circ$

**Figures 4.** In secondary winding induced (direct-axis with index $d$, quadrature-axis with index $q$) EMF effective values dependence form armature current for $\beta = 180^\circ$

Using second variant data results several similar diagrams are received. On figures 5 - 8 boundary variants are presented.
OPTIMIZATION OF SRFC’S ROTORS GEOMETRICAL DIMENSIONS

Research task, that is chosen for optimization is as follows.

Optimization systems boundaries are determined with chosen construction (SRFC with asymmetrical rotor and two windings in stator slots). To decrease variable parameter number it is assumed that geometrical dimensions and winding parameters are known.

For optimization quantitative criteria by second harmonics in secondary winding induced EMF $E_2$ is chosen (idle running).

For systems independence variables following characteristics are chose: SRFC rotor’s ferromagnetic parts filling angle $\beta$, armature primary windings current $I_a$.

For base of development system’s mathematical model on magnetic field theory supporting equations, which use FEM are chosen.

The aim of research is to determine in stator’s secondary winding induced EMF $E_2$ dependence from angle $\beta$ and armature current $I_a$.

Using QuickField software SRFC’s model is constructed.

In result of research following charts are obtained.
From figure 9 it is visible, that EMF $E_2$ curve increases faster when $\beta = 180^\circ$.
From figure 10 it is visible, that highest EMF $E_2$ value provide $\beta$ between $180^\circ$ and $200^\circ$.

**MAIN RESULT**

In order to receive highest in secondary winding induced EMF values frequency doubler’s rotor must be made of at least 50% from ferromagnetic material, rotor’s ferromagnetic parts filling angle $\beta$ must be between $180^\circ$ and $200^\circ$ and armature current must be as high as possible (in feasible constraint).

**REFERENCES**


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