Conversion of DC Armature Winding into Multi-Phase AC Winding

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Abstract. The paper is dedicated to the principles of transformation of a rotating armature of DC machine into a rotating AC armature of a reverse-type AC alternator, which represents finally the major part of a model brushless exciter. The methodology of this conversion is based on main principles of the theory of electrical machines [1, 2].

1. Introduction

When developing model installations and test-bed equipment one may face the problem of absence of a necessary synchronous alternator in presence of several DC machines of the desirable size or rating, or there appears a need in an electronic commutator. Or as in our case, one has to change the alternator field winding excitation from independent DC machine supply into a brushless excitation system [3] and is limited in time. Described below is the theoretical background of a transformation of DC drum winding into a multi-phase AC winding. It is confirmed by results of technological process and experimental tests. It is well-known that the electro-motive force, induced in the armature winding of both DC and AC electrical machines, has an AC character. In DC machines the AC current is being rectified by the commutator.

2. Initial DC armature winding

For the process description there is used a DC generator, manufactured in Belgorod, Russia, rated 34 kW. The DC armature winding represents a complex double-layer 4-pole wave winding (figure 1).

![Figure 1. Electrical scheme of initial wave DC winding.](image-url)
The number of sections equals 81 and the slot number is 27. The greatest common deviser is 3, therefore both from the point of view of the design and of electromagnetic behavior the DC winding consists of three totally identical parts. Therefore to simplify the technological process a three-phase AC armature winding was chosen. The winding has 6 parallel branches and all the three winding elements, shifted against each other by the 1/3 of circumference (27 bars or 9 slots) are equipotential. It should be noted that the winding sections are not identical. In one real slot there are 3 elementary slots, two first sections of each three are smaller than the last one and have the same winding steps for real slots. The third section’s step is by one real slot larger. As for the elementary slots all the steps are identical. For the process of technological transformation the DC winding sections are to be unsoldered from the commutator (figures 2, 3).

![Figure 2. End bars of the armature winding without the commutator.](image2)

![Figure 3. Technological boxes are being installed on the end bars.](image3)

Section voltage vectors in DC winding form a closed polygon with 27 angles (figure 4).

![Figure 4. No-load EMF of initial DC winding.](image4)

If we accept it approximately a circumference a DC no-load electro-motive force at the armature winding terminals equals the diameter of these circumference:

$$E_{DC} = \frac{Ze_0}{\pi},$$

$Z$ – number of slots, $e_0$ – no-load EMF of one section.

The amplitude of linear EMF of AC 3-phase winding ($\Delta$ connection) equals then
It means the final rating of AC alternator will be decreased by $\cos \pi/6$. In principle there exists a possibility of EMF increasing by the number of phases or a number of winding zones increase. But both variants result in a more complicated technological process.

3. AC armature winding

All the 81 sections are subdivided into 3 phases with 9 sections in each phase (figures 5, 6). The preferable variant of the phase connection is a delta one with all the sections being connected in series as it was performed in the initial DC winding. The delta connection is associated with simplified technological process and minimal work volume.

$$E_{AC} = E_{DC} \cos \pi / 2m = E_{DC} \cos \pi / 6.$$
4. Magnetic field calculations
Presented below are results of magnetic field calculations of the obtained AC machine, carried out by finite element method, program ELCUT. Figure 9 shows magnetic field in the machine interior in the no-load mode (additional poles of DC machine are withdrawn). Figure 10 represents the excitation winding field distribution along the average radius of the air-gap. Correspondingly figures 11-14 show magnetic fields, produced by the armature winding along the d and q axes, figures 15-16 – the total magnetic field under load.

![Figure 9. Magnetic field in the no-load curve.](image)

![Figure 10. No-load field along the air-gap circumference.](image)

![Figure 11. Armature winding reaction along q-axis.](image)

![Figure 12. Armature winding field along the air-gap circumference (q-axis).](image)
Figure 13. Armature winding reaction along d-axis.

Figure 14. Armature winding field along the air-gap circumference (d-axis).

Figure 15. Magnetic field distribution under load (cos φ=0.85).

Figure 16. Magnetic field along the air-gap circumference under load (cos φ=0.85).
As it may be obtained from figures 16 and 17 the armature reaction magnetizes the off-coming pole edge and demagnetizes the oncoming one (it is accepted that the armature rotates clockwise).

5. **Experimental verification of the winding transformation**

After the winding conversion was completed prior to the modified AC generator assembly the armature was tested with the drive motor, DC machine main poles, temporary bearings and temporary slip-rings. The obtained no-load three-phase EMF curves are presented in figure 17.

![AC armature EMF with temporary slip-rings and bearings](image)

**Figure 17.** AC armature EMF with temporary slip-rings and bearings.

It is obvious that a field pattern has higher harmonic components caused by an axis misalignment of the armature and inductor and by sliding contact quality, as well as due to presence of tooth high harmonics. As in our case the AC alternator represented the main exciter of the brushless exciter, the output voltage was rectified by the diode bridge.

6. **Conclusions**

1. Transformation of DC electrical machine into a reversed AC alternator may be needed in a number of cases during model experimental investigations.
2. The main element of this conversion is based on the exchange of electrical scheme of DC winding into AC one with corresponding technological operations.
3. The developed theoretical principals and technological process of conversion of DC commutator armature winding into a three-phase AC armature winding were confirmed by successful experimental tests of the new armature.
4. The process of winding transformation was successfully applied for the main exciter of the brushless excitation system.

7. **References**

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