ADDITIONAL LOSSES OF ASYNCHRONOUS MOTORS SUPPLIED BY FORCED-COMMUTATION INVERTER

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Introduction

It is known, that appreciable additional losses arise in induction motors fed by inverters, owing to the nonsinusoidal voltage waveform [1, 2]. The skin effect occurring in the squirrel-cage bars is the main cause of the increase of losses. Both measurements and calculations [3, 4] show, that the additional losses of the stator due to skin effect will reach about the double of the value without skin effect, while in the rotor this ratio may reach a higher than tenfold value. The losses can be reduced by improving the voltage waveform of the inverters.

1. Simple inverters

In these inverters the amplitude of the motor voltage is controlled at the input of the inverter, therefore in each period only 6 commutations are neccessary. Improvement of the voltage waveform could be achieved, if the d.c. input voltage of the inverter could be changed within 60°, for example by taking $\cos^n \omega_1 t$ in the interval from $-\pi/6$ to $\pi/6$ (Fig. 1). In this case $n=0$ gives the usual constant input voltage.

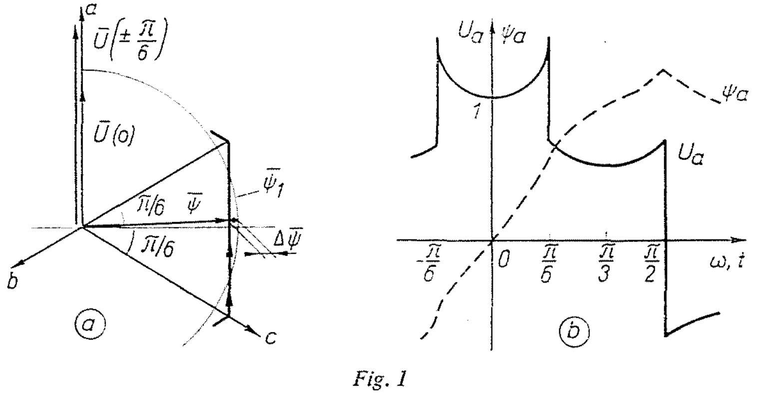

Fig. 1

Fig. 1 shows the case of $n=-2$, which is of interest because here the stator flux vector for the drawn sixth period, with neglection of the stator resistance, is

$$\bar{\Psi}=-\frac{je^{j\omega_1 t}}{\omega_1 \cos \omega_1 t} \tag{1}$$

so the stator flux will be in phase with the fundamental harmonic flux in every moment

$$\bar{\Psi}_1=-\frac{6j}{\omega_1\sqrt{3}\pi}e^{j\omega_1 t}. \tag{2}$$

Therefore the vector $\Delta\bar{\Psi}(\omega_1 t)=\bar{\Psi}-\bar{\Psi}_1$ will lie on the line of vector $\bar{\Psi}$, the higher harmonics will be relatively smaller and, in addition, the pulsating torques will be minimum, in no-load the pulsations will totally die away, and in the case of rated load they will reduce to 50% of the value of the usual $n=0$.

In Fig. 2 the additional stator and rotor copper losses are shown for different values of n (for 50 Hz) with consideration and neglection of the skin effect. The reference losses in the stator and rotor, with sinusoidal waveform, are rated losses.

The results are valid for the VZ 160 M4 type (11 kW, 190 V, Δ, 1470 rpm) machine. Fig. 3 shows the calculated and measured rotor resistance and stator transient inductance as function of the frequency.

According to the heat measurements the machine was heating especially around the 50 Hz, therefore calculations are usually given for the case of 50 Hz supply voltage. If the skin effect is neglected, the best results are obtained for $n=-2$, and this

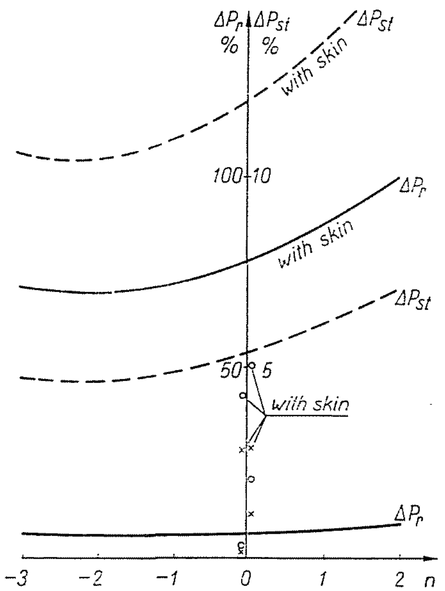

Fig. 2

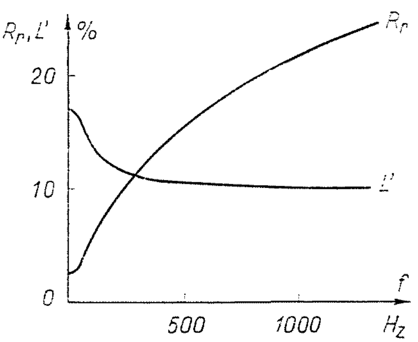

Fig. 3

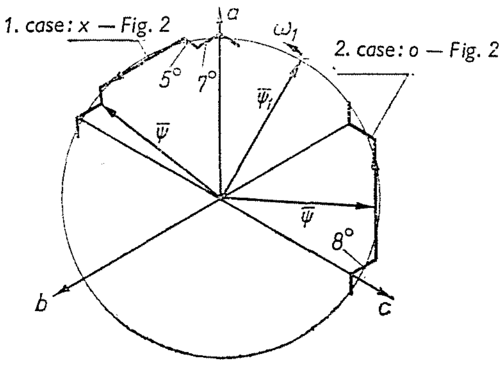

Fig. 4

is the best case also when the skin effect is present, but the increase of losses is quite considerable.

In every sixth period the harmonics can be reduced by means of several additive commutations [1, 3] if, within each portion of 60° of a period voltage vectors corresponding to the previous and the next 1/6 of a period are used (Fig. 4). Fig. 4 shows two different cases, and the losses can also be seen in Fig. 2. Calculations show that in the case of simple inverters the application of this method reduces the losses considerably. For example for the experimental machine the loss is reduced nearly to the half of the value obtained with conventional controls, and the control suggested above gives good results, irrespective of whether the skin effect is considered or neglected.

2. PWM Inverters

It the output voltage of the inverter is controlled by means of an inverter-control, where the impulses are symmetrical, then in the voltage spectrum the harmonics $\nu=1\pm 6cN$ ($c=1, 2, \ldots$ and N is the number of impulses for a sixth period) are very notable. In the case of a skin effect the losses due to these harmonics will be significant. The voltage of the d.c. voltage side of the forced-commutation inverter was 300 V. Fig. 5 and Fig. 6 show the additive losses as a function of N (for 50 Hz). It can be seen, that the losses are very high particularly in the rotor and in the case of symmetrical impulses they can be reduced best if $N=\infty$ (simple inverter), which is about 80% of the rated losses for the examined machine and is still a high value.

The losses can be reduced by making the impulses asymmetrical. For instance with a frequency distribution $\cos^{-2}\omega_1 t$ the losses can be reduced in the same way, as in the case of simple inverters. In Figs. 5 and 6 the approxiate points are marked by, “a”. It can be seen, that for $N=6$ nearly the same losses arise as in the case of a simple inverter. As this result is valid both with and without skin effect, it can be assumed that with asymmetrical impulse distribution no much better results can be achieved than in the case of the simple inverter.

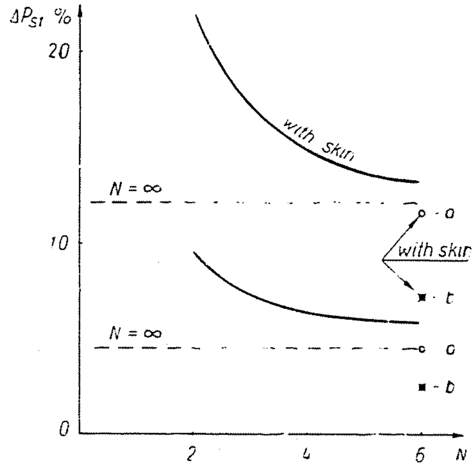

Fig. 5

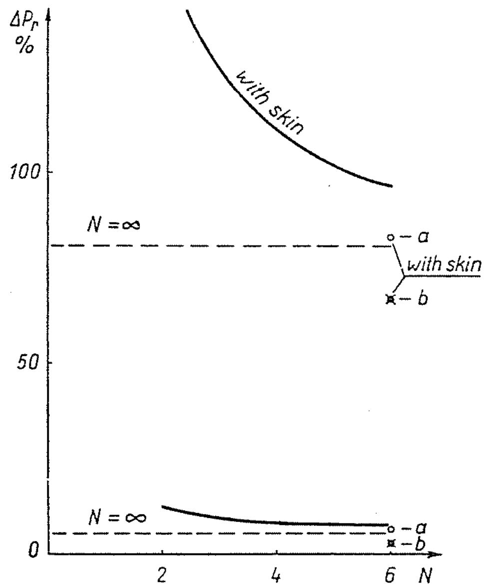

Fig. 6

Better results can be obtained with modified control, when within 60° for each impulse the direction of the voltage vector is changed, similarly to the simple inverters. For instance the interval $-\pi/6 \leqq \omega_1 t \leqq \pi/6$ is selected from $\bar{U}=1$, $\bar{U}=e^{j\pi/3}$ and $\bar{U}=e^{-j\pi/3}$ such, that the curve of flux vector $\bar{\Psi}$ should pass as near as possible to the circle of the fundamental vector $\bar{\Psi}_1$.

In Fig. 5 and 6 we marked the losses for $N=6$ with "b", where for the first impulse $\bar{u}=e^{-j\pi/3}$, for the 2 to 5 impulses $\bar{u}=1$ and for the 6-th impulse $\bar{u}=e^{j\pi/3}$. It can be seen that this result is much better than those obtained with the simple inverter.

The losses can be reduced, if the asymmetrical impulses are used in the case of modified control. Essentially this method is used by *Schonung and Stemmler* [5], and by *Pollack* [6].

Table 1

Percentage Losses due to harmonics		Carrier frequency, Hz 300		600		900		1200	
		reference waveform							
		Sch.	Pol.	Sch.	Pol.	Sch.	Pol.	Sch.	Pol.
stator	with skin effect	45.9	40.5	11.8	12.5	5.1	6.3	3.3	4
	without	22.7	21.4	4.7	5.8	1.8	2.8	1.2	2
rotor	with skin effect	265.3	227.5	106.9	95.5	58.2	56.4	42.1	39
	without	28.6	26.9	5.9	7.3	2.3	3.5	1.5	2.1

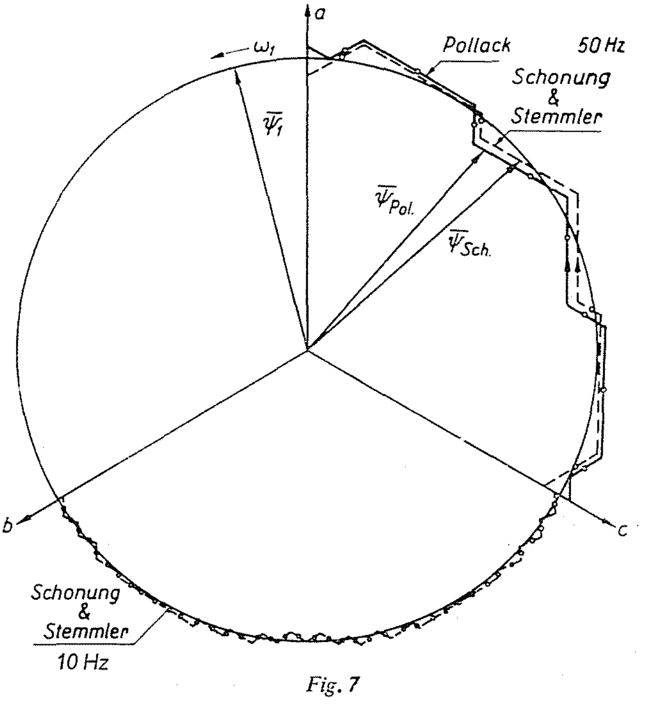

Fig. 7

Table 1 summarizes the calculated losses for the two methods described above for different carrier frequencies. The result is not in agreement with the relatively high number of the necessary commutations. To explain this we have drawn in Fig. 7 the flux vectors Ψ and Ψ_1 (for 600 Hz carrier frequencies). It can be seen, that these methods cannot give the best direction of the flux vector Ψ. In other words: with the same number of commutations and a better control the losses can be reduced. The same results were obtained also with a 10 Hz supply.

It must be mentioned that in the case of a suitably high carrier-frequency the order of the significant harmonics is considerably shifted upwards by both methods and thus the methods are very sensitive to the skin effect.

Conclusions

In squirrel-cage motors manufactured presently a great skin effect occurs, therefore when applying such motors the voltage waveform of the inverters must appropriately be improved. The methods usual at present are not yet optimal and further investigations are necessary aimed at elaborating new and more effective methods.

Summary

In squirrel-cage induction motors additive losses can be quite significant due to the skin effect, but they can be reduced by appropriate control of the inverters. The paper compares several new and already applied methods from the point of view of losses occurring in the coils of the motors, and states that in the control of inverters not all the possibilities of improving the voltage waveform have been exploited.

References

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