IMPACT OF SKIN EFFECT FOR THE DESIGN OF A SQUIRREL CAGE INDUCTION MOTOR ON ITS STARTING PERFORMANCES

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Abstract
Optimum estimate of the skin effect in the rotor bars of squirrel cage induction machines is important to find the starting torque and starting current since the developed torque is directly proportional to the bar resistance. This skin effect is directly related to the permeability and conductivity of the material used for the rotor bar. Here we use silver as magnetic material of very high conductivity to the rotor bar and observe the change in the starting performances like change in starting current, torque and efficiency due to skin effect in the squirrel case induction motor. Then the results are compared with the starting performances of the induction motor where such type of skin effect is not used. Starting current is found about 1.3 times the no load current due to the skin effect where as for the normal induction motor without skin effect the starting current is found about 3.25 times the no load current. Moreover torque vs speed and slip vs efficiency characteristics curves are analyzed and found remarkable change using skin effect.

Keywords: skin effect; slip; skin depth; induction motor; starting current; torque.

1. Introduction

A solid conductor may be thought of a bundle of large conducting strands. Alternating flux induces higher voltage acting on the interior strands than are induced near the surface of the conductor. By Lenz's Law, the induced voltage opposes the change of current producing it and the higher the voltage acting on the inner strands cause the higher current density in strands near the surface and therefore higher effective resistance. At higher frequency skin effect is a significant factor in large conductor. The skin effect causes the effective resistance of the conductor to increase with the frequency of the current because much of the conductor carries little current. Skin effect due to eddy currents set up the AC current. When the electromagnetic wave interacts with conductive material, mobile charge within the material is made to oscillate back and forth with the same frequency as the impinging fields. The movement of these charges usually electrons, constitute an alternating electric current the magnitude of which is greater at the conductors surface. The decline in the current density versus depth is known as the skin effect and the skin depth δ is a measure of the distance over which the current falls to 1/e of its original value where e=2.71. If JS is the current density at the surface the skin depth can also be defined as the depth below the surface of the conductor at which the current density decays to 1/e (about 0.37) of JS. It can be calculated as follows,

$$\delta = \sqrt{\frac{2\rho}{\mu\omega}}$$

Where,

ρ = resistivity of conductor

ω = angular frequency of current = 2π × frequency

μ = absolute magnetic permeability of conductor $=\mu_o.\ \mu_r$, where μ_o is the permeability of free space ($4\pi\times10^{-7}$ N/A^2) and μ_r is the relative permeability of the conductor.

The skin effect depends upon the nature of material used for the conductor diameter of the wire, frequency, shape of the wire. Skin depth varies as the inverse square root of the conductivity. This means that better conductors have a reduced skin depth. The overall resistance of the better conductor is lower even though the skin depth is less. This tends to reduce the difference in high frequency resistance between metals of different conductivity. Skin depth also varies as the inverse square root of the permeability of the conductor. Skin effect reduces both the effective thickness of lamination in power transformers and their losses. A general change in phase accompanies the change in magnitude so that at a given time and at appropriate depths the current can be flowing in the opposite direction to that at the surface. The effect was first described in a paper by Horace Lamb in 1883, for the case of spherical conductors, and was generalized to conductors of any shape by Oliver Heaviside in 1885. The conventional model of an induction machine, which consists of an equivalent circuit with a single loop, is not adequate to take into account the skin-effect in rotor bars; which may not be negligible when the machine is fed from non-sinusoidal voltage or current source [1, 2]. Pertinently, for the study of skin-effect in rotor bars, the rotor circuit needs to be modified in order to adequately take into account the wide range of frequencies occurring in the machine. Levy [3] and Creer [4] have proposed a rotor model with three rotor loops. In 2004, Dr.-Ing, O. I. Okoro [5], developed a mathematical analysis for the steady-state conventional and skin-effect models. The end region of the machine was modeled using a commercial three-dimensional finite-element package in order to gain some insight into the skin effect phenomenon [6].

In case of an induction motor the skin depth depends on the materials used for the rotor conductors. If the material is magnetic with high permeability then the skin depth will be low and therefore the impedance of the rotor bar will be high. Hence the starting torque is also high. At starting, the induction motor can be treated as a transformer with short-circuited secondary. This results a high rotor current and by transformer action a high stator current. Modern well designed induction motors usually take 6 to 8 times the rated full load current when rated full load voltage is applied which is really objectionable where as the starting torque is near about the rated full load torque. One way to reduce the starting current is to reduce the starting voltage as the rotor current is proportional to the starting voltage. Therefore, in order to reduce the starting current to 50 percent, it is necessary to reduce the starting voltage by the same percentage. But a serious objection of reducing starting voltage is the large reduction of starting torque. Because the starting torque is proportional to the square of the starting voltage as the torque is proportional to both Φ and I which are both proportional to the impressed voltage. In a 5 hp motor the starting torque will be reduced to 47% of rated full load torque from 187% starting torque with 220V applied. Therefore reduction of impressed voltage is not permissible. The problem of high starting current with a comparatively low starting torque can be solved by increasing the rotor resistance at starting. This will decrease the time phase angle between flux and the rotor current and give a greater torque per ampere. The rotor resistance at starting can be made high by using skin effect. In induction motors the rotor frequency varies with the slip, i.e. fr=sf, where, fr is rotor circuit frequency, and f is stator circuit frequency. The variation of rotor frequency may undergo in the order of 100 to 1 when acceleration from stand still to normal operating speed. The skin depth then varies accordingly. In case of induction motor the skin depth depends on the materials used for rotor conductors. If the material is magnetic with high permeability then the skin depth will be low and therefore the impedance of the rotor circuit will be high. Hence the starting torque will also be high. Thus higher rotor resistance at starting gives higher starting torque with low starting current. This can be achieved by using magnetic materials as the rotor bar. Silver has the electrical conductivity of 6.3×10^7 S/m, best electrical conductor of any known metal, Copper $5.9e^7$ S/m commonly used in electrical wire applications. Whereas Aluminum has the conductivity of 37.8×10^6 S/m. The relative permeability of Ag (.99983), Cu (.999994) and Al (1.000022) are almost same. Therefore, choosing Silver as magnetic material will decrease the skin depth i.e. increase the skin effect in the rotor bar of the squirrel cage induction motor and enhance the starting performance.

2. Experimental Details

The main concern of the construction of our motor is the rotor construction. We have constructed a squirrel cage rotor with copper and foils of silver as magnetic material which has very high conductivity in the rotor slot for obtaining the advantages of skin effect at the time of starting of the motor. With this constructed motor at rated voltage we measure the current, input power, speed at different torques. Torque is supplied from an electrodynamometer. After that we take the same readings for another motor where skin effect is not used. Using these data %speed or slip, output power and efficiency has been calculated for these two types of motor.

3. Results and Discussions

Slip or % speed vs current curves with and without skin effect are shown in Fig.1 and Fig. 2 respectively. The starting current for the motor without skin effect is found approximately 3.25 times the no load current. Using magnetic material silver with high conductivity we found the starting current is about 1.3 times the no load current. To understand the skin effect using magnetic material in the rotor bar the current at different speed is normalized by starting current shown in Fig.3 for those motors. From this figure it is clear that the machine without skin effect has very high current up to certain speed hence causes higher loss. So the skin effect reduces the starting current hence reduces loss and improves starting performance of squirrel cage induction motor.

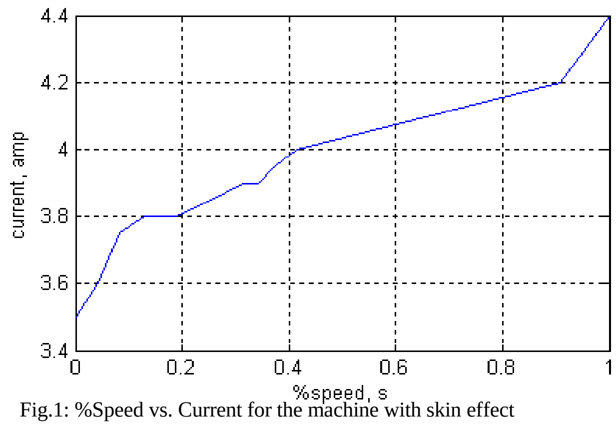

Fig.1: %Speed vs. Current for the machine with skin effect

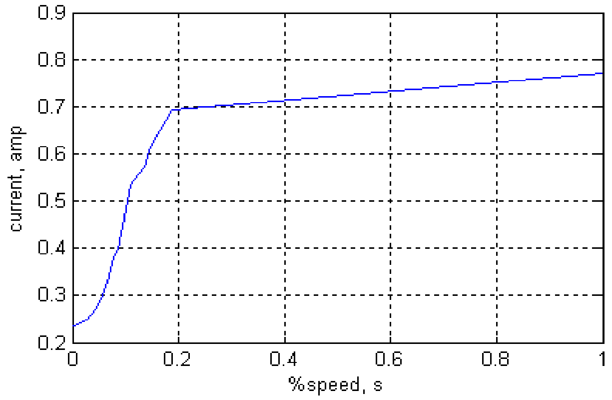

Fig.2: %Speed vs. Current for the machine without skin effect

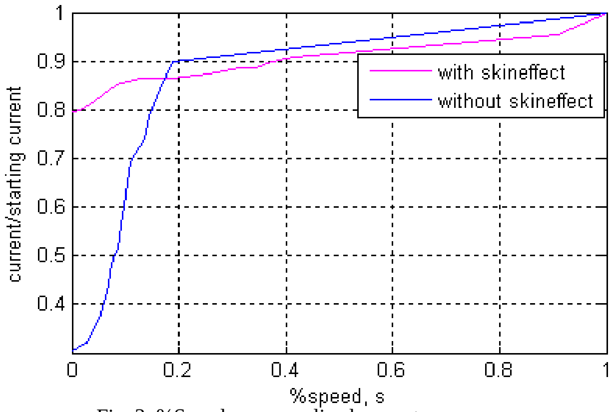

Fig. 3: %Speed vs. normalized current

Torque vs speed curve for the motor using skin effect and the motor without skin effect is shown in fig 4. and fig. 5. respectively. For the motor using skin effect the speed decreases quite smoothly with torque where as for the motor without skin effect it is found that the speed decreases very slowly up to full load torque. So, remarkable change has been found in the torque-speed curve using skin effect.

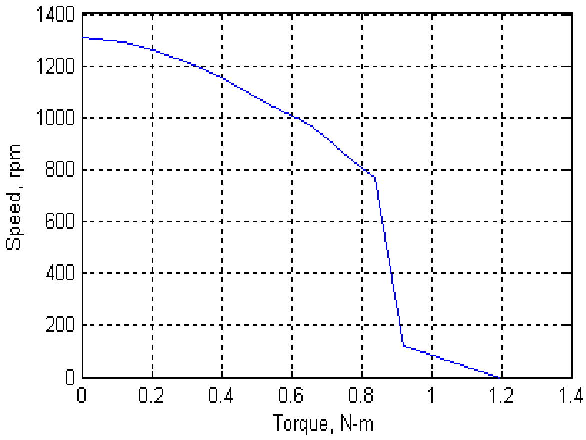

Fig.4: Torque vs speed curve for the machine using Skin effect.

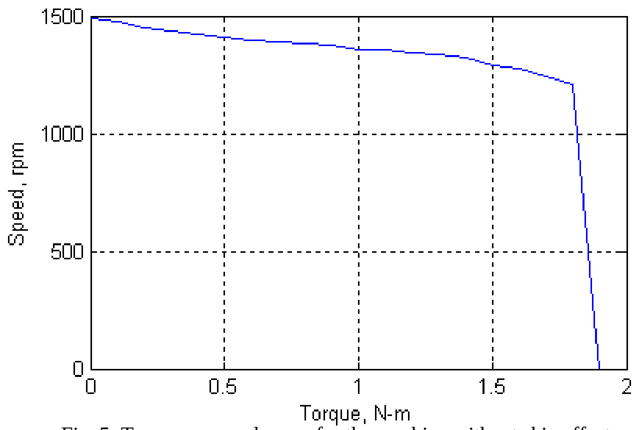

Fig. 5: Torque vs speed curve for the machine without skin effect

Lastly, efficiency curves are analyzed in fig. 6 for the two motors. The maximum efficiency has been found greater for the motor without skin effect. But, we get a wide range of efficient operation for the motor using skin effect i.e. %speed of 0.1 to approximately 0.4 (about 30% of the full operating region) can be operated above 50% efficiency. For the other motor %speed of .04 to approximately .25 (about 20% of the full operating region) can be operated above 50% efficiency. So, in this respect efficiency has improved by using skin effect.

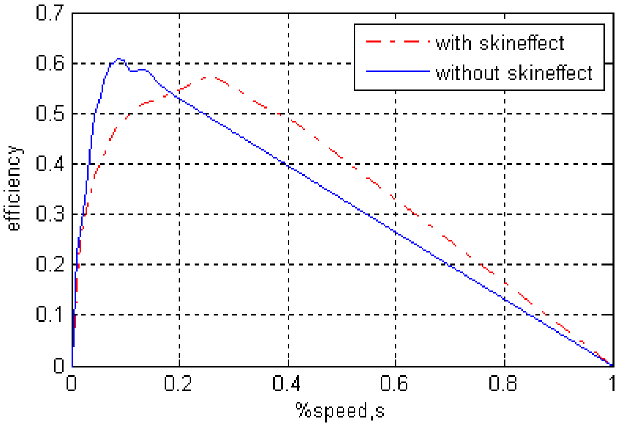

Fig. 6: Comparison of efficiencies for two types of motor

4. Conclusion

Our main concern is to improve the starting performance of the squirrel cage induction motor using skin effect. For this purpose we have used two different types of squirrel cage induction motors. For getting the advantage of skin effect in squirrel cage induction motor to improve the starting performance we have used silver a very good conductor as a magnetic material in the rotor bar for one of the machine. So, skin depth is reduced and the motor was found to run with a starting current which is 1.3 times the synchronous speed current. From our experiment it is clear that magnetic material with good conductivity has prominent effect in designing a squirrel cage induction motor. Here we perform the experiments using two different types of induction motor whose ratings were not identical. So, we could not compare the starting torque improvement using skin effect.

5. References

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