Effect of chording on the efficiency of induction motor supplied by PWM inverter

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Abstract. The increasing usage of the inverter fed three-phase induction motor due to latest technological innovations in the industry demands for designing a high efficiency motor. Three-phase induction motor stator coils were short pitched and tested with pulsewidth modulation (PWM) inverter voltage supply at various switching frequencies. Various loads were varied using eddy current brake and torque is measured using torque gauge. The effect of short pitching on the efficiency of novel winding designed motor were quantified and found that the shortest pitched coil radically improves the efficiency of the motor due to attenuation of lower order harmonics and reduced copper losses.

1. Introduction

Induction motors are extensively and dominantly used motors in domestic and industry purpose. The evolution of hybrid and electric vehicles paved a new path for these motors in a new application in mobility sector\cite{1}. Along with this, a wide develop in power sector is also evolved with the various application of newly introduced methods that may be found in \cite{2-8}. The advantage of using the induction motor is its ruggedness and minimal auxiliaries that enhanced its application. However, the losses in the induction motor has been a topic of discussion and research and hence various efficiency bands and premium quality high efficiency motors were developed\cite{9} to decrease losses and to increase efficiency and reduce the running cost. Typically, the running cost of induction motor at full load during its lifetime is 200 times of its buying cost \cite{10}.

In industrial applications, mismatching of the induction motor with respect to its application is another reason for the energy wastage \cite{11}. Using Induction motor at full speed where the actual load is spasmodic, for example, using induction motor for an exhaust vent fan in sinter plant of a steel
industries where the exhaust is only needed when the sinter and coke is burnt. This problem can be easily solved using speed control methodologies. With advancement of power electronics various speed strategies evolved and paved way to the technologies that can control the speed of induction motors and can save energy [12-15]. Pulse width modulation (PWM) is one of the methods that is employed in various industries, however, most of the induction motors are designed and manufactured for the sinusoidal voltage supplies. Using this kind of motors is one more hindrance that decrease the efficiency. This calls for the need to redesign and optimise the induction motor performance and improve its efficiency.

The above issue is dealt in the work presented and a novel winding is designed and tested that will improve the efficiency of the induction motor.

2. Methodology and test set-up
Two, four-pole, three-phase, 1-hp (746 Watts), 50Hz, 415V, commercial squirrel cage induction motor with stator concentric winding was unwound and one was re-wound with the coil pitch of 120 degree lap winding and other with full pitch coil of 180 degrees lap winding. The stator has 36 slots and pole pitch of 9 slot and per slot pitch is 20 degrees electrical. The full pitch was wound from slot 1 to 10 (9 slots, 180 degrees electrical) and short pitch was 1 to 7 (6 slots, 120 degrees electrical). These two motors were tested with sinusoidal and inverter with PWM supply with same load. These motors were tested with switching frequencies of 16kHz, 8kHz and 4kHz under modulation frequencies of 50 Hz PWM supply.

The motors were loaded with eddy current brake system as shown in figure 1. The torques were varied from 1N-m to 6.5N-m, 5.5N-m being the full load torque for the motors. In each scenario the torque is varied up to the unstable region. Power analyser was used to measure the input power and a torque meter and tachometer was used to measure the output power. The repeatability of the measurement was ±0.8%.

![Figure 1. Experimental Set-up.](image)

3. Results and discussions
To assess the effect of short pitching on the efficiencies under PWM supply both the motors’ data were plotted. The figure 2 and figure 3 shows the efficiency of the motor with 120° and 180° coil pitch winding supplied with 50Hz modulation frequency and 4kHz switching frequency.
It was observed that the efficiency of lowest coil pitch motor was increased by 6% when compared with the fill pitch coil motor at full load and the effect was significant when the motor was overloaded and increase in efficiency was 16%. It is to be noted that the joint length of the overhang on both side of the stator winding is equal to the length in the slot portion. As the coils are short pitched the amount of copper required at the overhang is drastically reduced and hence the copper losses.

The efficiency curves with the switching frequency of 8kHz and 16kHz are shown in figure4 and figure5. It is evident from figure2, figure4 and figure6 that as the switching frequency rises from 4kHz to 16kHz the efficiency curve is stabilizing at overload and this can be the added advantage when uprating of the existing motor is requires. However, if the actual efficiency is quantified then the machine running under lower switching frequency has the highest efficiency. It is coherent with the increase in the switching losses.

The full pitch motor struggled to maintain adequate efficiency when compared to shortest pitched motor at lighter loads and is apparent from the figure3, figure5 and figure7. With short pitching the stator winding, the lower order harmonics willassuaged [16] and this state was applicable in the case of 120° coil pitched motor, whereas, in 180° pitched motor these attenuation didn’t transpire. With raise in the switching frequency the harmonics increasesin fully pitched motor [17-21] and harmonic losses aided in decreasing the efficiency.

Drastic decrease in efficiency was evident in fully pitched coil and were measured as much as 10% and 18% at full load and overload machine respectively with highest switching frequency mode. The dip in the efficiency at overload occurs with rise in the switching frequency for 180° coil pitch motor.
The combined effect of change in the switching frequencies with short and fully pitched coil can be seen in figure 8. The overall efficiencies of both type of motor decreased with raise in the switching frequencies. The interesting scenario emerged with both the motors where the efficiencies were almost equal, however difference in their switching frequencies were notable. At full load, the efficiency of the 120° pitched motor at 16kHz switching frequency supply, which was the lowest efficient switching frequency mode, matched with 180° but at its highest efficient switching frequency of 4kHz.

4. Conclusion
The design of stator winding is the deciding factor in improving the efficiency of PWM-inverter fed three-phase induction motor. The motor with shortest pitch is considered as efficient with various switching frequencies when compared with fully pitched motor. Switching frequency plays a key role in deciding the efficiency for both type of motor with increase in 6% and 8% for short and fully pitched motor, respectively, at full load. There is positive effect of increasing switching frequency at overload condition that can be leveraged for uprating of the used motors.

5. References
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