A Comparative Study on Conventional and Superconducting Electrical Machines

Phaneendra Babu *Bobba*[1*], *G* Sandhya Rani[1], *Burra* Sujan Goud[2]
[1]EEE Department, GRIET, Hyderabad, Telangana
[2]UG Student, EEE Department, GRIET, Hyderabad, Telangana

Abstract: This paper investigates the potential benefits of utilizing superconducting materials in machines. The project focuses on replacing the conventional copper windings with superconducting materials in a machine. The machine is modelled and simulated using ANSYS software, both with conventional copper windings and with superconducting windings. A 3.7kw and 11kw 3 phase Induction machines are simulated with YBCO material applied to stator and rotor windings. The results show that the use of superconducting materials in the machine windings can significantly reduce energy losses and improve machine efficiency by 1 to 10%. Overall, the study suggests that superconducting machines offer a promising avenue for improving energy efficiency and reducing operating costs.

1 Introduction

The development of superconducting materials has opened up new possibilities for the design and performance of electric machines. Superconducting materials have the unique ability to conduct electricity with zero resistance when they are cooled below a certain critical temperature. This property leads to the development of high-performance electric machines that can operate with high efficiency, high power density, and low weight. Machines are widely used in various industrial applications due to their simple design, low cost, and high reliability. However, their performance is limited by the resistive losses in their copper windings. Superconducting materials can eliminate these losses and improve the efficiency and power density of machines. In this research paper, we will compare the performance of a machine made of superconducting materials with a conventional machine. We will evaluate the efficiency, power density, and other performance parameters of both machines under

[*] Corresponding Author: bobbaphani@gmail.com

different operating conditions. The objective of this research is to demonstrate the potential benefits of using superconducting materials in the design of electric machines and to provide a basis for future research and development in this field.

The paper is organized as follows: in section 2, we will provide a brief overview of the principles of induction machines and superconducting materials. In section 3, we will describe the design and construction of the superconducting induction machine. In section 4, we will present the experimental results and compare the performance of the superconducting induction machine with the conventional induction machine. Finally, in section 5, we will discuss the conclusions of this research and suggest future directions for research in this field.

2 Methodology

A superconductor is a material that exhibits zero electrical resistance when it is cooled below a certain temperature, known as the critical temperature (Tc). This means that a superconductor can conduct electrical current without any loss of energy due to resistance, making it highly efficient for electrical applications.

The phenomenon of superconductivity was first discovered in 1911 by Dutch physicist Heike Kamerlingh Onnes, who found that mercury exhibited zero resistance when cooled to 4.2 K (Kelvin), which is close to absolute zero temperature (-273.15°C).[4] Since then, many other superconducting materials have been discovered, including metallic alloys, ceramics, and organic compounds.

Superconducting materials are categorized into two types: type I and type II. Type I superconductors are characterized by a sharp transition to superconductivity at a specific temperature and a complete exclusion of magnetic fields, while type II superconductors exhibit a more gradual transition to superconductivity and can tolerate a limited amount of magnetic fields.

2.1 YBCO Superconductor:

YBCO is a type II superconductor made of yttrium, barium, and copper oxide. It is one of the most widely studied high-temperature superconductors, with a critical temperature (Tc) of around 93 K (-180°C) and a high critical magnetic field (Hc) that makes it suitable for a wide range of applications [4].

One of the key advantages of YBCO superconductors is their ability to operate at higher temperatures than other superconducting materials. This makes them more practical for use in applications that require high magnetic fields, such as MRI machines, particle accelerators, and power generation systems.

The production of YBCO superconductors is complex and requires specialized techniques, such as pulsed laser deposition and metal-organic chemical vapor deposition. These techniques involve depositing thin films of YBCO onto a substrate, which can then be used to create superconducting wires and coils [7].

YBCO superconductors have a number of potential applications in various fields, including power transmission, energy storage, and high-speed transportation. For example, YBCO coils can be used in high-efficiency motors for electric vehicles, or in generators for wind turbines.

2.2 Design of Induction Motor:

The design of motor has been done in Ansys RMxprt and Ansys Maxwell. Parameters in the table are given as input. The ANSYS RMXprt software tool provides a wide range of

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machine-specific, template-based interfaces for designing induction, synchronous, electronically and brush commutated machines. These templates enable easy entry of design parameters and facilitate the evaluation of design trade-offs at an early stage. By using the software, it is possible to quickly calculate critical performance data such as torque versus speed, power loss, flux in the air gap, power factor, and efficiency [1].

The model created using ANSYS RMXprt can be effortlessly exported to Maxwell project (2D/3D) for conducting Finite Element Method and electromagnetic transient analyses. The tool makes it possible to analyze the behaviour of various types of induction machines, including those made of superconducting materials, under different operating conditions. With its powerful features, ANSYS RMXprt helps designers and engineers optimize the design of induction machines, including the rotor and stator geometry, winding turns, and material selection.[5]. This can lead to better performance, efficiency, and reduced costs in the design and manufacturing of these machines.

Table 1 3.7 KW Three phase IM design parameters

Rated Power	3.7 KW
Rated Voltage	415 V
Poles	4
frequency	50 Hz
Winding	Delta
Speed	1500 rpm
No. of Stator Slots	36
Stator Outer Diameter(mm)	204
Stator Inner Diameter(mm)	140
Rotor Inner Diameter(mm)	43
End Ring Height(mm)	20
End Ring Width(mm)	7
No. of Rotor Slots	48
Rotor length(mm)	135

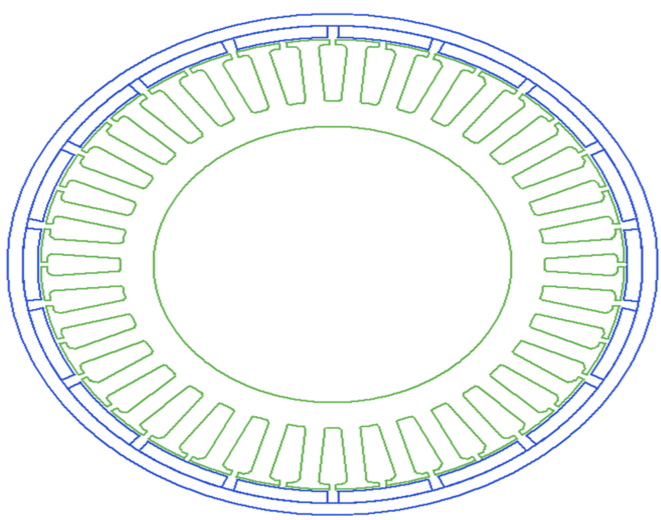

Fig.1. Design Schematic of Three Phase Induction Motor

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Table 2 Table 1 11 KW Three phase IM design parameters

Rated Power	11 KW
Rated Voltage	440 V
Poles	6
Winding	Star
frequency	50 Hz
Speed	1000 rpm
Stator Outer Diameter(mm)	390
Stator Inner Diameter(mm)	250
Length of Stator core(mm)	140
Number of Stator slots	54
Number of conductors per slot	28
Number of Rotor Slots	57
Rotor Outer Diameter(mm)	200
Rotor Inner Diameter(mm)	130

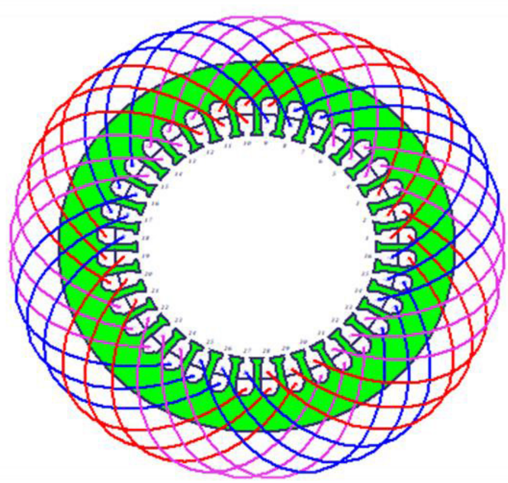

Fig.2. Winding Connection

Table 1 shows the important input parameters of the 3.7KW Machine. This data is taken from the reference [6]. Table 2 shows the important input parameters of 11KW Machine [2].

2.3 Superconducting Machine

A superconducting machine is an electrical machine that utilizes superconducting materials to reduce energy losses and increase efficiency. These machines are designed to operate at cryogenic temperatures, below the critical temperature (Tc) of the superconducting material. Superconducting machines can be used in a variety of applications, including power

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generation, transportation, and industrial processes [3]. The Machines created in Ansys with copper conductors, those conductors are replaced to YBCO tapes superconductors. Previously both stator and rotor are made by copper but now both are changed to YBCO tapes. We are assuming the machine is at -196 degree Celsius. Initially there is no superconducting material in software, I added the material by giving the properties of YBCO. The superconducting machine has more advantages than the conventional motors. The superconducting machine has more power density than the normal motor and it has less losses. Superconductors improves the efficiency of the machine. Superconducting machine produces comparatively less noise.

3 Simulation Results and Discussion

3.1 3.7 KW Induction Machine:

The loss plot of superconducting machine has shown in fig 3:

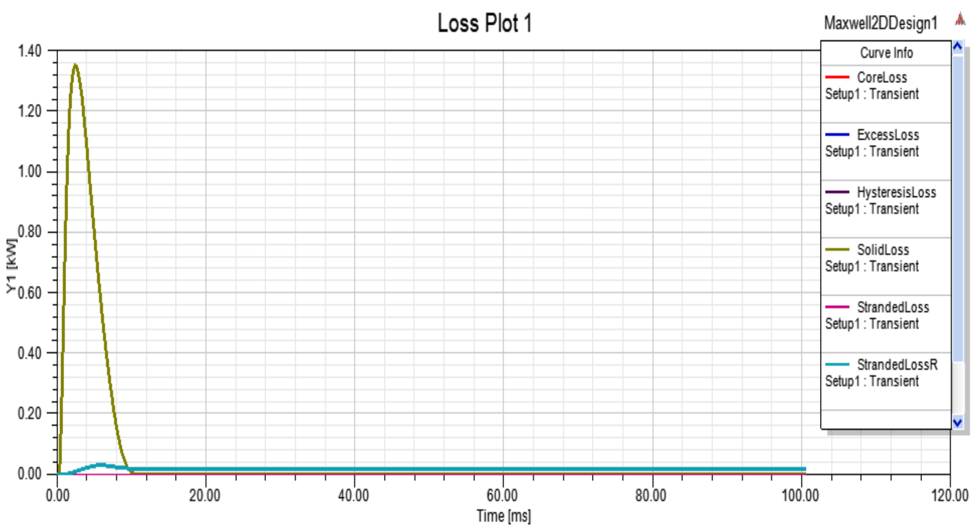

Fig.3 Losses of superconducting machine

The loss plot of conventional induction machine has shown in fig 4:

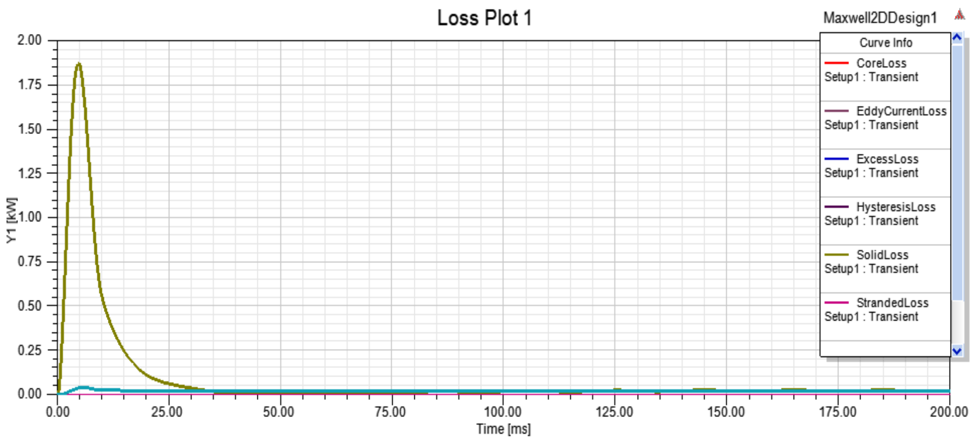

Fig.4 Losses of conventional Induction machine

The three phase currents plots of superconducting machine has shown in fig 5:

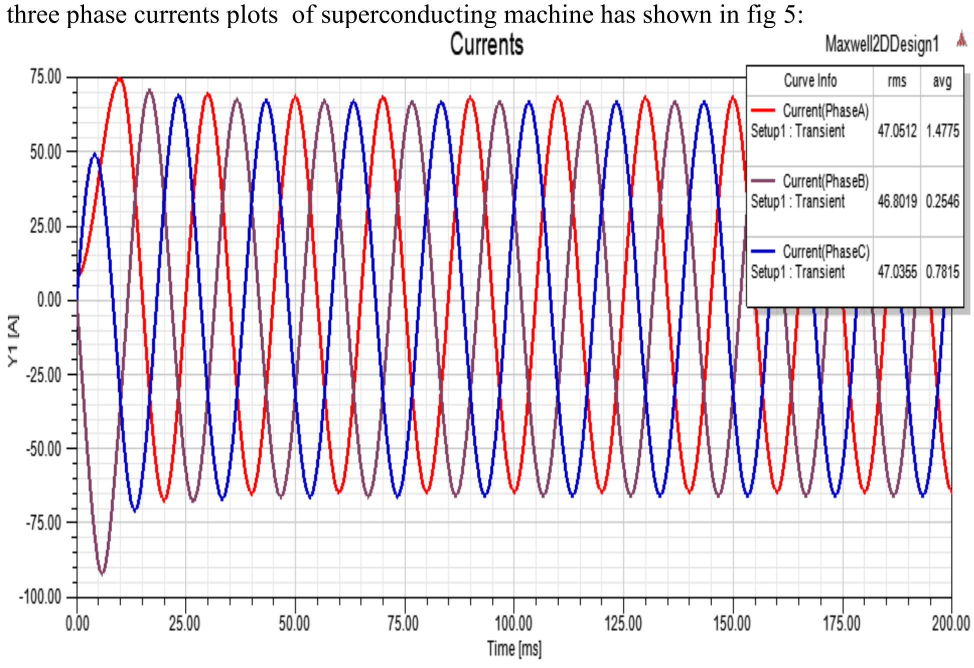

Fig.5 3 Phase Superconducting Induction Motor Current graph

The three phase current plots of conventional three phase Induction Motor:

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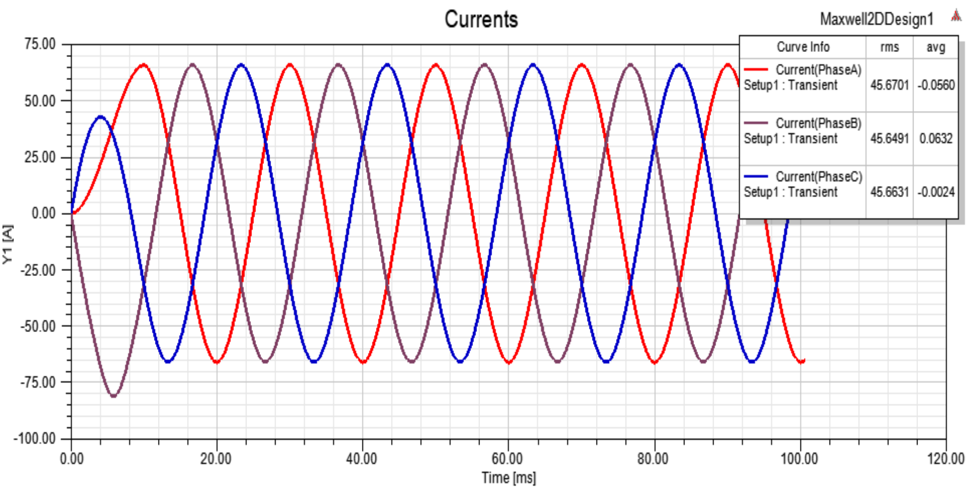

Fig.6 3 Phase Induction Motor Current graph

3.2 11KW Induction Machine:

The loss plot of both machine are shown in fig 7 and fig 8:

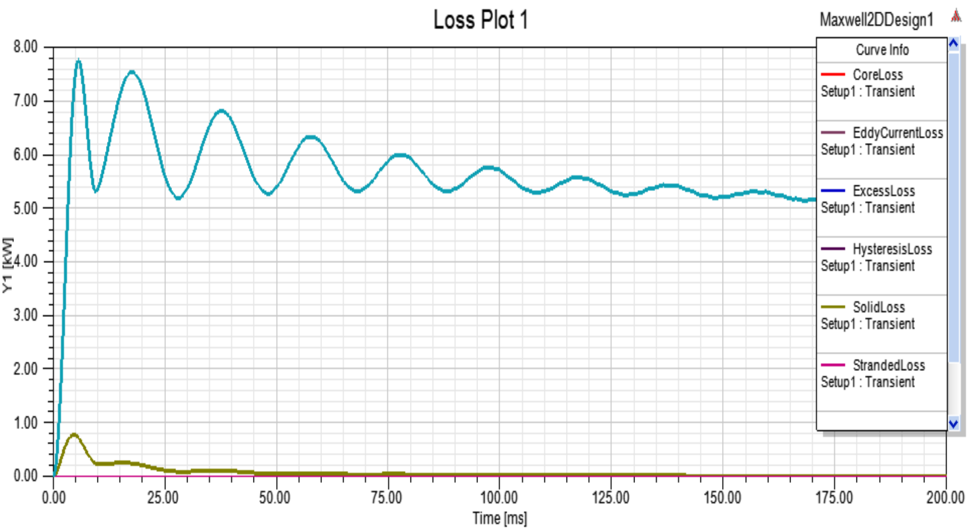

Fig.7 Loss plot of conventional Induction Motor

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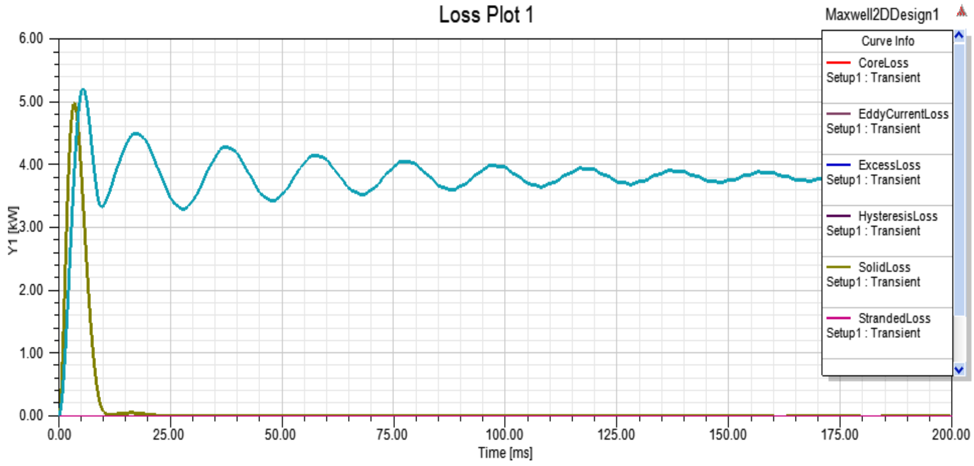

Fig.8 Loss plot of the superconducting induction motor

The graphs of induced voltages of both machines is shown in fig.9 and fig.10

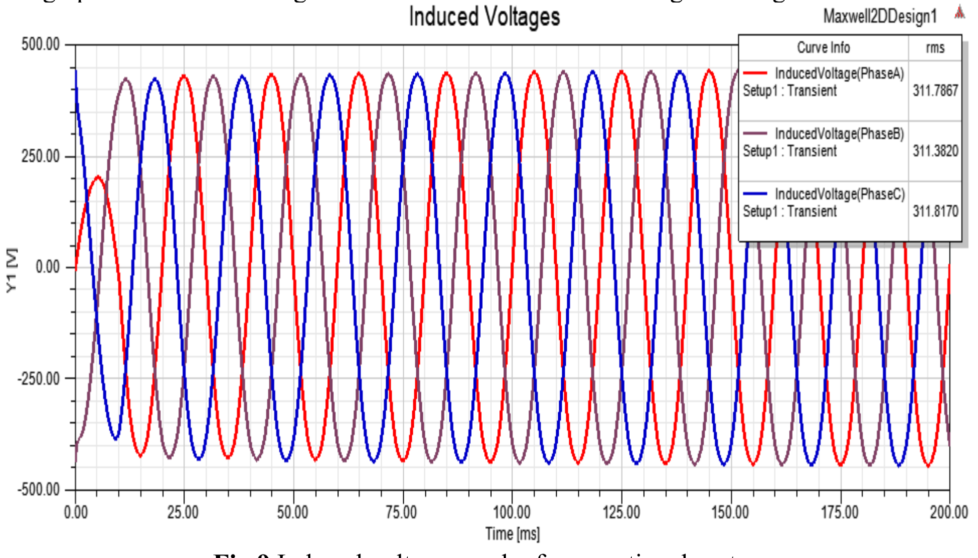

Fig.9 Induced voltage graph of conventional motor

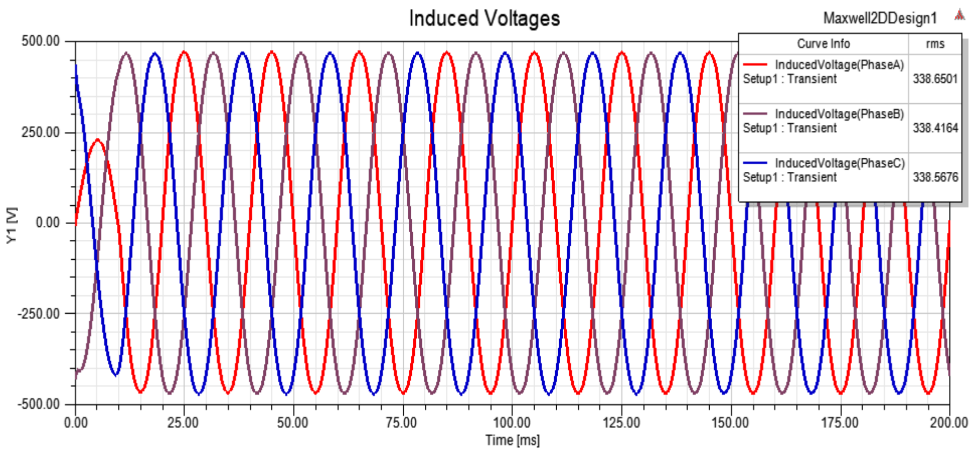

Fig.10 Induced Voltage graph of superconducting machine

Table 3 Comparison of 3.7 KW and 11KW Machines

parameter	3.7 KW Machine		11 KW Machine	
	Conventional	Superconducting	Conventional	Superconducting
LOSS	122 W	102 W	5726 W	4015 W
Efficiency	96%	97.45%	61%	73%

4 Conclusion

From Table 4 and from fig7 to 10, the use of superconducting material in the stator and rotor windings of an induction motor has shown significant improvements in terms of reducing losses and increasing efficiency compared to conventional induction motors with copper windings. The results of the simulation using Ansys Rmxprt and Maxwell 2D showed that a 3.7 kW superconducting induction motor had a reduction of 20 W in loss and a 1.25% increase in efficiency compared to a conventional induction motor. Similarly, an 11 kW superconducting induction motor showed a reduction of 1,711 W in loss and a 12% increase in efficiency compared to a conventional induction motor.

These results suggest that the use of superconducting material in induction motors could be a promising solution for improving the performance of such motors. Further studies could focus on optimizing the design of the superconducting motor to enhance its efficiency and reducing the cost of production of superconducting materials.

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