INTRODUCTION

Alumina ($\text{Al}_2\text{O}_3$) is one of the most widespread metal compounds in nature and makes up about 8.8% of the earth’s crust. Alumina is transformed into Aluminium through electrolytic reduction. Aluminium is used across industries and across products in our daily lives due to its relative cost-effectiveness and its alloys are used extensively for adding strength and utility. Aluminium production is therefore of vital economic importance across the world.

The single most important factor in Aluminium production is the cost of energy used in the process of converting Alumina to Aluminium. This energy, which accounts for nearly 35%-40% of the total cost of production of the metal, is primarily in the form of Direct Current (DC) power.

With the primary sources of electricity across the world providing Alternating Current (AC) power, an efficient AC-DC converter becomes a critical component in the electrolytic reduction process of extracting non-ferrous materials in general and aluminium in particular. With the growing importance of Aluminium and other non-ferrous industries, the requirement for efficient AC–DC converters has increased multi-fold.

The Hall-Heroult process is the basis of all primary Aluminium smelting plants in the world. In this process, Alumina ($\text{Al}_2\text{O}_3$) is dissolved in an electrolytic bath of molten cryolite (Sodium Aluminium Fluoride) at operating temperatures ranging from 920˚C to 970˚C under the influence of high intensity direct current. Compared to the production of other metals such as Copper and Zinc, Aluminium smelting is significantly more energy intensive. The specific energy consumption of DC power in a typical Aluminium smelter ranges from 13000 KWH to 14500 KWH per tonne of metal produced.

Across the world, more than 200 Aluminium smelters are currently producing molten Aluminium by consuming large amount of electrical energy from their captive power plants or grids. One such plant, which will be the main focus of research of this paper, is owned by Hindalco Industries Ltd in Renukoot, UP, India. This plant currently has an annual production capacity of 410,000 tonnes of Aluminium and 98,000 tonnes rolled products, 91,000 TPM of wire rods and 33,000 TPA extrusions. The Hindalco Aluminium smelter consists of 11 pot lines
with each line containing 200 pots connected in series. As the smelting process is continuous, a smelter cannot easily be stopped and restarted. Any interruption in production due to failure of power supply for more than four hours causes the metal in the pots to solidify. This then leads to the need for an expensive rebuilding process.

AC-DC convertor technology was based in Mercury based converters till late 1950. In 1960, the first diode rectifier was used in Aluminium smelters and ten years later thyristor rectifiers were in operation.

These two technologies have been competing with each other over the last multiple decades. At present, in Aluminium smelters the two types of AC-DC converters most commonly used are:

1) Uncontrolled rectifiers or Diode rectifiers and
2) Controlled rectifiers or Thyristor rectifiers

The acceptance of these rectification technologies across Aluminium smelters is based on the combination of several factors that are taken into consideration. These include – system reliability, investment cost, efficiency, current harmonic distortion, ripple, power factor, current regulation accuracy and the maintainability of the converters.

**Uncontrolled Rectifiers (Diode Rectifiers)**

Diode rectifiers are the simpler form of rectifiers and used as front end converters in DC power supplies. The circuit diagram of a diode rectifier is shown in Fig. 1
In 12 pulse rectification the predominant harmonic components in the current waveform are 11th and 13th. In this case the currents are balanced and there is no neutral current problem. To mitigate the low order harmonic problems of harmonics, multipulse (such as 24 and 36) are used at large plants like Hindalco. Phase shifting transformers with the appropriate phase shift are used to achieve 24 pulse operations. The dual advantage of a higher number of pulses is to lower total harmonic distortion (THD) of AC mains current and ripple free DC current. Control of current & voltage for a Diode rectifier is achieved by changing the input voltage by following means as follows:

1) By using On Load Tap Changers (OLTCs) at the rectifier transformers on the primary side of the transformers a rough voltage control can be achieved.

2) The Saturable Control Method by introducing variable impedance into the circuit, ahead of the diode rectifier. Using this impedance, a smooth control is achieved in the range of 50 - 80 V DC.

On Load Tap Changers and Saturable reactors are often used together to improve voltage control.

**Control rectifiers (Thyristor rectifiers)**
The Saturable Control Rectifiers or Thyristor rectifiers are capable of voltage regulation by means of gate control and the thyristor rectifier is controlled electronically. For a thyristor rectifiers, the fundamental component of current lags the respective phase voltage by triggering angle \( \alpha \) with a displacement factor of \( \cos \alpha \). Fig 2 shows the circuit diagram of a fully controlled rectifier.

![Circuit Diagram](image)

**Fig 2**

In Thyristor Rectifiers, the firing angle helps to control the voltage and current. When a thyristor rectifier is controlled through a small delay firing angle it performs like a diode rectifier using saturable reactor control. It has fast and smooth output control to the order of milliseconds.

Due to the use of these semiconductors AC – DC converters in Aluminium smelters over many years, several serious issues related to the power system and efficiency of conversion have become a prominent feature of Aluminium smelters. These include the generation of current harmonics, voltage distortion in controlled rectifiers, poor power factor, voltage dips, issues relating to reliability, maintainability, efficiency and investment cost etc.

Given the competing technologies available, it remains a complex task for the industry to objectively choose the appropriate converter technology for Aluminium smelters. Over the last two decades, both these technologies have competed for market share and mind share and have effectively been opted for based on supplier marketing and recommendations from maintenance and operation engineers.
In this research a comparative study of diode and thyristor converters with an assessment of the advantages and disadvantages of each technology will be undertaken. The practical pros and cons of both technologies will be elaborated in great detail and parameters will be compared, specifically current harmonics, ripples, power factor, AC voltage dips, efficiency, investment cost and maintenance cost.

This research is expected to be of immediate relevance to the Non Ferrous industry, particularly Aluminium Plants, to help them meet the challenges of objectively selecting the most efficient and suitable converter technology for their Aluminium smelters.