# DEPARTMENT OF APPLIED PHYSICS

# RECTIFIER

# SEMICONDUCTOR DEVICES

# (EP-301)

# PROJECT REPORT

**SUBMITTED BY :**

**HARSH PANCHAL 2K18/EP/031**

**JAI PRAKASH 2K18/EP/033**

**Under the supervision of**

**Professor A.S Rao**

# ACKNOWLEDGEMENT

We have taken efforts in this project. However, it would not have been possible without the support and help of many individuals and organizations. We would like to extend my sincere thanks to all of them.

We are highly indebted to DTU and especially to Prof. A.S Rao our Faculty Supervisor, for their guidance and constant supervision as well as for providing necessary information regarding the project & also for their support in completing the project.

Last but not least, we would like to thank our respective families for their endless support and help throughout the duration of the work.

Thank you

# ABSTRACT

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as rectification. Physically, rectifiers take a number of forms, including vacuum tube diodes, mercury-arc valves, copper and selenium oxide rectifiers, semiconductor diodes, silicon-controlled rectifiers and other silicon-based semiconductor switches. Historically, even synchronous electromechanical switches and motors have been used. Rectifiers have many uses, but are often found serving as components of DC power supplies and high-voltage direct current power transmission systems.

# CONTENTS

# INTRODUCTION

During the last few years the demand for small rectifiers has grown rapidly. This growth has been due to the increasing use of small portable batteries and also to the increasing practice of using low rates for charging larger batteries. This latter method of charging is called "trickle charging" and requires a small current to maintain the battery in a charged condition. Because of this small current requirement and the general availability of alternating-current power, rectifiers of small output are extensively used.

For larger amounts of direct-current power, of course, the use of synchronous converters, motor-generator sets, and the mercury arc rectifiers are too well known to require further attention here.

Since the use of rectifiers is nearly always for charging batteries, tests were made under various conditions during the charging of a battery. The theory of rectification presented, therefore, takes into account the presence of a counter electromotive force. Because of the suitability of the electrolytic rectifier for developing the theory of rectification and for studying the effect of various factors upon rectification, it is discussed at considerable length.

# Theory And Methodology

Although in our daily life we use A.C. current devices. But rectifier is a 'Electronic device which converts A.C. power into D.C. power'.

The study of the junction diode characteristics reveals that the junction diode offers a low resistance path, when forward biased, and a high resistance path, when reverse biased. This feature of the junction diode enables it to be used as a rectifier.

The alternating signals provides opposite kind of biased voltage at the junction after each half-cycle. If the junction is forward biased in the first half-cycle, its gets reverse biased in the second half. It results in the flow of forward current in one direction only and thus the signal gets rectified.

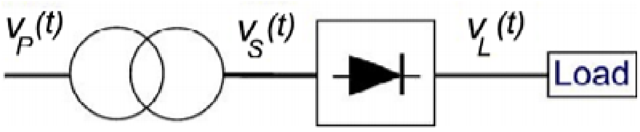
In other words, we can say, when an alternating e.m.f. signal is applied across a junction diode, it will conduct only during those alternate half cycles, which biased it in forward direction.

The circuits we will be working with are the basic limiting circuit, half-wave and full-wave rectifiers. Rectification may serve in roles other than to generate direct current for use as a source of power. Because of the alternating nature of the input AC sine wave, the process of rectification alone produces a DC current that, though unidirectional, consists of pulses of current. Many applications of rectifiers are such as half wave rectifier, full wave rectifier and center tapped full wave rectifier. In these applications the output of the rectifier is smoothed by an electronic filter (usually a capacitor)to produce a steady current. More complex circuitry that performs the opposite function, converting DC to AC, is called an inverter.

Rectifier circuits may be single-phase or multi-phase (three being the most common number of phases). Most low power rectifiers for domestic equipment are single-phase, but three-phase rectification is very important for industrial applications and for the transmission of energy as DC (HVDC).

# PERFORMANCE PARAMETERS

Before starting to examine different topologies for single-phase or multi-phase rectifiers, we should define some parameters. These parameters are needed to compare the performances among the different structures.




Let's assume to have ideal switches (diodes or thyristors) with zero commutation time (i.e. instantaneous turn on and off) and zero on-resistance (i.e. when conducting they present neither voltage drop nor losses). The load itself is an ideal resistance. The generic scheme is reported in figure above . At the input of the rectifier there are one or more AC voltages from the secondary of the transformer. At the output of the rectifier, on the "load", there is also a time-dependant voltage. This voltage, as it will be shown, is a "combination" of the voltages at the input of the rectifier stage.

The DC voltage on the load is the average over the period T of the output voltage of the rectifier :

$$V_{DC} = \frac{1}{T}\int_0^T v_L(t)dt$$

Similarly, it is possible to define the rms voltage on the load:

$$V_L = \sqrt{\frac{1}{T}\int_0^T v_L^2(t)dt}$$

The ratio of the two voltages is the Form Factor (FF):

$$FF = \frac{V_L}{V_{DC}}$$

This parameter is quite important since it is an index of the efficiency of the rectification process.

Having assumed the load to be purely resistive, it is possible to define the currents as :

$$i_L(t) = \frac{v_L(t)}{R_L}$$

$$I_{DC} = \frac{V_{DC}}{R_L}$$

$$I_L = \frac{V_L}{R_L}$$

The Rectification Ratio (η), also known as rectification efficiency, is expressed by:

$$\eta = \frac{P_{DC}}{P_L + P_D}$$

where

$$P_{DC} = V_{DC} \cdot I_{DC}$$

$$P_L = V_L \cdot I_L$$

$$P_D = R_D \cdot I_L^2$$

By explicating above equation we get

$$\eta = \frac{V_{DC} \cdot I_{DC}}{V_L \cdot I_L + R_D \cdot I_L^2} = \frac{V_{DC}^2}{V_L^2} \cdot \frac{1}{1 + R_D / R_L}$$

We have assumed to have ideal switches, with no losses, that is RD = 0. Therefore,

$$\eta = \left(\frac{V_{DC}}{V_L}\right)^2 = \left(\frac{1}{FF}\right)^2$$

The Ripple Factor (RF) is another important parameter used to describe the quality of the rectification. It represents the smoothness of the voltage waveform at the output of the rectifier (we have to keep in mind that our goal is to obtain a voltage and a current in the load as steady as possible). The RF is defined as the ratio of the effective AC component of the load voltage vs. the DC voltage.

$$RF = \frac{\sqrt{V_L^2 - V_{DC}^2}}{V_{DC}} = \sqrt{FF^2 - 1}$$

A transformer is usually used both to introduce a galvanic isolation between the rectifier input and the AC mains and to adapt the rectifier AC input voltage to a suitable level for the required application. One of the parameters used to define the characteristics of the transformer is the Transformer Utilization Factor (TUF)

$$TUF = \frac{P_{DC}}{Effective\ Transformer\ VA\ Rating} = \frac{P_{DC}}{\frac{VA_P + VA_S}{2}}$$

where $V_{AP}$ and $V_{AS}$ are the power ratings at the primary and secondary of the transformer.

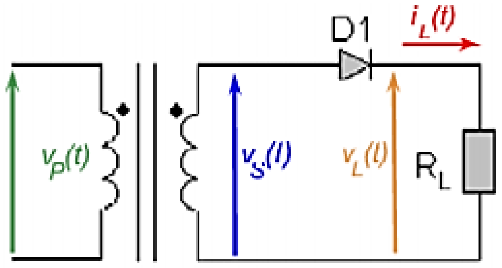
# Rectifier Circuits

Rectifier circuits may be single-phase or multi-phase. Most low power rectifiers for domestic equipment are single-phase, but three-phase rectification is very important for industrial applications and for the transmission of energy as DC (HVDC).

## Single-phase rectifiers

### I. Half-wave rectifier

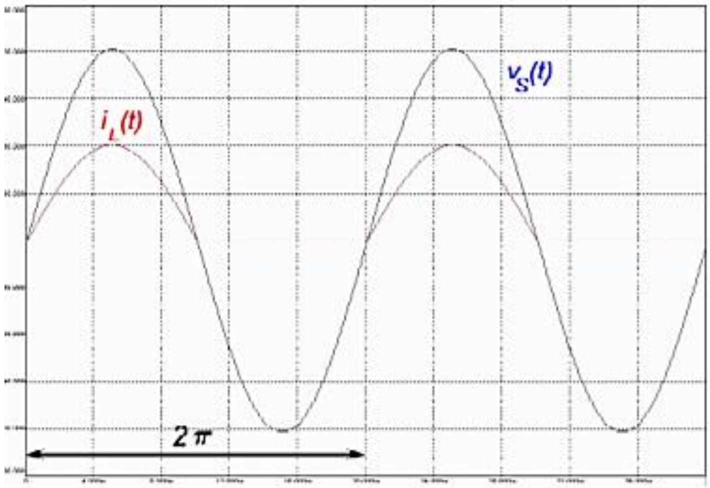
This is the simplest structure. Only one diode is placed at the secondary of the transformer.




Structure of the Single-Phase, Single-Way, Half-Wave rectifier.

Figure above shows the waveforms of the voltage at the secondary and of the current in the load. Since the load is a resistance, the voltage on the load is proportional to the current.

It is quite evident why this type of rectifier is called "half-wave": the rectification process occurs only during half period. It is also called "single-way" because the load current iL(t) circulates in the secondary winding always in the same direction.




Waveforms of the Single-Phase, Single-Way, Half-Wave rectifier.

Using the definitions reported in the previous section, we get the following results.

$$V_{DC} = \frac{1}{T}\int_0^T v_L(t)dt = \frac{1}{2\pi}\int_0^\pi V_S \sin(\varpi t)dt = \frac{V_S}{\pi}$$

And, similarly, we can calculate the other parameters.

$$V_L = \sqrt{\frac{1}{T}\int_0^T v_L^2(t)dt} = \sqrt{\frac{1}{2\pi}\int_0^\pi V_S^2 \sin^2(\varpi t)dt} = \frac{V_S}{2}$$

$$I_{DC} = \frac{V_{DC}}{R_L} = \frac{V_S}{\pi \cdot R_L}$$

$$I_L = \frac{V_L}{R_L} = \frac{V_S}{2 \cdot R_L} = I_S$$

The current in the secondary of the transformer can flow only when the diode conducts and therefore it is equal to the current in the load.

$$FF = \frac{V_L}{V_{DC}} = \frac{\pi}{2}$$

$$\eta = \left(\frac{1}{FF}\right)^2 = \frac{4}{\pi^2} = 0.405$$

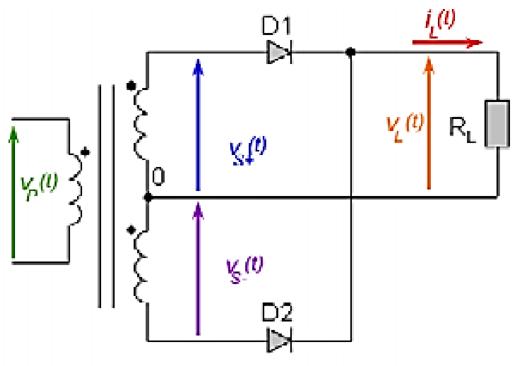
$$RF = \sqrt{FF^2 - 1} = 1.21$$

The poor performances of this rectifier are confirmed also from the utilization of the transformer.

we get TUF = 0.323 (or TUF = 0.286 according to some authors)

## II. Full-wave rectifier

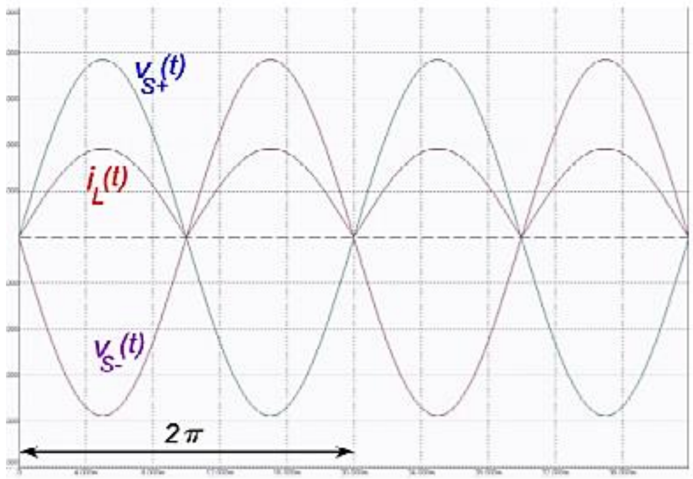
In order to use both half of the secondary AC voltage waveform, one can use two diodes and create a return path for the current adding a tap at the centre of the secondary winding. This is the so-called Centre-Tapped rectifier.




Structure of the Single-Phase, Single-Way, Full-Wave rectifier.

Diode D1 conducts during the positive half wave of the voltage. Diode D2 conducts in the negative half. The current always flows from the common point of the diodes, through the load and back to the central tap of the transformer.

As shown in figure, the rectification occurs during the whole period of the voltage. This is a "full-wave" rectifier. It has to be noted that also in this case the current flows in the same direction through the two halves of the secondary winding. Therefore this is a single-way structure, too.




Waveforms of the Single-Phase, Single-Way, Full-Wave rectifier.

Using the definitions reported in the previous section and the symmetries, we get the following results.

$$V_{DC} = \frac{1}{T}\int_0^T v_L(t)dt = \frac{2}{2\pi}\int_0^\pi V_S \sin(\varpi t)dt = \frac{2 \cdot V_S}{\pi}$$

$$V_L = \sqrt{\frac{1}{T}\int_0^T v_L^2(t)dt} = \sqrt{\frac{1}{\pi}\int_0^\pi V_S^2 \sin^2(\varpi t)dt} = \frac{V_S}{\sqrt{2}}$$

$$I_{DC} = \frac{V_{DC}}{R_L} = \frac{2 \cdot V_S}{\pi \cdot R_L}$$

$$I_L = \frac{V_L}{R_L} = \frac{V_S}{\sqrt{2} \cdot R_L}$$

$$FF = \frac{V_L}{V_{DC}} = \frac{\pi}{2 \cdot \sqrt{2}} = 1.11$$

$$\eta = \left(\frac{1}{FF}\right)^2 = 0.81$$

$$RF = \sqrt{FF^2 - 1} = 0.483$$

Being a single-way topology, there is a direct current in both the secondary windings and this brings to a low.

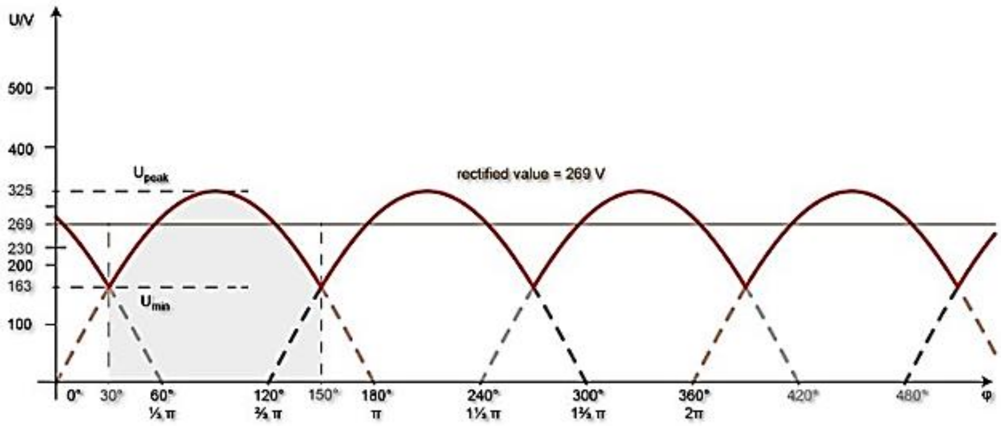
TUF = 0.671 (or TUF = 0.572 according to some authors)

## Three-phase rectifiers

Single-phase rectifiers are commonly used for power supplies for domestic equipment. However, for most industrial and high-power applications, three-phase rectifier circuits are the norm. As with single-phase rectifiers, three-phase rectifiers can take the form of a half-wave circuit, a full-wave circuit using a centertapped transformer, or a full-wave bridge circuit. Thyristors are commonly used in place of diodes to create a circuit that can regulate the output voltage. Many devices that provide direct current actually generate three-phase AC. For example, an automobile alternator contains six diodes, which function as a full-wave rectifier for battery charging.

### I. Three-phase, half-wave circuit

An uncontrolled three-phase, half-wave midpoint circuit requires three diodes, one connected to each phase. This is the simplest type of three-phase rectifier but suffers from relatively high harmonic distortion on both the AC and DC connections. This type of rectifier is said to have a pulse-number of three, since the output voltage on the DC side contains three distinct pulses per cycle of the grid frequency:




The average no-load output voltage results from the integral under the graph of a positive half-wave with the period duration of (from 30° to 150°):

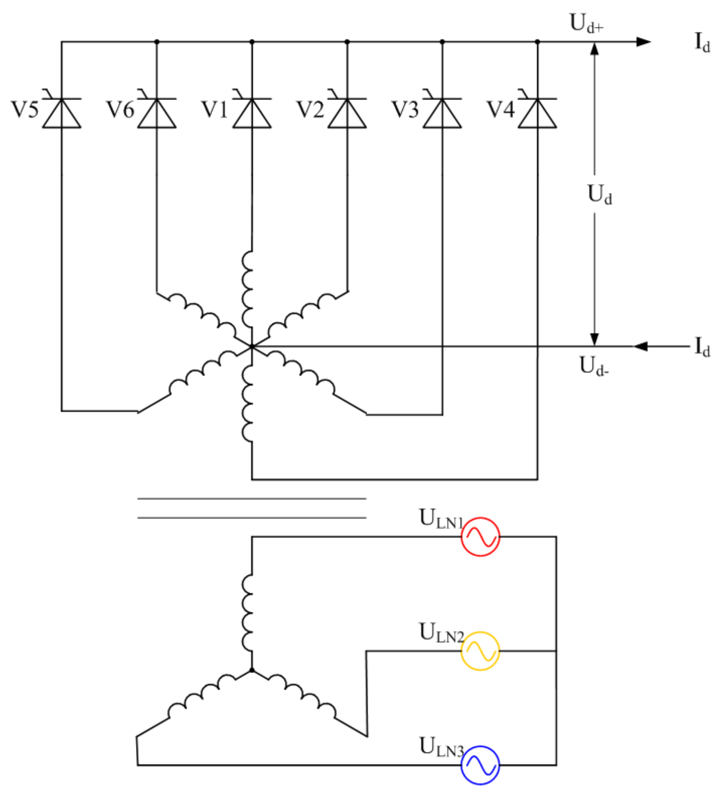
$$V_{\mathrm{dc}} = V_{\mathrm{av}} = \frac{1}{\frac{2}{3}\pi} \int_{30^\circ}^{150^\circ} V_{\mathrm{peak}} \cdot \sin\varphi \cdot \mathrm{d}\varphi = \frac{3 \cdot V_{\mathrm{peak}}}{2\pi} \cdot (-\cos 150^\circ + \cos 30^\circ)$$

$$= \frac{3 \cdot V_{\mathrm{peak}}}{2\pi} \cdot \left[ -\left(-\frac{\sqrt{3}}{2}\right) + \frac{\sqrt{3}}{2} \right] = \frac{3 \cdot \sqrt{3} \cdot V_{\mathrm{peak}}}{2\pi}$$

$$\Rightarrow V_{\mathrm{dc}} = V_{\mathrm{av}} = \frac{3 \cdot \sqrt{3} \cdot \sqrt{2} \cdot V_{\mathrm{LN}}}{2\pi} \Rightarrow V_{\mathrm{av}} = \frac{3 \cdot \sqrt{6} \cdot V_{\mathrm{LN}}}{2\pi} \approx 1{,}17 \cdot V_{\mathrm{LN}}$$

## II. Three-phase, full-wave circuit using center-tapped transformer

If the AC supply is fed via a transformer with a center tap, a rectifier circuit with improved harmonic performance can be obtained. This rectifier now requires six diodes, one connected to each end of each transformer secondary winding. This circuit has a pulse number of six, and in effect, can be thought of as a six phase, half-wave circuit. Before solid state devices became available, the half wave circuit, and the full-wave circuit using a center tapped transformer, were very commonly used in industrial rectifiers using mercury-arc valves. This was because the three or six AC supply inputs could be fed to a corresponding number of anode electrodes on a single tank, sharing a common cathode. With the advent of diodes and thyristors, these circuits have become less popular and the three-phase bridge circuit has become the most common circuit.




Above is the Controlled three-phase full-wave rectifier circuit using thyristors as the switching elements, with a center-tapped transformer, ignoring supply inductance

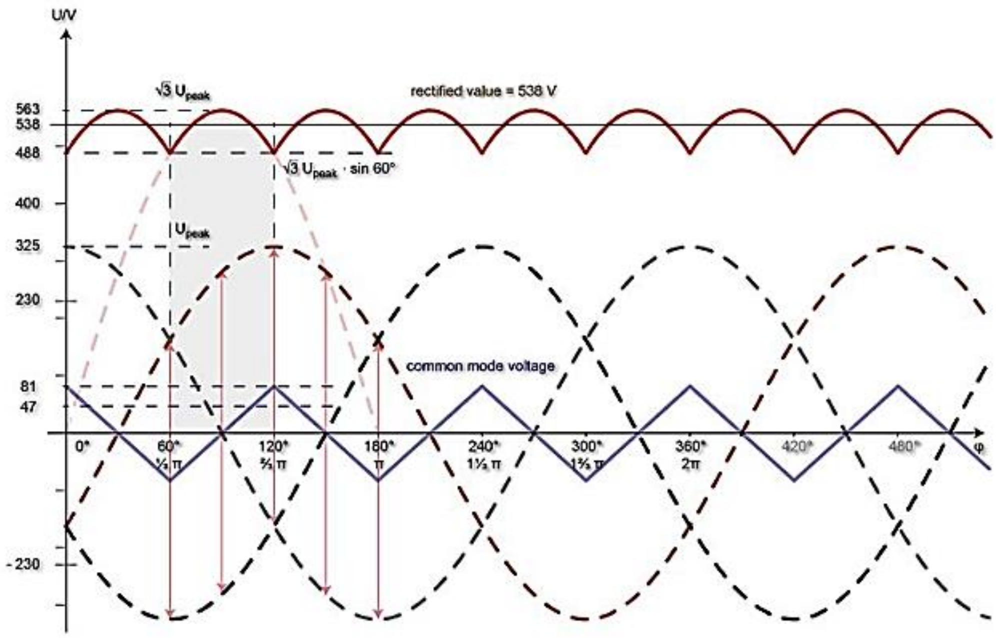
## III. Three-phase bridge rectifier

For an uncontrolled three-phase bridge rectifier, six diodes are used, and the circuit again has a pulse number of six. For this reason, it is also commonly referred to as a six-pulse bridge. The B6 circuit can be seen simplified as a series connection of two three-pulse center circuits.

For low-power applications, double diodes in series, with the anode of the first diode connected to the cathode of the second, are manufactured as a single component for this purpose. Some commercially available double diodes have all four terminals available so the user can configure them for single-phase split supply use, half a bridge, or three-phase rectifier.

For higher-power applications, a single discrete device is usually used for each of the six arms of the bridge. For the very highest powers, each arm of the bridge may consist of tens or hundreds of separate devices in parallel or in series.

The pulsating DC voltage results from the differences of the instantaneous positive and negative phase voltages phase-shifted by 30°:




The ideal, no-load average output voltage of the B6 circuit results from the integral under the graph of a DC voltage pulse with the period duration of (from 60° to 120°) with the peak value

$$V_{\mathrm{dc}} = V_{\mathrm{av}} = \frac{1}{\frac{1}{3}\pi} \int_{60^\circ}^{120^\circ} \sqrt{3} \cdot V_{\mathrm{peak}} \cdot \sin\varphi \cdot \mathrm{d}\varphi = \frac{3 \cdot \sqrt{3} \cdot V_{\mathrm{peak}}}{\pi} \cdot (-\cos 120^\circ + \cos 60^\circ)$$

$$\Rightarrow V_{\mathrm{dc}} = V_{\mathrm{av}} = \frac{3 \cdot \sqrt{3} \cdot \sqrt{2} \cdot V_{\mathrm{LN}}}{\pi} \Rightarrow V_{\mathrm{av}} = \frac{3 \cdot \sqrt{6} \cdot V_{\mathrm{LN}}}{\pi} \approx 2{,}34 \cdot V_{\mathrm{LN}}$$

# Rectification technologies and some important applications

## I. Electromechanical

Before about 1905 when tube type rectifiers were developed, power conversion devices were purely electro-mechanical in design. Mechanical rectifiers used some form of rotation or resonant vibration driven by electromagnets, which operated a switch or commutator to reverse the current.

These mechanical rectifiers were noisy and had high maintenance requirements. The moving parts had friction, which required lubrication and replacement due to wear. Opening mechanical contacts under load resulted in electrical arcs and sparks that heated and eroded the contacts. They also were not able to handle AC frequencies above several thousand cycles per second.

## II. Electrolytic

The electrolytic rectifier was a device from the early twentieth century that is no longer used. A home-made version is illustrated in the 1913 book The Boy Mechanic but it would be suitable for use only at very low voltages because of the low breakdown voltage and the risk of electric shock.

## III. Mercury-arc

A rectifier used in high-voltage direct current (HVDC) power transmission systems and industrial processing between about 1909 to 1975 is a mercury-arc rectifier or mercury-arc valve.

## IV. Crystal detector

Invented by Jagadish Chandra Bose and developed by G. W. Pickard starting in 1902, it was a significant improvement over earlier detectors such as the coherer. The crystal detector was widely used prior to vacuum tubes becoming available. One popular type of crystal detector, often called a cat's whisker detector, consists of a crystal of some semiconducting mineral, usually galena with a light springy wire touching its surface. Its fragility and limited current capability made it unsuitable for power supply applications.

# BIBLIOGRAPHY


- https://www.wikipedia.org/
- www.google.com
- http://vlabs.iitb.ac.in/vlab/electrical/exp2/Theory.pdf
- Book – Semiconductor Physics and Devices