Generation of high voltages

A fundamental knowledge about generators and circuits which are in use for the generation of high voltages belongs to the background of work on h.v. technology.

Generally commercially available h.v. generators are applied in routine testing laboratories; they are used for testing equipment such as transformers, bushings, cables, capacitors, switchgear, etc. The tests should confirm the effi-ciency and reliability of the products and therefore the h.v. testing equipment is required to study the insulation behaviour under all conditions which the apparatus is likely to encounter. The amplitudes and types of the test voltages, which are always higher than the normal or rated voltages of the apparatus under test, are in general prescribed by national or international standards or recommendations, and therefore there is not much freedom in the selection of the h.v. testing equipment. Quite often, however, routine testing laboratories are also used for the development of new products. Then even higher volt-ages might be necessary to determine the factor of safety over the prospective working conditions and to ensure that the working margin is neither too high nor too low. Most of the h.v. generator circuits can be changed to increase the output voltage levels, if the original circuit was properly designed. There-fore, even the selection of routine testing equipment should always consider a future extension of the testing capabilities.

The work carried out in research laboratories varies considerably from one establishment to another, and the type of equipment needed varies accordingly. As there are always some interactions between the h.v. generating circuits used and the test results, the layout of these circuits has to be done very carefully. The classes of tests may differ from the routine tests, and therefore specially designed circuits are often necessary for such laboratories. The knowledge about some fundamental circuits treated in this chapter will also support the development of new test circuits.

Finally, high voltages are used in many branches of natural sciences or other technical applications. The generating circuits are often the same or similar to those treated in the following sections. It is not the aim, however, of this introductory text to treat the broad variations of possible circuits, due to space limitation. Not taken into account are also the differing problems of electrical power generation and transmission with high voltages of a.c. or d.c., or the pure testing technique of h.v. equipment, the procedures of which may be found in relevant standards of the individual equipment. Power generation and transmission problems are treated in many modern books, some of which are listed within the bibliography of an earlier report.

AC to DC Generation:

In h.v. technology direct voltages are mainly used for pure scientific research work and for testing equipment related to HVDC transmission systems. There is still a main application in tests on HVAC power cables of long length, as the large capacitance of those cables would take too large a current if tested with a.c. voltages (see, however, 2.2.2: Series resonant circuits). Although such d.c. tests on a.c. cables are more economical and convenient, the validity of this test suffers from the experimentally obtained stress distribution within the insulating material, which may considerably be different from the normal working conditions where the cable is transmitting power at low-frequency alternating voltages. For the testing of polyethylene h.v. cables, in use now for some time, d.c. tests are no longer used, as such tests may not confirm the quality of the insulation. [50]

High d.c. voltages are even more extensively used in applied physics (accelerators, electron microscopy, etc.), electromedical equipment (X-rays), industrial applications (precipitation and filtering of exhaust gases in thermal power stations and the cement industry; electrostatic painting and powder coating, etc.), or communications electronics (TV, broadcasting stations). Therefore, the requirements on voltage shape, voltage level, and current rating, short- or long-term stability for every HVDC generating system may differ strongly from each other. With the knowledge of the fundamental generating principles it will be possible, however, to select proper circuits for a special application.

This chapter discusses the generation of the following main classes of volt-ages: direct voltages, alternating voltages, and transient voltages.
A simple Half Wave Rectifier is nothing more than a single pn junction diode connected in series to the load resistor. As you know a diode is to electric current like a one-way valve is to water, it allows electric current to flow in only one direction. This property of the diode is very useful in creating simple rectifiers which are used to convert AC to DC.

If you look at the above diagram, we are giving an alternating current as input. Input voltage is given to a step-down transformer and the resulting reduced output of the transformer is given to the diode 'D' and load resistor RL. The output voltage is measured across load resistor RL.

As part of our "Basic Electronics Tutorial" series, we have seen that rectification is the most important application of a PN junction diode. The process of rectification is converting alternating current (AC) to direct current (DC).

Half Wave Rectifier Operation

Simply put, a half wave rectifier removes the negative half cycle of an AC input and allows only the positive cycles to pass creating a DC flow.

To understand the operation of a half wave rectifier perfectly, you must know the **theory part** really well. If you are new to the concepts of a PN junction and its characteristics, I recommend you to read the half wave rectifier theory part first.

The operation of a half wave rectifier is pretty simple. From the theory part, you should know that a pn junction diode conducts current only in 1 direction. In other words, a pn junction diode conducts current only when it is forward biased. The same principle is made use of in a half wave rectifier to convert AC to DC. The input we give here is an alternating current. This input voltage is stepped down using a transformer. The reduced voltage is fed to the diode 'D' and load resistance RL. During the positive half cycles of the input wave, the diode 'D' will be forward biased and during the negative half cycles of input wave, the diode 'D' will be reverse biased. We take the output across load resistor RL. Since the diode passes current only during one-half cycle of the input wave, we get an output as shown in the diagram. The output is positive and significant during the positive half cycles of the input wave. At the same time output is zero or insignificant during negative half cycles of the input wave. This is called ***half wave rectification.***

Explaining Half Wave Rectification in academic words!

When a single rectifier diode unit is placed in series with the load across an ac supply, it converts alternating voltage into a uni-directional pulsating voltage, using one-half cycle of the applied voltage, the other half cycle being suppressed because it conducts only in one direction. Unless there is an inductance or battery in the circuit, the current will be zero, therefore, for half the time. This is called ***half-wave rectification***. As already discussed, a diode is an electronic device consisting of two elements known as cathode and anode. Since in a diode electrons can flow in one direction only *i.e.* from the cathode to anode, the diode provides the unilateral conduction necessary for rectification. This is true for diodes of all types-vacuum, gas-filled, crystal or semiconductor, metallic (copper oxide and selenium types) diodes. Semiconductor diodes, because of their inherent advantages are usually used as a rectifying device. However, for very high voltages, vacuum diodes may be employed.

Working of a Half wave rectifier

The half-wave rectifier circuit using a semiconductor diode (D) with a load resistance R_L but no smoothing filter is given in the figure. The diode is connected in series with the secondary of the transformer and the load resistance R_L. The primary of the transformer is being connected to the ac supply mains.

The ac voltage across the secondary winding changes polarities after every half cycle of the input wave. During the positive half-cycles of the input ac voltage *i.e.* when the upper end of the secondary winding is positive w.r.t. its lower end, the diode is forward biased and therefore conducts current. If the forward resistance of the diode is assumed to be zero (in practice, however, a small resistance exists) the input voltage during the positive half-cycles is directly applied to the load resistance R_L, making its upper-end positive w.r.t. its lower end. The waveforms of the output current and output voltage are of the same shape as that of the input ac voltage.

During the negative half cycles of the input ac voltage *i.e.* when the lower end of the secondary winding is positive w.r.t. its upper end, the diode is reverse biased and so does not conduct. Thus during the negative half cycles of the input ac voltage, the current through and the voltage across

the load remains zero. The reverse current, being very small in magnitude, is neglected. Thus for the negative half cycles, no power is delivered to the load.
Thus the output voltage (VL) developed across load resistance R_L is a series of positive half cycles of alternating voltage, with intervening very small constant negative voltage levels, It is obvious from the figure that the output is not a steady dc, but only a pulsating dc wave. To make the output wave smooth and useful in a DC power supply, we have to use a filter across the load. Since only half-cycles of the input wave are used, it is called a *half wave rectifier*.

Half Wave Rectifier Theory

Rectification is an application of the pn junction diode. A half wave rectifier is a device which makes use of key properties of a pn junction diode. So to understand the underlying theory behind a half wave rectifier, you need to understand the pn junction and the characteristics of the pn junction diode. We have developed two articles to help you understand both of them.

1)Understanding the PN Junction – This article will help you to understand the pn junction and the underlying theory behind using PN junction as a rectifier.
2) Characteristics of PN junction diode – This article will help you to understand the characteristics of a pn junction diode with help of graphs. You can understand the behavior of a diode across various voltage levels and how it conducts.
Note:- There is an interesting story behind the invention of PN junction diode. The story revolves around the perseverance of a young scientist at Bell Laboratories in USA, Mr. Russel Ohl. In the story, you will learn how great inventions happen and how some bright minds of the 1930’s like Walter Brattain (one among the 3 who invented transistor) worked together to bring great inventions t our life
Power Supply Specifications of a rectifier
The most important characteristics which are required to be specified for a power supply are the required output dc voltage, the average and peak currents in the diode, the peak inverse voltage (PIV) of diode, the regulation and the ripple factor.
Advantages and Disadvantages of Half wave rectifier:
A half wave rectifier is rarely used in practice. It is never preferred as the power supply of an audio circuit because of the very high ripple factor. High ripple factor will result in noises in the input audio signal, which in turn will affect audio quality.

The advantage of a half wave rectifier is only that its cheap, simple and easy to construct. It is cheap because of the low number of components involved. Simple because of the straight forwardness in circuit design. Apart from this, a half wave rectifier has more number of disadvantages than advantages!

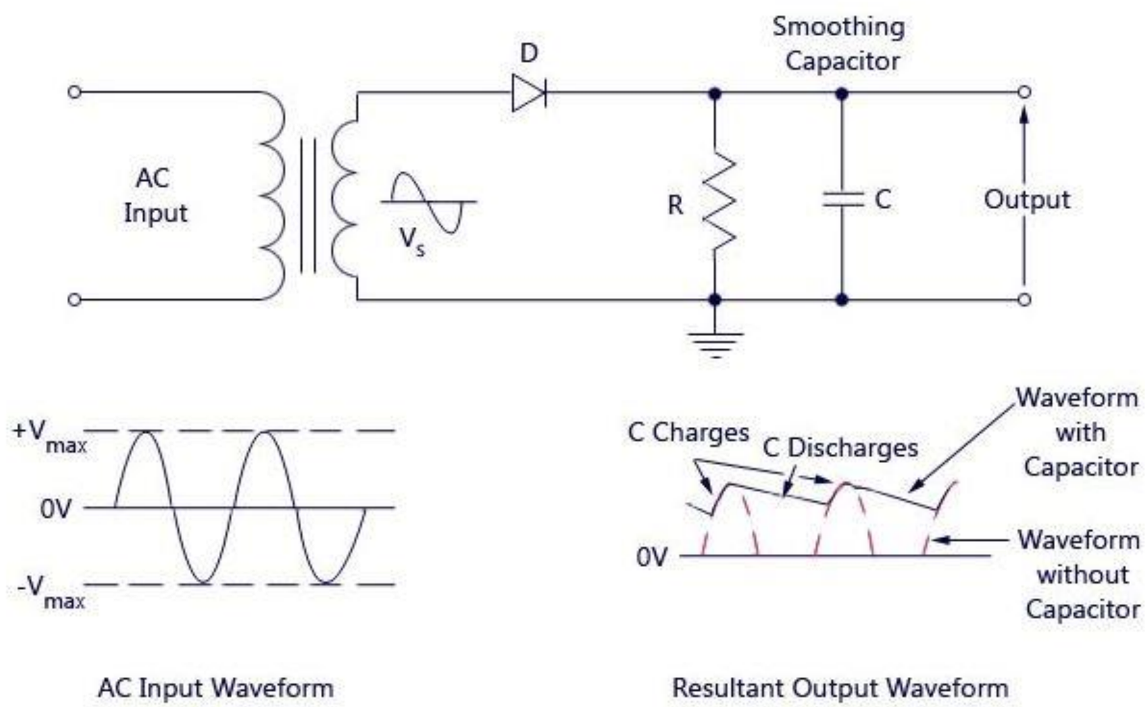
Disadvantages of Half wave rectifier
1. The output current in the load contains, in addition to dc component, ac components of basic frequency equal to that of the input voltage frequency. Ripple factor is high and an elaborate filtering is, therefore, required to give steady dc output.
2. The power output and, therefore, rectification efficiency is quite low. This is due to the fact that power is delivered only during one-half cycle of the input alternating voltage.

3. Transformer utilization factor is low.
4. DC saturation of the transformer core resulting in magnetizing current and hysteresis losses and generation of harmonics.
The DC output available from a half-wave rectifier is not satisfactory to make a general power supply. However, it can be used for some applications like battery charging.

Half Wave Rectifier with Capacitor Filter

The output of half wave rectifier is not a constant DC voltage. You can observe from the output diagram that its a pulsating dc voltage with ac ripples. In real life applications, we need a power supply with smooth waveforms. In other words, we desire a DC power supply with the constant output voltage. A constant output voltage from the DC power supply is very important as it directly impacts the reliability of the electronic device we connect to the power supply.

We can make the output of half wave rectifier smooth by using a filter (a capacitor filter or an inductor filter) across the diode. In some cases, a resistor-capacitor coupled filter (RC) is also used. The circuit diagram below shows a half wave rectifier with capacitor filter.



Half Wave Rectifier with Capacitor Filter – Circuit Diagram & Output Waveform

Full-wave Rectifier circuit:

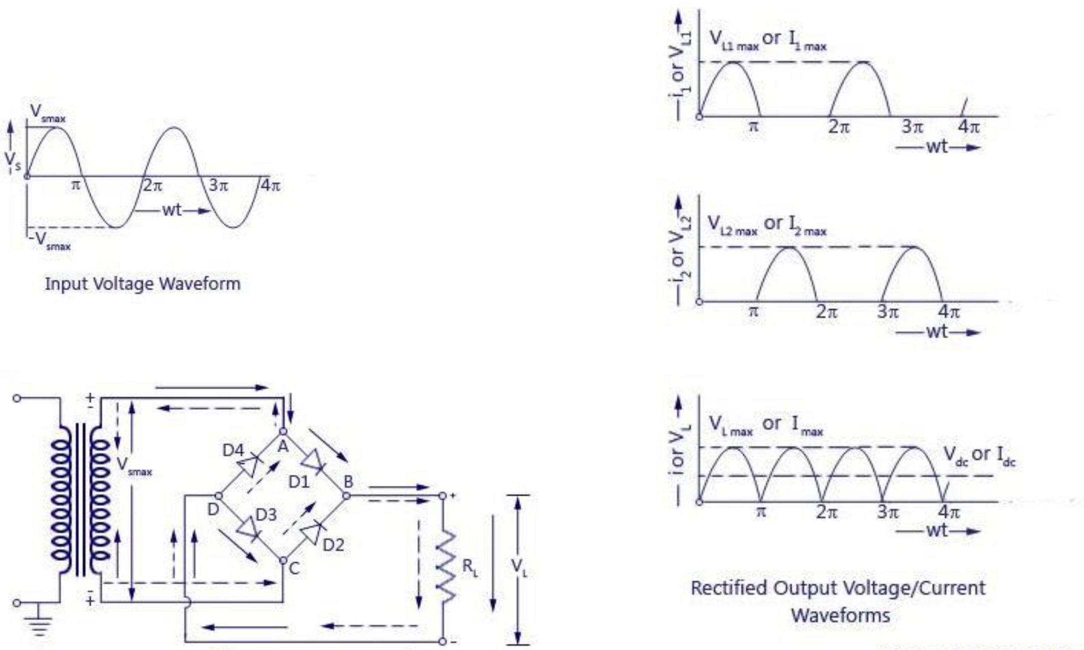
A Full wave rectifier is a circuit arrangement which makes use of both half cycles of input alternating current (AC) and converts them to direct current (DC). In our tutorial on **Half wave rectifiers**, we have seen that a half wave rectifier makes use of only one-half cycle of the input alternating current. Thus a full wave rectifier is much more efficient (double+) than a half wave rectifier. This process of converting both half cycles of the input supply (alternating current) to direct current (DC) is termed full wave rectification.
Full wave rectifier can be constructed in 2 ways. The first method makes use of a centre tapped transformer and 2 diodes. This arrangement is known as **Center Tapped Full Wave Rectifier**.
The second method uses a normal transformer with 4 diodes arranged as a bridge. This arrangement is known as a Bridge Rectifier.

Full Wave Rectifier Theory

To understand full wave bridge **rectifier theory** perfectly, you need to learn half wave rectifier first. In the tutorial of half wave rectifier, we have clearly explained the basic working of a rectifier. In addition, we have also explained the **theory behind a pn junction** and the **characteristics of a pn junction diode**.

Full Wave Rectifier – Working & Operation

The working & operation of a full wave bridge rectifier is pretty simple. The circuit diagrams and waveforms we have given below will help you understand the operation of a bridge rectifier perfectly. In the circuit diagram, 4 diodes are arranged in the form of a bridge. The transformer secondary is connected to two diametrically opposite points of the bridge at points A & C. The load resistance R_L is connected to bridge through points B and D.

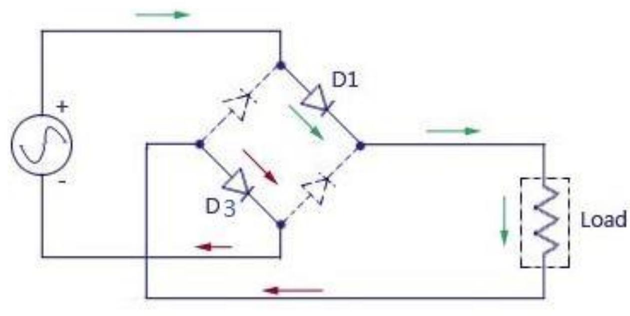


BRIDGE RECTIFIER

Full Wave Bridge Rectifier – Circuit Diagram with Input and Output Wave Forms

During the first half cycle

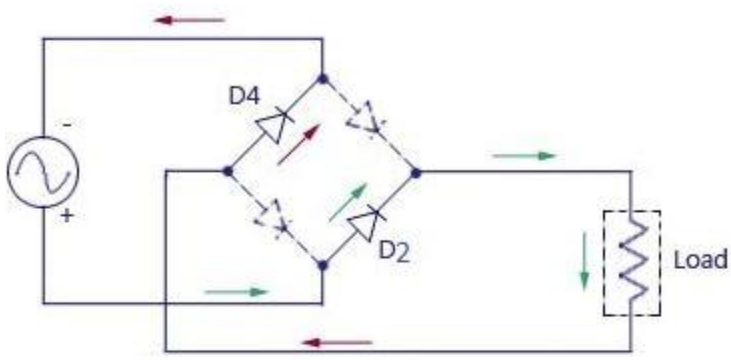
During the first half cycle of the input voltage, the upper end of the transformer secondary winding is positive with respect to the lower end. Thus during the first half cycle diodes D1 and D_3 are forward biased and current flows through arm AB, enters the load resistance R_L, and returns back flowing through arm DC. During this half of each input cycle, the diodes D_2 and D_4 are reverse biased and current is not allowed to flow in arms AD and BC. The flow of current is indicated by solid arrows in the figure above. We have developed another diagram below to help you understand the current flow quickly. See the diagram below – the green arrows indicate the beginning of current flow from the source (transformer secondary) to the load resistance. The red arrows indicate the return path of current from load resistance to the source, thus completing the circuit.



Flow of current in Bridge Rectifier

During the second half cycle

During the second half cycle of the input voltage, the lower end of the transformer secondary winding is positive with respect to the upper end. Thus diodes D_2 and D_4 become forward biased and current flows through arm CB, enters the load resistance R_L, and returns back to the source flowing through arm DA. The flow of current has been shown by dotted arrows in the figure. Thus the direction of flow of current through the load resistance R_L remains the same during both half cycles of the input supply voltage. See the diagram below – the green arrows indicate the beginning of current flow from the source (transformer secondary) to the load resistance. The red arrows indicate the return path of current from load resistance to the source, thus completing the circuit.



Path of current in 2nd Half Cycle

Peak Inverse Voltage of a Full wave bridge rectifier:

Let's analyse peak inverse voltage (PIV) of a full wave bridge rectifier using the circuit diagram. At any instant when the transformer secondary voltage attains positive peak value Vmax, diodes D1 and D3 will be forward biased (conducting) and the diodes D2 and D4 will be reverse biased (non conducting). If we consider ideal diodes in bridge, the forward biased diodes D1 and D3 will have zero resistance. This means voltage drop across the conducting diodes will be zero. This will result in the entire transformer secondary voltage being developed across load resistance RL.

Thus PIV of a bridge rectifier = Vmax (max of secondary voltage)

Bridge Rectifier Circuit Analysis

The only difference in the analysis between full wave and centre tap rectifier is that

1. In a bridge rectifier circuit, two diodes conduct during each half cycle and the forward resistance becomes double ($2R_F$).
2. In a bridge rectifier circuit, Vsmax is the maximum voltage across the transformer secondary winding whereas in a centre tap rectifier Vsmax represents that maximum voltage across each half of the secondary winding.

The different parameters are explained with equations below:

1. **Peak Current**

The instantaneous value of the voltage applied to the rectifier is given as

$$vs = Vsmax \sin wt$$

If the diode is assumed to have a forward resistance of R_F ohms and a reverse resistance equal to infinity, the current flowing through the load resistance is given as

i1 = Imax Sin wt and i2 = 0 for the first half cycle and i1 = 0 and i2 = Imax Sin wt for second half cycle

The total current flowing through the load resistance R_L, being the sum of currents i1 and i2 is given as
i = i1 + i2 = Imax Sin wt for the whole cycle.

Where the peak value of the current flowing through the load resistance R_L is given as
Imax = Vsmax/($2R_F$ + R_L)

2. Output Current

Since the current is the same through the load resistance RL in the two halves of the ac cycle, magnitude od dc current Idc, which is equal to the average value of ac current, can be obtained by integrating the current i1 between 0 and pi or current i2 between pi and 2pi.

$$\text{So } I_{dc} = 1/\pi \int_0^{\pi} i1\, d(wt) = 1/\pi \left[\int_0^{\pi} Imax\, Sin\, wt d(wt)\right] = 2I_{MAX}/\pi$$

Output Current of Full Wave Rectifier

3. DC Output Voltage

Average or dc value of voltage across the load is given as

$$Vdc = Idc\, R_L = 2/\pi\, Imax\, R_L$$

DC Output Voltage of Full Wave Rectifier

Merits and Demerits of Full-wave Rectifier Over Half-Wave Rectifier

Merits – let us talk about the advantages of full wave bridge rectifier over half wave version first. I can think about 4 specific merits at this point.

- Efficiency is double for a full wave bridge rectifier. The reason is that, a half wave rectifier makes use of only one half of the input signal. A bridge rectifier makes use of both halves and hence double efficiency
- The residual ac ripples (before filtering) is very low in the output of a bridge rectifier. The same ripple percentage is very high in half wave rectifier. A simple filter is enough to get a constant dc voltage from the bridge rectifier.
- We know the efficiency of FW bridge is double than HW rectifier. This means higher output voltage, Higher transformer utilization factor (TUF) and higher output power.

Demerits – Full-wave rectifier needs more circuit elements and is costlier.

Merits and Demerits of Bridge Rectifier Over Center-Tap Rectifier.

A centre tap rectifier is always a difficult one to implement because of the special transformer involved. A centre tapped transformer is costly as well. One key difference between center tap &

bridge rectifier is in the number of diodes involved in construction. A center tap full wave rectifier needs only 2 diodes whereas a bridge rectifier needs 4 diodes. But silicon diodes being cheaper than a center tap transformer, a bridge rectifier is much-preferred solution in a DC power supply. Following are the advantages of bridge rectifier over a center tap rectifier.

- A bridge rectifier can be constructed with or without a transformer. If a transformer is involved, any ordinary step down/step up transformer will do the job. This luxury is not available in a center tap rectifier. Here the design of rectifier is dependent on the center tap transformer, which can not be replaced.
- Bridge rectifier is suited for high voltage applications. The reason is the high peak inverse voltage (PIV) of bridge rectifier when compared to the PIV of a center tap rectifier.
- Transformer utilization factor (TUF) is higher for bridge rectifier.

Demerits of Bridge rectifier over center tap rectifier

The significant disadvantage of a bridge rectifier over center tap is the involvement of 4 diodes in the construction of bridge rectifier. In a bridge rectifier, 2 diodes conduct simultaneously on a half cycle of input. A center tap rectifier has only 1 diode conducting on one-half cycle. This increases the net voltage drop across diodes in a bridge rectifier (it is double to the value of center tap).

Applications of Full wave Bridge rectifier

Full wave rectifier finds uses in the construction of constant dc voltage power supplies, especially in general power supplies. A bridge rectifier with an efficient filter is ideal for any type of general power supply applications like charging a battery, powering a dc device (like a motor, led etc) etc. However, for an audio application, a general power supply may not be enough. This is because of the residual ripple factor in a bridge rectifier. There are limitations to filtering ripples. For audio applications, specially built power supplies (using IC regulators) may be ideal.