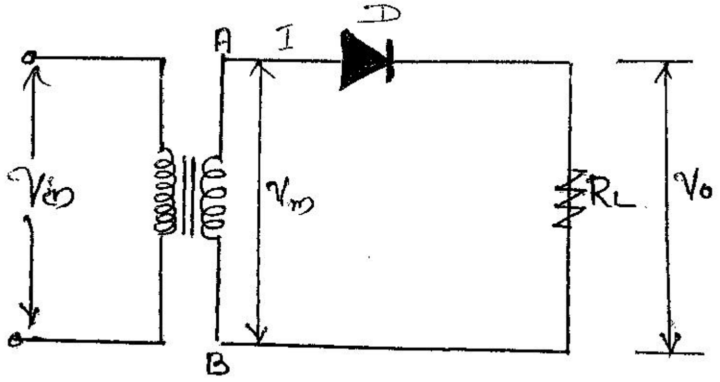
Rectifiers

The "rectifier" is a circuit which converts AC voltage and currents into pulsating DC voltages and currents. Rectifiers are grouped into two catagories depending on the period of conduction.

a. Half Wave Rectifiers
b. Full Wave Rectifiers.

* Half Wave Rectifier

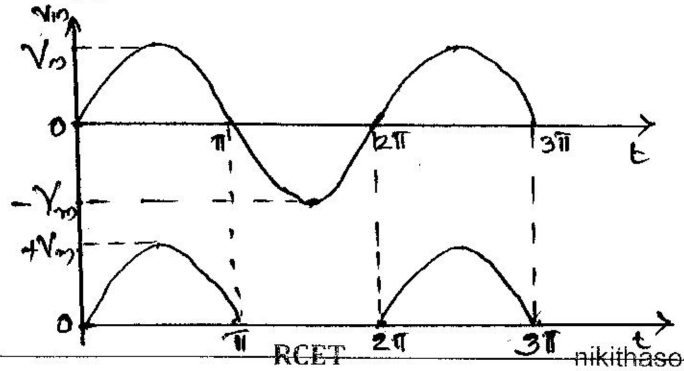


In half-wave rectification, when AC supply is applied at the input, only positive half cycle appears across the load, whereas, the negative half cycle is suppressed.

For half-wave rectification, only one crystal diode is used. The AC supply to be rectified is generally given through a transformer. The transformer is used to step-down the mains supply voltage. It also isolates the rectifier circuit from power lines & thus reduse the risk of electric shock.

When AC supply is switched on, the alternating voltage [V_{in}] appears across the terminals AB at secondary winding. During positive half cycle, the terminal A is positive with respect to B and the crystal diode is forward biased. Therefore, it conducts and current [i] flows through the load resistor R_L. This current varies in magnitude. Thus, a positive half cycle of output voltage [$V_{out} = iR_L$] appears across the load resistor [R_L]. During negative half cycle, the terminal A is negative with respect to B and the crystal diode is reverse biased. Under this condition, the diode does not conduct and no current flows through the circuit. Therefore, no voltage appears across the load resistor R_L in the negative half cycle of the input.

Analysis of halfwave rectifier



The input sinusoidal voltage applied at the input of the transformer is given by

$$V_i = V_m \sin \omega t$$

The diode current or load current is given by

$$i(t) = I_m \sin \omega t \quad \text{for} \quad 0 \leq \omega t \leq \pi$$
$$= 0 \quad \text{for} \quad \pi \leq \omega t \leq 2\pi$$

Maximum or peak current through the circuit

$$I_m = \frac{V_m}{R_f + R_L}$$

where R_f = forward resistance of the diode.
R_L = load resistance.

* The average or DC current

$$I_{dc} = \frac{1}{T}\int_0^T i(t)\, dt$$

$$~~= \frac{1}{2\pi}\int_0^{2\pi} I_m \sin\omega t\, dt~~$$

$$= \frac{1}{2\pi}\int_0^{2\pi} i(t)\, d(\omega t)$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} I_m \sin\omega t\, d(\omega t) + \int_{\pi}^{2\pi} 0\, d(\omega t)\right]$$

when $i(t) = 0$ for the interval $\pi \leq \omega t \leq 2\pi$

Hence $I_{dc} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin \omega t \, d(\omega t)$

$$= \frac{I_m}{2\pi}\int_0^{\pi} \sin \omega t \, d(\omega t)$$

$$= \frac{I_m}{2\pi}\left[-\cos \omega t\right]_0^{\pi}$$

$$= \frac{I_m}{2\pi}\left[-\cos \pi + \cos 0\right]$$

$$= \frac{2I_m}{2\pi}$$

$$= \frac{I_m}{\pi}$$

$$I_{av} = I_{dc} = \frac{I_m}{\pi} = \frac{V_m}{\pi\left[R_f + R_L\right]}$$

* DC output voltage.

$$V_{dc} = I_{dc} \cdot R_L$$

$$= \frac{I_m}{\pi} R_L$$

$$= \frac{V_m}{\pi}\,\frac{R_L}{R_F + R_L}$$

$$= \frac{V_m}{\pi\left[1 + \frac{R_f}{R_L}\right]}$$

$$\cong \frac{V_m}{\pi} \quad \left[\text{if } R_F \ll R_L\right]$$

* RMS current

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T i^2(t)\, d(\omega t)}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2(t)\, d(\omega t)}$$

$$= \sqrt{\frac{1}{2\pi}\left[\int_0^{\pi} I_m^2 \sin^2\omega t\, d(\omega t) + \int_{\pi}^{2\pi} 0\, d(\omega t)\right.}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\omega t \cdot d(\omega t)}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\int_0^{\pi} \frac{1-\cos 2\omega t}{2}\, d(\omega t)} \qquad \left[\because \sin^2\omega t = \frac{1-\cos 2\omega t}{2}\right]$$

$$= \sqrt{\frac{I_m^2}{4\pi}\int_0^{\pi} (1-\cos 2\omega t)\, d(\omega t)}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\left[\omega t - \frac{1}{2}\sin 2\omega t\right]_0^{\pi}}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\left[\pi - \frac{1}{2}\sin 2\pi - 0 + \frac{1}{2}\sin 0\right.}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\left[\pi - \frac{1}{2}\sin 2\pi\right]}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\cdot \pi}$$

$$I_{rms} = \frac{I_m}{2} = \frac{V_m}{2(R_F+R_L)}$$

* RMS voltage

$$V_{rms} = I_{rms} \cdot R_L$$

$$= \frac{I_m}{2} \cdot R_L$$

$$= \frac{V_m}{2} \frac{R_L}{R_F+R_L}$$

$$= \frac{V_m}{2} \qquad \left[\because R_F << R_L \right]$$

* The DC output power

$$P_{dc} = I_{dc}^2 \cdot R_L$$

$$= \frac{I_m^2}{\pi^2} \cdot R_L$$

$$= \frac{V_m^2 \cdot R_L}{\pi^2 (R_F+R_L)^2}$$

* The AC input power.

$$P_{ac} = P_d + P_L$$

$$= I_{rms}^2 \cdot R_F + I_{rms}^2 \cdot R_L$$

$$= \frac{I_m^2}{4} \cdot R_F + \frac{I_m^2}{4} R_L$$

$$= \frac{I_m^2}{4} \left[R_F + R_L \right]$$

where $P_d \rightarrow$ Power dissipated across diode

$P_L \rightarrow$ Power dissipated across load resistance.

* Rectifier Efficiency.

Rectifier efficiency is defined as the ratio of the DC o/p power [Pdc] to the AC input power [Pac]

$$\eta = \frac{P_{dc}}{P_{ac}}$$

$$= \frac{\left(\frac{I_m^2}{\pi^2}\right) R_L}{\left(\frac{I_m^2}{4}\right)(R_F+R_L)}$$

$$= \frac{4}{\pi^2} \cdot \frac{R_L}{R_F+R_L}$$

$$= \frac{0.406}{1+\frac{R_f}{R_L}}$$

$$\% \eta = \frac{0.406}{1+\frac{R_f}{R_L}} \times 100$$

$$= \frac{40.6}{1+\frac{R_f}{R_L}} \%$$

$$= 40.6\% \quad [\text{if } R_f << R_L]$$

* Ripple Factor

Ripple Factor is a measure of purity of the dc output of a rectifier. It is defined as the ratio of the effective value or rms value of the ac component of voltage or current to the average value of voltage or current.

$$\text{ie, } \gamma = \frac{\text{rms value of the ac components of wave}}{\text{average dc value}}$$

$$= \frac{\cancel{V}_{ac}}{I_{dc}}$$

$$I_{rms} = \sqrt{I_{dc}^2 + I_1^2 + I_2^2 + I_3^2 + \dots}$$

$$= \sqrt{I_{dc}^2 + I_{ac}^2}$$

$$\therefore \gamma = \frac{\sqrt{I_{ac}^2}}{I_{dc}}$$

$$= \frac{I_{ac}}{I_{dc}}$$

$$= \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}}$$

$$= \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

We know for a half-wave rectifier,

$$I_{rms} = \frac{I_m}{2} \quad \text{and}$$

$$I_{dc} = \frac{I_m}{\pi}$$

Hence, Ripple factor, $\gamma = \sqrt{\frac{(I_m/2)^2}{(I_m/\pi)^2} - 1}$

$$= \sqrt{\left(\frac{\pi}{2}\right)^2 - 1}$$

$$= 1.21$$

Peak Inverse Voltage PIV

~~Peak~~ The maximum value of reverse voltage that a PN junction [or diode] can withstand without damaging itself is called its ~~maximum forward~~ Peak inverse voltage [PIV]

In a half wave rectifier, the peak inverse voltage equals the peak value of the applied voltage.

$$PIV = V_m$$

Advantages of Half wave Rectifier

* It is simple and Low cost circuit

Disadvantages

* Low Rectification efficiency
* High Ripple factor
* DC saturation of transformer core, which results when the current in the secondary side of transformer flows in the same direction, leads to hysteresis losses & harmonics in the output.

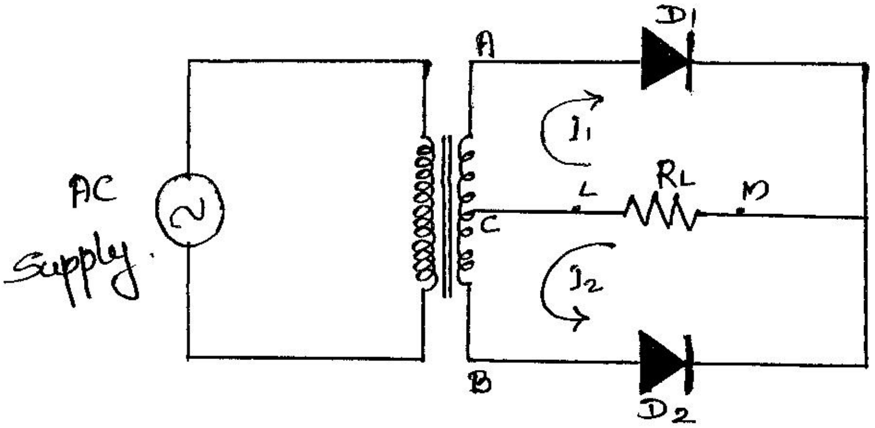
Full-wave Rectifiers

In full wave rectification, when AC supply is applied at the input, during both the half cycles [ie, positive as well as negative] current flows through the load in the same direction. The following two circuits are commonly employed.

i) Centre-tap full wave rectifier

ii) Full-wave Bridge rectifier

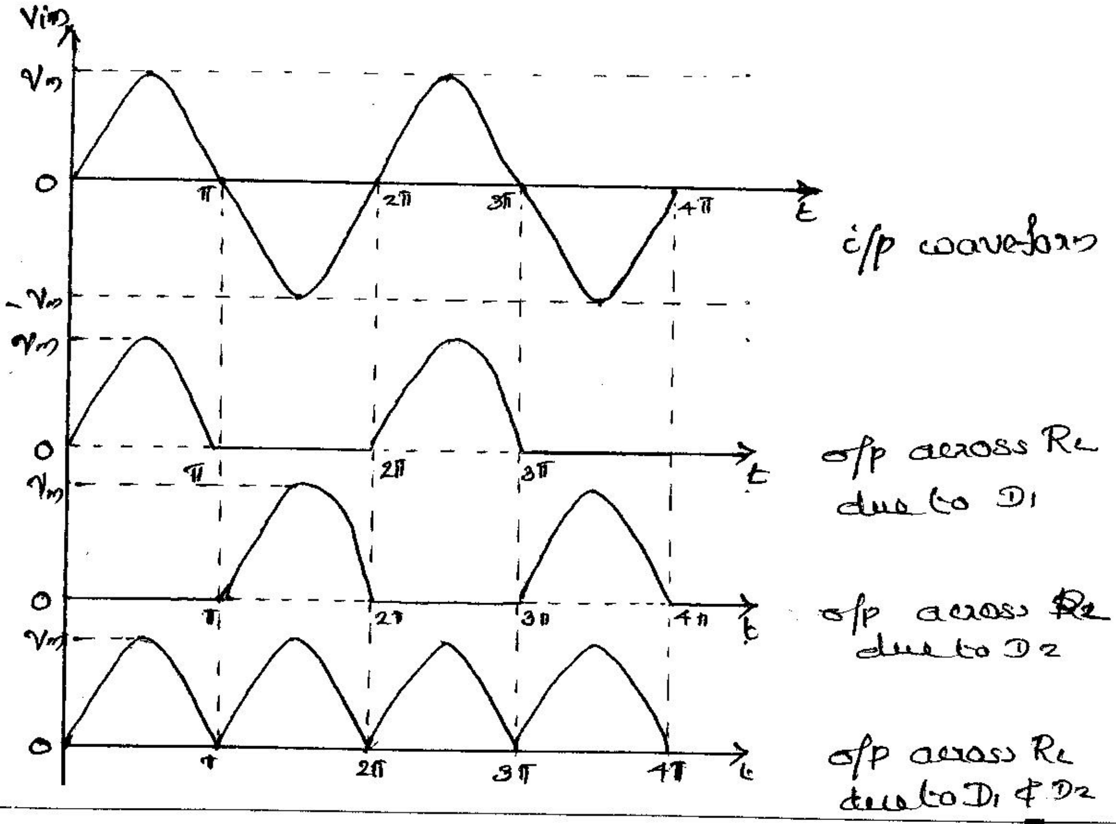
i. Centre-tap full wave rectifier



In this circuit, a transformer with secondary winding AB tapped at the centre point C. The two diodes D_1 & D_2 are connected in the circuit so that each one of them uses one half cycle of input AC voltage. The diode D_1 utilises the AC voltage appearing across the upper half [AC] of secondary winding for rectification while D_2 uses the lower half [CB] of secondary winding.

When AC supply is switched on, the alternating voltage V_{in} appears across the terminals AB of secondary winding of transformer. During positive half cycle of secondary voltage, the end A becomes positive and end B negative. This makes the diode D_1 forward biased and diode D_2 reverse biased. Therefore, diode D_1 conducts while diode D_2 does not. Thus, current [I_1] flows through diode D_1, load resistor R_L [from

M to L] and the upper half of the secondary as shown in the fig: During negative half cycle, the end B becomes positive and end A becomes negative. This makes diode D_2 forward biased and diode D_1 reverse biased. Therefore, diode D_2 conducts while diode D_1 does not. Thus current [I_2] flows through diode D_2, load resistor R_L [from M to L] and the lower half of the secondary as shown in the fig: It may be seen that the current flows through the load resistor R_L in the same direction [ie from M to L] during positive as well as negative half cycle of input ac voltage. Therefore dc o/p voltage [$V_{out} = iR_L$] is obtained the load resistor R_L.



The total current flowing through the R_L is the sum of the individual currents i_1 & i_2

$$i(t) = i_1(t) + i_2(t)$$

$$i_1(t) = I_m \sin \omega t \quad \text{for } 0 \leq \omega t \leq \pi$$
$$= 0 \quad \text{for } \pi \leq \omega t \leq 2\pi$$

and $i_2(t) = 0 \quad \text{for } 0 \leq \omega t \leq \pi$

$$= I_m \sin \omega t \quad \text{for } \pi \leq \omega t \leq 2\pi$$

* Average or DC value

DC or average current is of the same form in the two halves of the ac cycle hence it is calculated for half cycle of i/p only.

$$I_{dc} = \frac{1}{T}\int_0^T i(t)\, dt$$

$$= \frac{1}{\pi}\int_0^{\pi} I_m \sin \omega t \, d(\omega t)$$

$$= \frac{I_m}{\pi}\left[-\cos \omega t\right]_0^{\pi}$$

$$= \frac{I_m}{\pi}\left[-\cos \pi + \cos 0\right]$$

$$= \frac{2 I_m}{\pi}$$

Dc o/p voltage is.

$$V_{dc} = I_{dc} R_L$$

$$= \frac{2I_m}{\pi} . R_L$$

* RMS value.

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T i^2(t)\, dt}$$

$$= \sqrt{\frac{1}{\pi}\int_0^{\pi} I_m^2 \sin^2 \omega t\, d(\omega t)}$$

$$= \sqrt{\frac{I_m^2}{\pi}\int_0^{\pi} \frac{1-\cos 2\omega t}{2}\, d(\omega t)}$$

$$= \sqrt{\frac{I_m^2}{\pi 2}\left[\cancel{\frac{1}{2}} \times \omega t - \frac{\sin 2\omega t}{2}\right]_0^{\pi}}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\left[\pi - \frac{1}{2}\sin 2\pi - 0 + \frac{1}{2}\sin 0\right]}$$

$$= \sqrt{\frac{I_m^2}{\cancel{2}\pi} . \pi} = \frac{I_m}{\sqrt{2}}$$

$$\boxed{I_{rms} = \frac{I_m}{\sqrt{2}}}$$

$$V_{rms} = I_{rms} \cdot R_L$$

$$= \frac{I_m}{\sqrt{2}} \cdot R_L$$

$$= \frac{V_m}{\sqrt{2}}$$

* Power

DC o/p power

$$P_{dc} = I_{dc}^2 \cdot R_L$$

$$= \frac{4 I_m^2}{\pi^2} \cdot R_L$$

AC ~~o/p~~ i/p power

$$P_{ac} = I_{rms}^2 \left[R_F + R_L \right]$$

$$= \frac{I_m^2}{2} \left[R_F + R_L \right]$$

* Efficiency

Rectifier efficiency, $\eta = \frac{P_{dc}}{P_{ac}}$

$$= \frac{\frac{4 I_m^2}{\pi^2} R_L}{\frac{I_m^2}{2}(R_F+R_L)}$$

$$= \frac{8}{\pi^2} \frac{R_L}{R_F+R_L}$$

$$= \frac{8}{\pi^2} \quad \text{if } R_F << R_L$$

$$\% \eta = \frac{8}{\pi^2} \times 100$$

$$= 81\%$$

* Ripple Factor

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

$$\frac{I_{rms}}{I_{dc}} = \frac{I_m}{\sqrt{2}} \times \frac{\pi}{2 I_m} = \frac{\pi}{2\sqrt{2}}$$

$$= \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1}$$

$$= \sqrt{1.11^2 - 1} = 0.48$$

* Peak Inverse Voltage.

During positive half cycle of input D_1 is conducting D_2 is off. The maximum voltage at the lower part of the transformer is V_m and the voltage drop across the R_L due to diode D_1 conducting is V_m. Hence the total voltage across the diode D_2 is $2V_m$.

Thus $PIV = 2V_m$

The same procedure is repeated when D_1 is OFF and D_2 is ON.

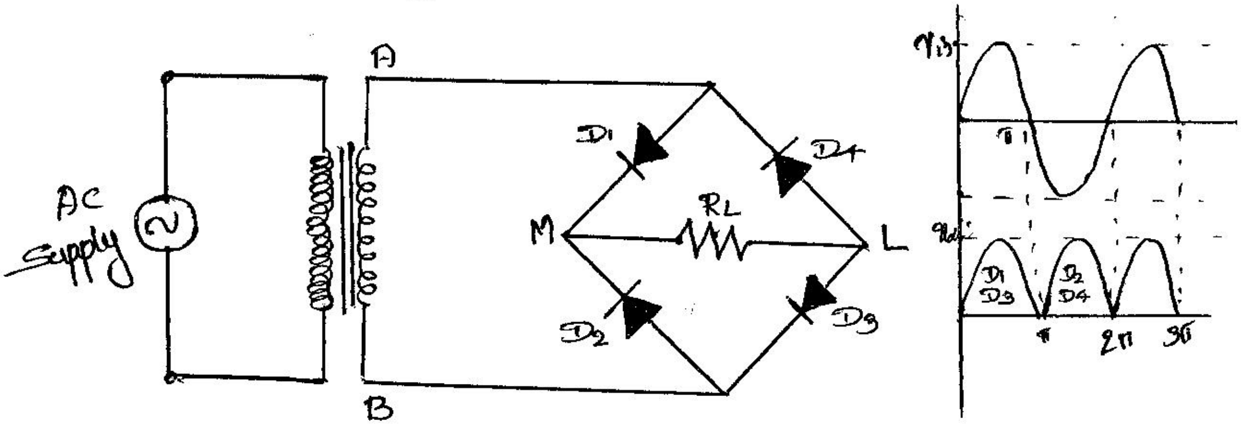
Advantages

- * The output voltage and transformer efficiency are high
- * The DC saturation of the core is avoided as current flows through the two halves of the centre p tapped secondary of the power transformer in opposite direction.
- * Low ripple factor.

Disadvantages.

- Usage of additional diode and bulky transformer is needed, and hence increase in cost.
- PIV of diode is high [i.e, $2V_m$]

ii. Full wave Bridge Rectifier



The circuit contains four diodes D_1, D_2, D_3 & D_4 connected to form a bridge. The AC supply to be rectified is applied to the diagonally opposite ends of the bridge. Whereas, the load resistor R_L is connected across the remaining two diagonally opposite ends of the bridge.

When AC supply is switched on, the alternating voltage V_m appears across the terminals AB of secondary winding of transformer which needs rectification.

During positive half cycle of secondary voltage, the end A becomes positive and end B negative. This makes diodes D_1 & D_3 forward biased and diodes D_2 & D_4 reverse biased. Therefore, diodes D_1 & D_3 conduct while diodes D_2 & D_4 do not. Thus, current [i] flows through diode D_1, load resistor R_L [from M to L], diode D_3 and the transformer secondary.

During negative half cycle, the end A becomes negative & end B positive. This brings diodes D_2 & D_4 under forward bias and diodes D_1 & D_3 under reverse bias. Therefore, diodes D_2 and D_4 conduct while diodes D_1 & D_3 do not. Thus current [i] flows through diode D_2, load resistor R_L [from M to L], diode D_4 & the transformer secondary.

Advantages.

- The centre-tap transformer is eliminated
- The diodes having low (half) PIV are needed as the PIV across each diode is one-half to that of the centre-tap circuit.

Disadvantages.

- It needs 4 diodes.
- This circuit is not suitable when a small voltage is required to be rectified. It is because in this case two diodes are connected in series and offers double voltage drop due to their internal resistance.

Comparison.

Parameter.	Half wave Rectifier	Centre-tapped FW Rectifier	Bridge Rectifier.
1. I_{rms}	$I_m/2$	$I_m/\sqrt{2}$	$I_m/\sqrt{2}$
2. I_{dc}	I_m/π	$2I_m/\pi$	$2I_m/\pi$
3. V_{dc}	V_m/π	$2V_m/\pi$	$2V_m/\pi$
4. % efficiency	40.6%	81.0%	81.0%
5. Ripple factor.	1.21	0.482	0.482
6. Peak Inverse voltage	V_m	$2V_m$	V_m
7. Cost	Low	Costly	less costly
8. No: of diodes	1	2	4
9. Transformer necessary	No	Yes	No