$$= 60 + 18.457 + 17.857 + 1.0804 = 97.3944 \text{ kWh}$$

$$\text{and Total output} = 4200 \text{ kWh}$$

$$\therefore \text{All day } \eta = \frac{\text{Total output for 24 hours}}{\text{Total output for 24 hours} + \text{total energy spent for 24 hours}} \times 100$$

$$= \frac{4200}{4200 + 97.3944} \times 100 = \mathbf{97.73\ \%}$$

1.22 Autotransformer

Asked in 2004-05

Uptill now the two winding transformers are discussed in which the windings are electrically isolated and the e.m.f. in secondary gets induced due to induction. In practice, it is possible to use only one winding for the transformer so that part of this winding is common to the primary and secondary. Such a special type of transformer having only one winding such that part of the winding is common to the primary and secondary is called **autotransformer**. Obviously the two windings are electrically connected and it works on the principle of conduction as well as induction. Such an autotransformer is very much economical where the voltage ratio is less than 2 and the electrical isolation of the two windings is not necessary. The power transfer in 2 winding transformer is fully inductively while in autotransformer the power is transferred from primary to secondary by both inductively as well as conductively.

1.23 Construction

In an autotransformer only one winding is wound on a laminated magnetic core while in 2 winding transformer, two windings are wound. The single winding of the autotransformer is used as primary and secondary. The part of the winding is common to both primary and secondary. The voltage can be stepped down or stepped up using an autotransformer. Accordingly the autotransformers are classified as step up autotransformer and step down autotransformer.

The Fig. 1.36 (a) shows the conventional two winding transformer while the Fig. 1.36 (b) and (c) show the step down and step up autotransformers respectively.

In step down autotransformer shown in the Fig. 1.36 (b), the entire winding acts as a primary while the part of the winding is used common to both primary and secondary. Thus AB forms the primary having N_1 turns while BC forms the secondary with N_2 turns. As $N_2 < N_1$, the output voltage $V_2 < V_1$ and it acts as a step down auto transformer. In step up autotransformer shown in the Fig. 1.36 (c), the entire winding acts as secondary while the part of the winding is used common to both primary and secondary. Thus AB forms the secondary having N_2 turns while BC forms the primary with N_1 turns. As $N_2 > N_1$, the output voltage $V_2 > V_1$ and it acts as a step up autotransformer.

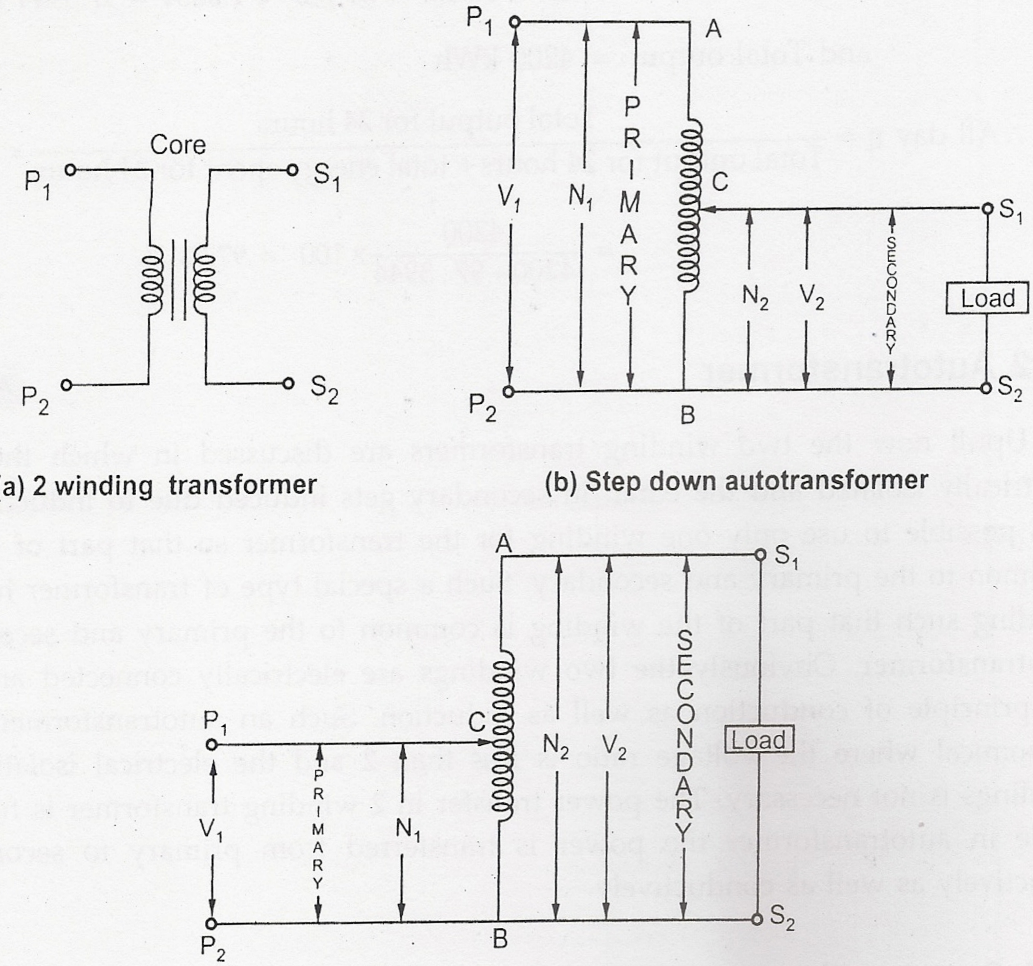


Fig. 1.36 Autotransformer

The current distribution in the step down and step up autotransformers is shown in the Fig. 1.37 (a) and (b) respectively.

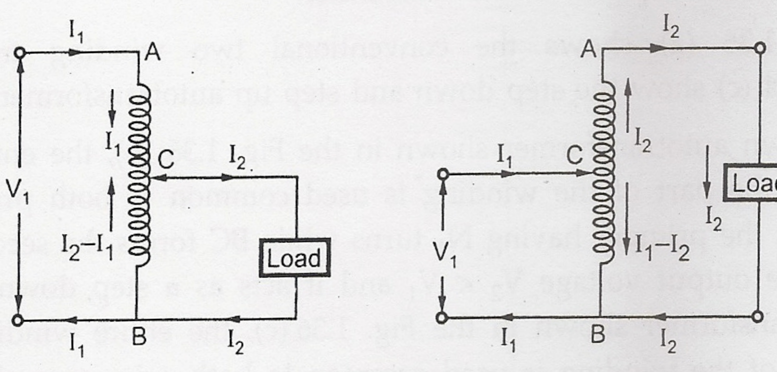


Fig. 1.37 Current distribution in autotransformer

1.24 Transformation Ratio of an Autotransformer

Neglecting the losses, the leakage reactance and the magnetising current, the transformation ratio of an autotransformer can be obtained as,

$$K = \frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1}$$

K is greater than unity for step up autotransformer while K is less than unity for step down autotransformer.

Due to the use of single winding, compared to the normal two winding transformer, for the same capacity and voltage ratio, there is substantial saving in copper in case of autotransformers.

Let us obtain the expression for the copper saving in the autotransformers.

1.25 Copper Saving in Autotransformer

Asked in 2004-05

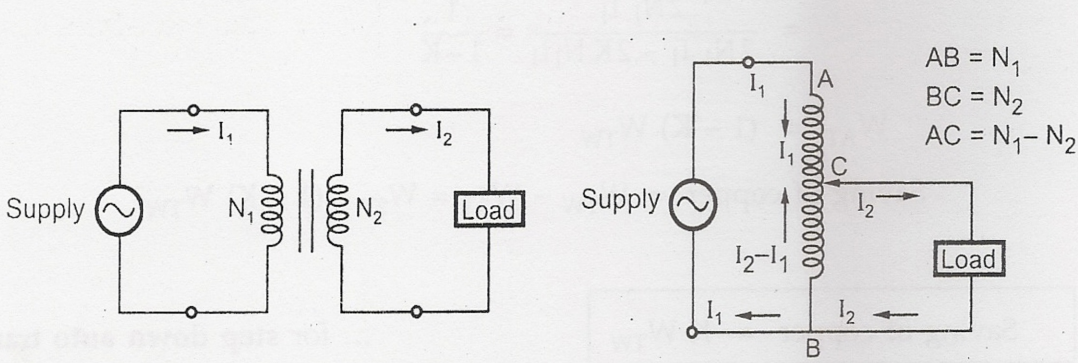
For any winding, the cross-section of winding is proportional to the current I. While the total length of the winding is proportional to the number of turns N. Hence the weight of copper is proportional to the product of N and I.

$\therefore$ Weight of copper $\propto$ NI

where $\quad I$ = current in the winding

and $\quad N$ = number of turns of the winding

Consider a two winding transformer and step down autotransformer as shown in the Fig. 1.38 (a) and (b).



(a) Two winding transformer (b) Step down autotransformer

Fig. 1.38

Let $\quad W_{TW}$ = total weight of copper in two winding transformer

W_{AT} = weight of copper in autotransformer

In two winding transformer,

Weight of copper of primary $\propto N_1 I_1$

Weight of copper of secondary $\propto N_2 I_2$

$\therefore \quad W_{TW} \propto N_1 I_1 + N_2 I_2$ ... total weight of Cu

In case of step down autotransformer.

Weight of copper of section AC $\propto (N_1 - N_2) I_1$

Weight of copper of section BC $\propto N_2 (I_2 - I_1)$

$\therefore \quad W_{AT} \propto (N_1 - N_2) I_1 + N_2 (I_2 - I_1)$ ... total weight of Cu

Taking ratio of the two weights,

$$\frac{W_{TW}}{W_{AT}} = \frac{N_1 I_1 + N_2 I_2}{(N_1 - N_2) I_1 + N_2 (I_2 - I_1)}$$

$$= \frac{N_1 I_1 + N_2 I_2}{N_1 I_1 - N_2 I_1 + N_2 I_2 - N_2 I_1}$$

$$= \frac{N_1 I_1 + N_2 I_2}{N_1 I_1 + N_2 I_2 - 2 N_2 I_1}$$

But $\quad K = \dfrac{N_2}{N_1} = \dfrac{I_1}{I_2}$

$$\therefore \quad \frac{W_{TW}}{W_{AT}} = \frac{N_1 I_1 + K N_1 \cdot (I_1 / K)}{N_1 I_1 + K N_1 \cdot (I_1 / K) - 2(K N_1) I_1}$$

$$= \frac{2 N_1 I_1}{2 N_1 I_1 - 2 K N_1 I_1} = \frac{1}{1 - K}$$

$\therefore \quad W_{AT} = (1 - K) W_{TW}$

$\therefore \quad$ Saving of copper $= W_{TW} - W_{AT} = W_{2T} - (1 - K) W_{TW}$

Saving of copper $= K W_{TW}$	

... for **step down auto transformer**

Thus saving in copper is K times the total weight of copper in two winding transformer.

And

saving of copper $= \dfrac{1}{K} W_{TW}$

... for **step up auto transformer**

Key Point: *As the transformation ratio increases, the saving in copper is more and more.*

1.26 Power Transfer in Autotransformer

It is mentioned earlier that the power input to an autotransformer gets transferred to the secondary by two ways i.e.

1. By electromagnetic induction i.e. inductively
2. By conduction i.e. directly as windings are electrically connected.

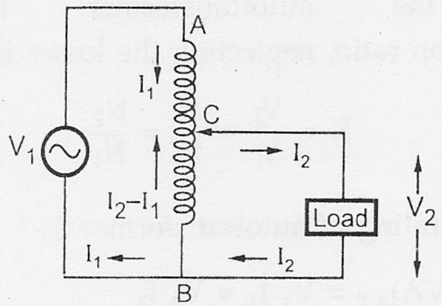


Fig. 1.39

Consider a loaded autotransformer shown in the Fig. 1.39.

The current drawn from the supply is I_1 while the input voltage is V_1.

$\therefore$ Input power $= V_1 I_1$

While the load current is I_2 at a load voltage V_2.

$\therefore$ Output power $= V_2 I_2$

Now BC portion has N_2 turns and acts as secondary. The current induced in this secondary due to transformer action is $I_2 - I_1$ while secondary induced voltage is V_2.

$\therefore$ P_t = Power transformed inductively i.e. transformer action

$$= (I_2 - I_1) V_2 = V_2 I_2 - V_2 I_1$$

But $$K = \frac{V_2}{V_1} = \frac{I_1}{I_2}$$

$\therefore$ $$P_t = K V_1 \cdot \frac{I_1}{K} - K V_1 I_1 = V_1 I_1 - K V_1 I_1$$

$\therefore$ $$\boxed{P_t = (1 - K) V_1 I_1 = (1 - K) \times \text{input power}}$$

While the remaining power which is (K × input power) gets transferred directly i.e. conductively as windings are electrically connected.

$\therefore$ P_t = power transformed = (1 – K) × input power

and P_c = power conducted through = K × input power

$\therefore$ P_c = (load power output) – P_t

Key Point: *Thus for the same excitation voltage and winding currents, the autotransformer gives more output than two winding transformer. Hence autotransformer has higher efficiency.*