Applications of second order curves

Aims:

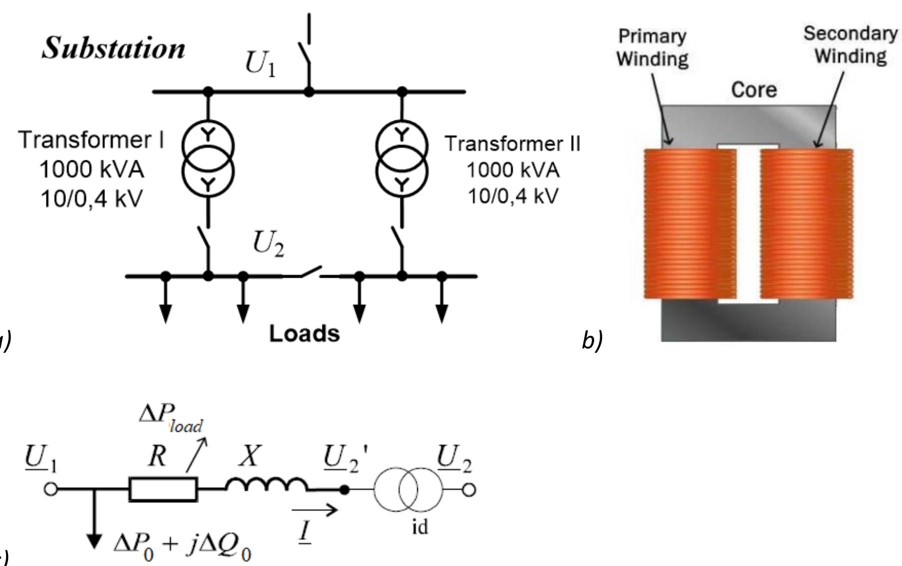
1) Students are introduced to the concept of using second order curves in maritime problems
2) Students know how to use second order curves in order to solve configuration of the electrical substation problems

Second order curves and optimal operation of electrical substation

There is always concern about decreasing active power losses in electrical networks. It reduces bills for electricity for mainland customers and the consumption of the fuel on board of ships. One of tasks related to active power saving is the choosing of the proper configuration of the electrical substation.

A distributing substation usually contains two transformers that steps down middle voltage U_1 of 6…35 kV to low voltage U_2 = 0.4 kV (Fig. 3.1, *a*). That is the case for port network and for many ships with the on-board gird containing a high-voltage part.

a)



c)

Fig. 3.1. Single-line diagram of three-phase electrical substation with two transformers (*a*), single-phase transformer design (*b*), simplified equivalent circuit of a transformer (c).

Each transformer has at least two windings: middle voltage (ML) and low voltage (LV) ones (Fig. 3.1, *b*). Those are wound around a magnetic core that facilitates energy transfer from MV side to LV side (Fig. 3.1, *b*). The active power losses have place in each of the transformer component.

The active power loss in magnetic core ΔP_0 is called core loss or no-load loss and it is supposed to be almost constant. It is because this loss depends on voltage U_1 that is kept as stiff as possible. That is why the iron loss is often modelled as a constant power load (Fig. 3.1, *c*).

The active power losses in MV and LV windings called copper losses are often considered together and they happens in aggregated resistance R of both the windings called short-circuit resistance (Fig. 3.1, *c*). This variable loss depends on loading of a transformer, i.e. on the load current I flowing through the windings to consumers. That is why it is also called load loss and may be calculated as follows:

a) Single-phase transformer $\Delta P_{load} = I^2R$;

b) Three-phase transformer $\Delta P_{load} = 3I^2R$.

The total active power loss in transformer can be found in this way:

a) Single-phase case $\Delta P_l = \Delta P_0 + I^2R$;

b) Three-phase case $\Delta P_l = \Delta P_0 + 3I^2R$.

It is clear that total active power loss in transformer depends on the squared load current forming a parabolic curve shifted upwards by amount of no-load active loss (Fig. 3.2, curve P_l).

If two similar transformers operates in parallel then the total loss in substation transformers (Fig. 3.2, curve P_{I+II}) may be calculated in the next way:

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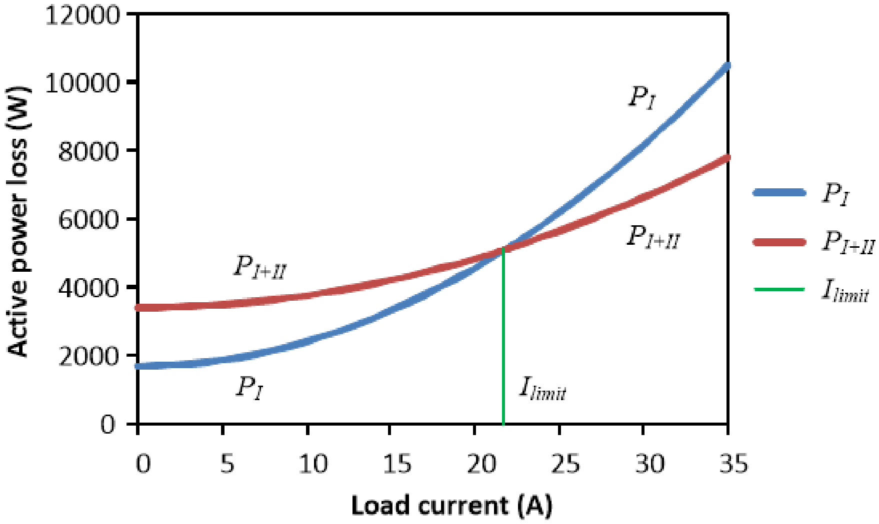

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Fig. 3.2. Active power losses at the substation with a single operating transformer (curve P_I) and two transformers in parallel connection (curve P_{I+II}).

a) Single-phase case $\Delta P_{I+II} = 2\Delta P_0 + \dfrac{I^2 R}{2}$;

b) Three-phase case $\Delta P_{I+II} = 2\Delta P_0 + \dfrac{3I^2 R}{2}$.

The optimal choice of the substation configuration, i.e. whether to keep in operation one or two transformers in parallel connection in order to get minimum active power loss, depends on some boundary load current I_{limit}. If the load current is less than I_{limit} then the operation with a single transformer is preferable. If the load current is greater than I_{limit} then the substation configuration with two operating transformers gives less loss of active power.

Example

There are two three-phase transformers at the substation with the following parameters:

Nominal power: 1000 kVA

Nominal voltages: 10.5/0.4 kV

No-load loss: ΔP_0 = 1700 W

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Short-circuit resistance: R = 2.4 Ω.

Find at which boundary load current I_{limit} the substation should be switched from the operation with a single transformer to the operation with two transformers in parallel.

Solution: The active power loss under operation with a single transformer can be expressed as

$\Delta P_{\mathrm{I}} = \Delta P_0 + 3RI^2 = 1700 + 7.2I^2$ (Fig. 3.2, curve P_{I}).

In the case of two transformers in parallel connection, the active power loss depends on current as follows

$\Delta P_{\mathrm{I+II}} = 2\Delta P_0 + \dfrac{3RI^2}{2} = 3400 + 3.6I^2$ (Fig. 3.2, curve $P_{\mathrm{I+II}}$).

The intersection point of two parabolas gives us the value of I_{limit}. It can be found by equating the expressions for ΔP_{I} and $\Delta P_{\mathrm{I+II}}$

$1700 + 7.2\,I_{limit}^2 = 3400 + 3.6\,I_{limit}^2 \rightarrow 3.6\,I_{limit}^2 = 1700 \rightarrow I_{limit} = 21.7$ A.

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