COMBINED TRANSFORMER TYPE VAU - OPTIMAL SOLUTION FOR HV SUBSTATION

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Summary:

The basic characteristics of a new concept of combined transformers consisting of an inverse current transformer and a voltage transformer with open core are described. Thanks to its technological design and simplicity, the new concept allows the commercial manufacture of combined transformers for the highest equipment voltages up to 420 kV inclusive. The main advantages of combined transformer installation in power-system are described and explained.

Key words: instrument transformer, combined transformer, Ferro-resonance, switchyard

1. Introduction

The combined transformer is defined as a transformer consisting of a current transformer and a voltage transformer in the same enclosure. Because of many advantages, this technical solution is very popular in many countries. Same reports say that in the most developed industrial countries, the population share of combined transformers in the total number of instrument transformers at the voltage levels 123 and 245 kV amounts to approx. 50%. According to the mentioned report, no combined transformers with oil -paper insulation are installed at voltages higher than 300 kV.

There are in principle two main combined transformer designs, which have been used in service up to now. The first one, oil-paper insulated, consists of an inverse current transformer placed in the head of the combined transformer, and an inductive voltage transformer with a closed core, placed at the bottom of the transformer in a separate metal enclosure. Main insulation of these transformers forms two separate capacitive bushing which are placed in the same insulator. This is considered to be a fundamental drawback of mentioned solution, because the voltage is distributed along the height of individual bushing of opposite sign, so that the places of the same potential should be adjusted in space.

The second design is combined transformers with main insulation of SF_6 gas. The most frequent solution of this technology is with the current transformer and the voltage transformer installed in the combined transformer head, where the voltage transformer with closed core can be above or below the inverse current transformer. However, such solutions, which fundamentally at lower voltages keep all advantages and drawbacks of separate designs of SF_6-gas insulated current and voltage transformers, at a higher rated voltage become voluminous because of the increase of transformer head dimensions. Naturally, for this reason the transformer resistance to mechanical forces in operation is reduced, and because of its high gravity point its stability is reduced.

2. Description of the new solution

Few years ago in KONCAR new type of combined transformers was developed. The concept of the new solution is based primarily on the many years of positive experience in the production and operation of voltage transformers with open magnetic core and inverse current transformers. Namely, the combined transformer according to the new solution Fig. 1 consists of head (1), pin-type insulator (2) and casing (3).

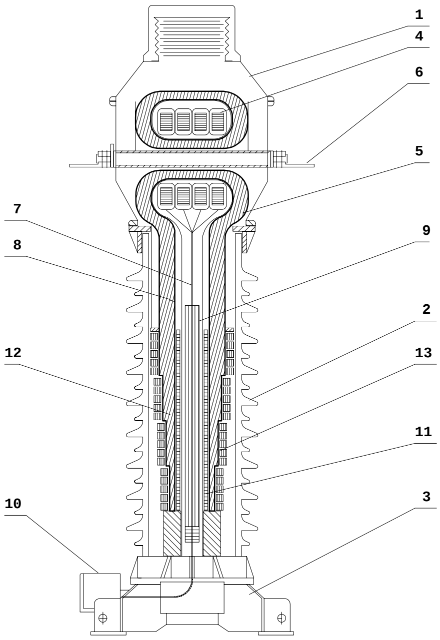

Figure. 1. Longitudinal cross-section of combined transformer

The same as in the inverse current transformer, the cores and the secondary windings (4) of current transformers are placed in the head and insulated from the head potential by means of paper-oil insulation (5). Joined to this insulation, as inseparable whole there is insulation (12) of supporting mechanical tube (8) through which the secondary terminals of current transformer (7) are passing. The primary winding (6) of the current transformer is shown in this design as bar-type winding. In practice there are other versions with a bigger number of turns and multiple reconnection on the primary side. Basically, the usual concept of inverse current transformer has been used for the combined transformer in such a way that the open magnetic core (9) and the voltage transformer secondary winding (11) are placed inside a hollow tube (8). The voltage transformer primary winding (13) is distributed on the main insulation (12) periphery in the transformer vertical axis. Depending on the rated voltage, it can be divided into several up to several dozens of sections.

The new concept, in relation to other known solutions, is characterised by a number of advantages:

- Combined transformers of this design, take relatively small space. This is achieved by placing the voltage transformer with open magnetic core and secondary windings inside the supporting tube, which carries the active part of the current transformer.
- The voltage transformer primary winding which is distributed along the pin-type insulator height, optimises the potential distribution along the transformer height and also contributes to space saving.
- By placing the voltage transformer core and windings inside the pin-type insulator, a uniform distribution of weight inside the transformer is obtained which contributes to the improvement of its mechanical stability.
- The technology of manufacture and assembly of combined transformer of this concept is similar to the manufacture and assembly of inverse type current transformers which allows relatively simple production for higher voltages, e.g. for U_m = 420 kV.
- Due to open core of voltage transformer this design is ferro-resonace free
- Inductive voltage transformers as a part of combined transformer has relatively large cross section of primary winding so transformer is very powerful in discharging of transmission lines

3. Main characteristics of VAU - type combined transformers

This type of transformers has been produced for all the highest voltage for equipment from 72,5 kV to 420 kV. They are manufactured in many variants depending on number of current transformer cores, rated primary and secondary currents, number of secondary windings of voltage transformers, rated primary and secondary voltage, rated voltage factor and its duration, rated burdens and accuracy class requirements. Main dimensions and sketch drawing are given on figure 2. and Table I.

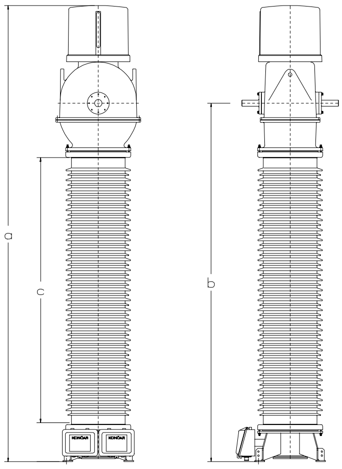

Figure 2. Sketch drawing of combined transformer VAU type

Generally, it can be said that current part of combined transformers has up to six cores, but in view of inverted current transformer, maximum value of rated primary current relatively is high and for not primary re-connectable transformer amounts 6000A. For primary re-connectable transformer upper limits are 2x2000A, respectively 4x1000 A. Voltage part of combined transformer has up four secondary windings.

Table I - Main dimensions of combined transformer VAU type

Type: VAU-	a [mm]	b [mm]	c [mm]
72,5	2415 ±20	1630 ±20	1000
123	2615 ±20	1830 ±20	1200
170	3045 ±20	2265 ±20	1640
245	3750 ±20	2950 ±20	2160
362	4580 ±20	3750 ±20	2960
420	5680 ±20	4630 ±20	3540

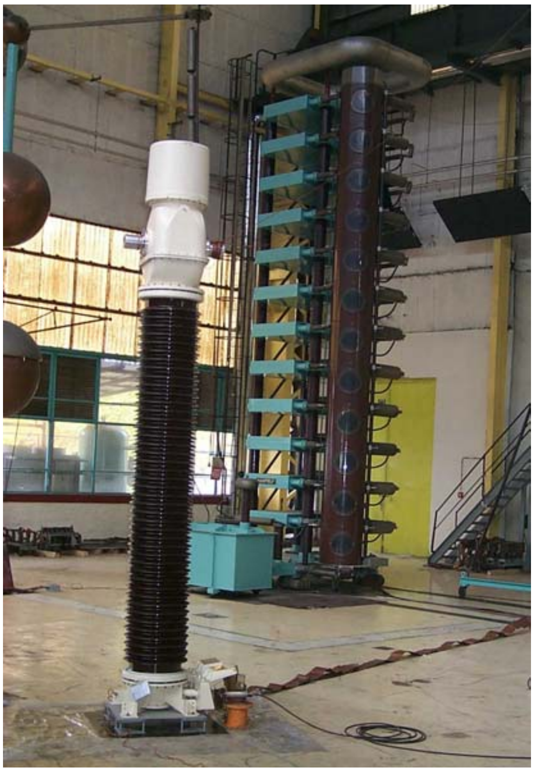

Figure 3. Combined instrument transformer VAU-420 under lighting impulse test of 1300 kV.

4. Combined transformer in substations

The main advantages of installation combined instead of current and voltage transformers in substation can be described and derived from Figure 4.

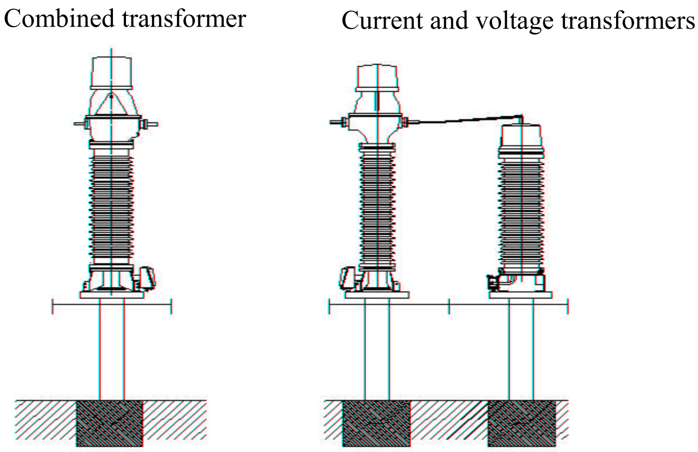

Figure 4. Advantages of combined transformers

From Figure 4, it is quite clear that organizations, which used combined transformers in service instead of separate current and voltage units, have following benefit:

- in principal pay lower price for transformer(s)
- have less transportation cost
- need less clamping materials
- have less component in substation (service and mechanical defects)
- need less required space for installation
- need less pylons
- need less foundations

On the Figures 5 and 6, cross section of typical field in 123 kV switchyard shows that total required space for complete switchyard is significantly reduced, about 7.7 %, when combined transformer type VAU-123 is used instead of separate current and voltage transformers.

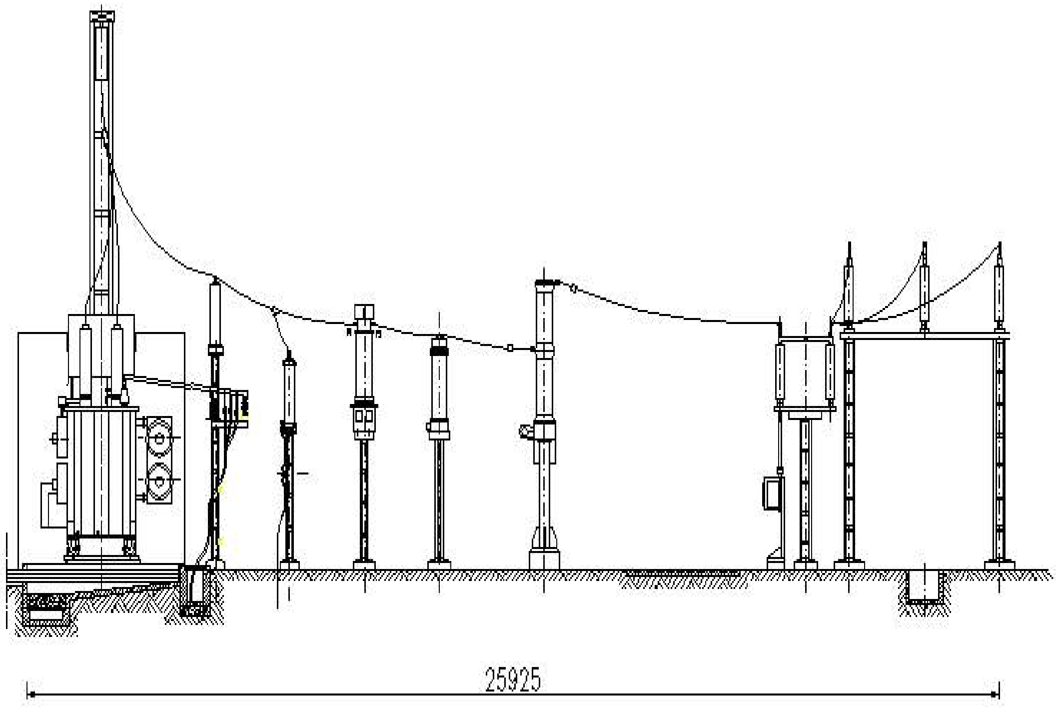

Figure 5. Cross-section of 123 kV switchyard with current and voltage transformers

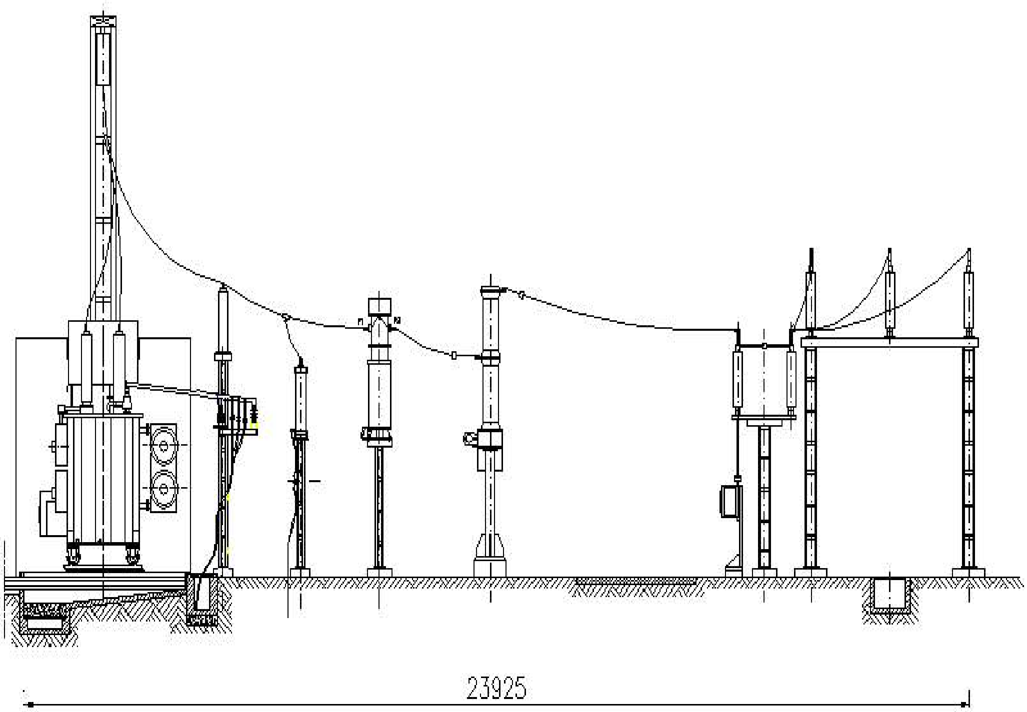

Figure 6. Cross section of 123 kV switchyard with combined transformer

5. VAU type combined transformer and Ferro-resonance phenomena

The Ferro-resonance phenomena may be caused by switching operations in a network between the non-linear reactance of the inductive voltage transformers and capacitance of the network forming a resonant circuit. Result of a Ferro-resonance is stable oscillation, which may damage transformer by over-heating and/or over-voltage stresses. Typical network configurations, which may lead to Ferro-resonance, are as follows:

- Single-phase Ferro-resonance in a configuration where an inductive voltage transformer is connected to a high voltage line, which is de-energised but running alongside another, energised line.
- Single phase Ferro-resonance between a inductive voltage transformer and HV/MV capacitance of a supply transformer
- Single phase Ferro-resonance between a inductive voltage transformer and the grading capacitance of an open circuit breaker
- Three phase Ferro-resonance with inductive voltage transformer connected to a system with isolated neutral and very low zero sequence capacitance

In practice it is not always possible to avoid the configurations sensitive to the Ferro-resonance. Since Ferro-resonance occurs only in unfavourable combinations of capacitance and the non-linear reactance of inductive voltage transformers it is important to recognise these configurations.

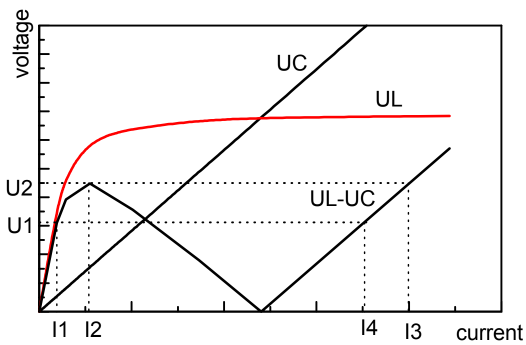

Figure 7. Graphical solution of Ferro-resonance phenomena

For better understudying of the Ferro-resonance phenomena we can help ourselves to graphical solution of serial connection of capacitor and non-linear inductor given on Figure 7. On figure 7, voltages across non-linear inductor (UL) and capacitor (UC) are given versus their currents. Theoretically, supply voltage of serial combination for a stable condition is given by curve (UL-UC). If U1 is the voltage in the normal service conditions through non-linear resistor and capacitor flows current I1. We can assume that supply voltage suddenly reaches value U2 and a little exceeds it. Then supply current skip from the I2 too much higher value I3. If we reduce afterward supply voltage to the normal value U1, current I4 much higher then I1 will now flows in the circuit. In the same time voltages across inductor and capacitor are much higher then in normal conditions. This condition can last for a long time and cause overheating of non-linear inductor and capacitor as well as over-voltage across them.

Why is combined transformer type VAU Ferro-resonance free? Voltage part of it consists of an inductive voltage transformer with open core and magnetic flux is closed through neighbouring air. Due to this fact magnetising current is relatively high and magnetising characteristics of such transformer (U-I diagram) more laid down to the current axis then in the case of transformers with closed core. Figure 8. For the most unfavourable values of capacitance which in practice can result with Ferro-resonance (capacitance of substation bus bar, capacitance of current and power transformers, capacitance of circuit breaker grading capacitor) intersection between magnetising characteristics of combined transformer type VAU and capacitor line is impossible (see figure 8.). Even in the case that in particular networks combination, above-mentioned intersection become possible, low value of rated induction ensures that exciting voltage for Ferro-resonance become very remote. Additionally special compensating winding built in transformer is very effective burden to suppress transient phenomena.

As a manufacturer of inductive voltage transformer with open core for more of 40 years we have never faced problem of Ferro-resonance with this type of transformer.

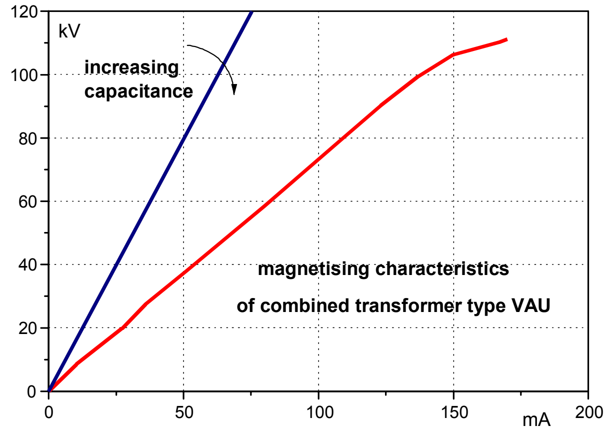

Figure 8. Magnetising characteristics of combined transformer VAU-123 and typical capacitance U-I diagram

6. Conclusion

Generally said combined transformers are very popular electrical devices in many the most developed country. Its main advantages are described in chapter 4. It is shown that savings in substations, if combined transformers is used instead of current and voltage transformer, amounts about 7.7 % for 123 kV and estimated about 4 % for 420 kV.

Comparing with other design of combined transformers, combined transformer type VAU has several additional advantages. Optimal potential distribution and voltage stresses along insulator height, very good mechanical stability, ability to be manufactured very simple for very high voltage e.g. 420 kV, excellent Ferro-resonance characteristic and ability for discharging transmission lines are the most important advantages of this transformer type.

7. References

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