Mathematical Model on Internal Overvoltages HV Windings

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***Abstract*—The issue of insulation damage to unit transformer windings coming about because of inner overvoltages is presented. The paper presents the simulations results in the field of analyzes of voltage dissemination along transformer windings at various switching operations and turbulences in the power line. For the computations, a numerical model of windings of a typical unit transformer was utilized, taking into account its actual parameters. The results of computations and summary are given.**

***Keywords*— HV windings, voltage distribution, protection level, simulation.**

I. Introduction

Issues related to dangerous surges internal in transformer windings resulting in major breakdowns of large transformers network or units have been known for seventies years of the last century. Then too serious clarification work has begun the causes of damage to transformers. In last years this subject is relevant again due to intensification of failure of transformers, mainly unit transformers occurring both in foreign and national. Research related to formation internal resonant overvoltages in the windings transformer and in terms of mitigation measures or eliminating their effects are carried out intensively by many research centers and factories design teams [1].

II. Voltage exposures of unit transformers

During the operation of the transformer winding they are subject to various types of stress interactions in the form of switching overvoltages, lightning overvoltages and ground fault surges they may have oscillatory or aperiodic nature. Moreover, on the transformer winding is influenced by the operating voltage of mains frequency. The winding of the transformer provides complex system connected in series-parallel longitudinal partial capacitances and inductances (within the same winding) and transverse (to another winding or to ground). The transformer winding is a complex system of longitudinal (within the same winding) and transverse (with respect to another winding or ground) capacitances and partial inductances connected in series-parallel. If the voltage excitation in the form of oscillating or aperiodic overvoltages applied to the transformer terminals is characterized by a frequency close to or equal to one of the winding resonance frequencies, then resonant vibrations may occur in the part of the winding where its own resonant frequency is close to the excitation frequency. The switching overvoltage frequencies range from several hundred hertz to several dozen kilohertz and create the possibility of inducing resonant vibrations inside the transformer windings. An additional contributing factor inducing resonant vibrations in the winding transformer, except for the frequency of external vibrations similar to one of the resonance frequencies transformer, are the correct overvoltage amplitude external, weak suppression of the overvoltage waveform and sufficiently long duration [2].

As a result of internal resonance overvoltages in transformer windings, their insulation is often damaged, leading to internal short-circuits, which may result in a serious failure of the transformer, causing its shutdown. Such cases were noted both in the domestic energy sector and in many foreign energy sectors. This is a serious operational problem for the power industry due to the costs of transformer renovation and costs resulting from interruptions in electricity supply.

Some of the power evacuation systems from the power plant have a fairly specific configuration consisting of presence between the unit transformer and the nearest power station of the line section overhead or cable and at the circuit breaker location synchronizing the unit with the power grid in power station. This track configuration power evacuation promotes overvoltages due to the initiation of wave phenomena in the lines during connections and disturbances and may cause failure transformers.

III. Computer simulations of switching and fault processes and the accompanying overvoltages in the windings of a unit transformer

In recent years, major transformer failures causing significant electricity outages and costs resulting from the renovation of transformer units. In one of the domestic power plants, in a unit transformer working in the line-transformer system occurred in a series of internal damage in a short time.

To investigate the causes of these failures was carried out simulation calculations to estimate the level of overvoltages in the coils of the emerging windings during various switching operations and during earth faults in the unit line. Simulation calculations made using the EMTP (Electro – Magnetic Transients Program) in ATP (Alternative Transients Program) version. The subject of the article are the results of these studies [3] .

The diagram of the modeled power evacuation system from the power plant is shown in Figure 1.

For the correct representation of the transformer model its characteristics were measured in an unloaded state and in a state short circuit. In the calculation of overvoltages in windings transformer, the construction of its windings is taken into account and the upper and lower windings are mapped voltage using a ladder diagram – assuming division of HV windings into 45 coils. Model inductance the ladder was determined on the basis of parameters technical transformer, and model capacity was calculated using the capacitance measurement data unit transformer made after the last one renovation. The model data calculated in this way was verified determining analytically its characteristics frequency and comparing them with the measured one's transformer characteristics [4] .

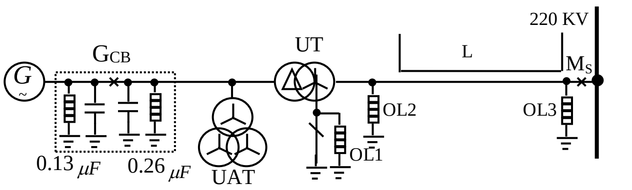


Fig. 1. Diagram of the modeled path of power evacuation from the power plant (G - generator 282 MVA, 15.75 kV; UT - unit transformer 270 MVA, 250 kV / 15.75 kV; UAT - unit auxiliary transformer 32 MVA, 15.75 kV / 6 kV / 6 kV; L - 220 kV two-circuit line, line length l_L = 22 km; G_{CB} - generator circuit breaker including capacitors and overvoltage limiters; M_S - mains switch; OL1, OL2, OL3 - overvoltage limiters)

The power output from the considered power plant is made in the form of connected 220 kV overhead line to one of the 220 kV systems of the neighboring station power. The line is built as double-track, mainly on double-track lattice poles Mc2 type and partially on M52 series columns, o two-triangle system of working conductors with two lightning conductors. The 220 kV line was modeled according to Bergeron's diagram (distributed parameters) taking into account, on the basis of the line passport, types working and lightning conductors, number and types poles, cable suspension geometry, etc.

IV. THE SCOPE OF SIMULATION CALCULATIONS

Simulation calculations of overvoltages occurring in the considered network line (substation - 220 kV line circuit breaker - 220 kV line – unit transformer - generator circuit breaker - generator, including auxiliary transformer, overvoltages limiters and capacitors installed on both sides of the generator circuit breaker) were carried out in relation to selected switching operations of the 220 kV mains and generator circuit breaker and disturbances in the 220 kV line posing the greatest overvoltage risks [5].

The scope of calculations included:

- Switching on an unloaded unit transformer switch in the substation.
- Switching on an unloaded unit transformer with a circuit breaker in a power substation.
- Ignition-free switching off of a loaded unit transformer with a circuit breaker in a power substation.
- Connecting the generator with a generator circuit breaker to the network - synchronization.
- Switching off the loaded generator with a generator switch.
- Switching off single-phase faults in 220 kV line, at distances: 0.1; 0.25; 0.5; 0.75 line lengths from the unit transformer and at the end of the line.
- Single-pole ignition with open circuit breaker contacts in the substation during synchronization.

V. RESULTS OF SIMULATION CALCULATIONS

Table 1 presents the results of the largest calculations overvoltages on HV and LV windings unit transformer and on HV winding coils.

The results are presented in the form of overvoltage factors calculated:

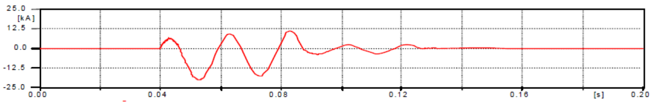
- by referring to the peak value of the rated phase voltage of the transformer HV and LV winding and denoted respectively k_{HV} and k_{LV},
- by reference to the rated voltage of the transformer primary coil in steady state, which was taken as $\frac{\sqrt{2}\times 250}{\sqrt{3}\times 45}$ kv and marked k_{coil}.

Table 1 also shows the numbers of the coils with the highest overvoltages.

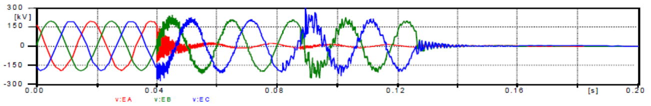
TABLE I. OVERVOLTAGE FACTORS ON HV AND LV WINDING TERMINALS OF A UNIT TRANSFORMER AND ON THE MOST EXPOSED HV WINDING COILS DURING VARIOUS SWITCHING OPERATIONS

Type of switching operation	**K_{HV}**	**K_{LV}**	**K_{coil} / coil no**
Switching on an unloaded unit transformer with the M_S circuit breaker	1.69	2.10	11.0/1
Switching off the loaded unit transformer with the M_S circuit breaker	1.44	1.17	1.3/45
Connecting the generator to the network with a G_{CB} generator switch-synchronization	<1.1	<1,1	<1.1
Switching off the loaded generator with the G_{CB} generator switch	<1.1	<1,1	<1.1
Switching off a single-phase short circuit in the overhead line, at a distance of 0.1 I_L	1.33	1,10	4.1/1
A disconnection of a single-phase fault in the overhead line at a distance of 0.25 I_L	1.37	1,10	13.2/1
Switching off a single-phase fault in the overhead line at a distance of 0.5 I_L	1.49	1,12	3.7/1
A disconnection of a single-phase short circuit in the overhead line at a distance of 0.75 I_L	1.45	1,21	2.3/1
Switching off a single-phase short circuit at the end of the overhead line	1.60	1,28	1.9/1
Single-pole ignition in the compartment of the M_S switch	1.68	1,24	6.0/1

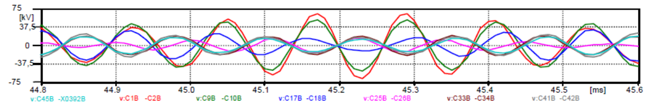
In order to illustrate the nature of the phenomena, Fig. 2 presents an example of a printout of the current and voltage waveforms occurring during the selected switching operation.



Single-phase short-circuit current (at the fault location) - I_k ”= 9.54kA



Voltages on HV terminals of a unit transformer, k_{HV} = 1.37



Voltages on coils 1, 9, 17, 25, 33, 41 and 4 5 phases C. k_{coil1} = 13.2

Fig. 2. Switching off a single-phase short-circuit at a distance of 0.25 of the line length from the unit transformer

VI. Conclusion

The calculations showed that among those considered of cases, the largest internal overvoltage in HV windings of the transformer occur during breaking single-phase earth faults in the line overhead 220 kV, when the fault location is at ¼ of the line length from the unit transformer. It is related to the frequency of external overvoltages on the HV terminals of the unit transformer, which in such the case is very close to the resonant frequency transformer (approx. 9.1 kHz). In case of short circuits in the line in distances other than ¼ I_L from the unit transformer the level of internal overvoltages is lower due to detuning the system from the resonant frequency. A high level of internal overvoltages on the HV winding coils was also noted during the unloaded path of power output switching on with a circuit breaker in a 220 kV substation (k_{coil} = 11).

Synchronization of the block with the network using a 220 kV switch installed at the end of the block line, with the occurrence of 1-pole ignition on its open contacts, it causes dangerous internal overvoltages, the level of which reaches the value of 6 as above. Synchronization of the unit with a generator circuit breaker allows to avoid such dangerous exposures of transformer windings.

Switching operations with a generator circuit breaker, such as connecting the generator to the mains and switching it off under load, do not cause dangerous internal overvoltages in the transformer windings. Internal overvoltage factors do not exceed the level of 1.1 as above. Similarly, switching off the loaded path of power output with a circuit breaker in a 220 kV substation poses a slight risk of overvoltage in the windings, k_{coil} = 1.3.

The calculation results indicate that the greatest overvoltages internal ones occur on the extreme coils of the winding HV, mostly on the first coil, counting from the terminal linear transformer [6] .

It should be noted that during all considered cases of switching operations and disturbances, the level of external overvoltages at the terminals of the windings of the unit transformer was moderate and did not exceed 1.69 as above. in relation to HV winding and 2.1 as above on the LV winding. The overvoltage limiters installed on the input terminals of the transformer, selected in accordance with the rules, practically do not protect the windings from internal overvoltages, because the level of external overvoltages is definitely lower than the protection level of overvoltage limiters.

In order to limit the influence of internal overvoltages on the insulation of transformer windings is being improved voltage distribution along the winding is selected higher isolation levels, detuning capacitors or metal oxide overvoltage limiters attached to parts of the windings most at risk. Such a solution can only be introduced during production transformer or during emergency renovation. However, it requires thorough prior knowledge expected voltage exposures that may occur in the transformer winding, under specific conditions systemic and localization [7]

VII. References

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