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FERRORESONASE AT OPEN PHASE OPERATING CONDITIONS OF POWER TRANSFORMERS

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Abstract

This paper presents the results of investigation by computer software of the ferroresonce overvoltage on MV network at open phase operating condition with and without connection to earth on source and load sides of distribution transformer.

The results of the study show that ferroresonance overvoltage may be controlled by replacing fuses with circuit breakers on HV side to ensure switching-off all phases. Insertion of resistor or reactor in the neutral of source side and loading the transformer with 5% active load will help in suppressing overvoltages.

Keywords

Ferroresonance, Over Voltage , open Phase operating Condition, Non-linear Inductance.

1. Introduction

The resonance in a linear circuit containing inductance and capacitance is well known phenomena. Analytical description of the transient processes in a linear circuit can be obtained by solving a system of linear differential equations, and the solution is clearly straightforward [1]. The resonant frequency for known values of inductance and capacitance can be predicted. This resonance effect presents one stable operational state, and its effects are mitigated by the system frequency control or by the introduction of pure resistance [2].

When the circuit contains nonlinear elements such as transformer core, the resonance situation is called ferroresonance. In this case, the inductive reactance depends on frequency and the magnetic flux density of the iron core.

In complex three-phase circcuits with nonlinear elements analytical analysis of transient processes are usually impossible. Graph-analytical method of analysis gives qualitative understanding of the possible states of the circuit and the approximate value of the variable voltage on elements for the simple series connection of L and C in a circuit. The analysis of series ferroresonance is given in [1].

It should be stated here that the only practical and reliable way to study ferroresonance phenomena in three-phase networks is by modeling of transient processes by computer software. These softwares should have the possibility of modeling the three-phase magnetic systems with the solution of systems of electrical and magnetic transient processes at the same time. One of these programs is intended for the calculation of transients in arbitrary schemes of electric circuits containing active resistance, inductance, capacitance, voltage and current sources, switches, controlled semiconductor valves, non-linear active resistance of arcs, and complex model of feromagnetic devices. The diagram of magnetic circuit and electrical connection of transformer windings can be arbitrary. The data required for such program are: geometrical dimensions of ferromagnetic cores (length and cross-sections), the location of the windings on the magnetic system, active resistance and number of turns.

The above mentioned program was used to study ferroresonance in distribution network of 6-35 KV. In this paper, the results of investigating the ferroresonance at open phase operating conditions of power transformer are presented.

2. The equivalent diagram

In MV network, where the winding of the step-down transformer is connected in delta-wye to ground, the open phase operating condition may occur as a result of fuse burn-out in one or two phases at high voltage side of transformer, incomplete phase switching on, open and drop wires of overhead lines at load side [3, 4]. As a result, ferroresonance can cause sustained overvoltages which are dangerous for distribution equipment [5].

Fig. 1 represents the equivalent circuit for computer modeling of ferroresonance for noncomplete switching on one of the phases, with open conductor near source or open conductor near load with or without earth connection.

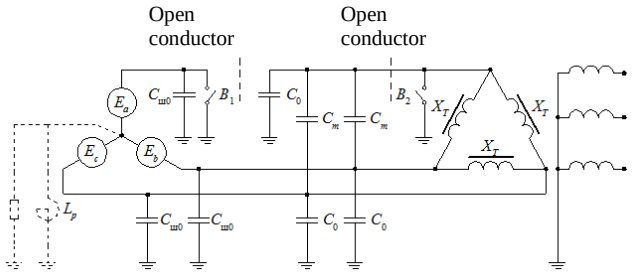

Fig. 1

Open phase operating condition in this case may be combined with one of the phases connected to earth on the source or load side (this is the case where one of wires of the overhead lines is dropped to earth). The LV winding of the transformer 6/0.4 KV is connected in wye to ground and the neutral is unloaded.

3. Ferroresonance overvoltage as a result of unswitched-on phase on source side

In operating condition of two-phase switching of transformer (the other phase is open without connection to earth), the over voltage will reach 4.2 p.u. on one of the HV side of transformer phases (unswitched) when the capacitive current of the supply transformer is equal to 0.7 A.

It is interesting to note that overvoltage on step-down transformer 6/0.4 KV will reach 2.7 p.u. on two phases at small loading condition of transformer (at night condition when the load of transformer is small). That will lead to damage of home appliances and devices.

Fig. 2 shows ferroresonance process at open phase operating condition (switching on of two phases while the other phase is open and connected to ground on HV side) of 6/0.4 KV, Δ / Y to ground, 1000 KVA transformer, when the capacitive current of the network is equal to 15A.

It was found that insertion of reactor in the neutral of the transformer on the supply side will eliminate ferroresonance overvoltage when open phase operating condition occurs without connection to earth.

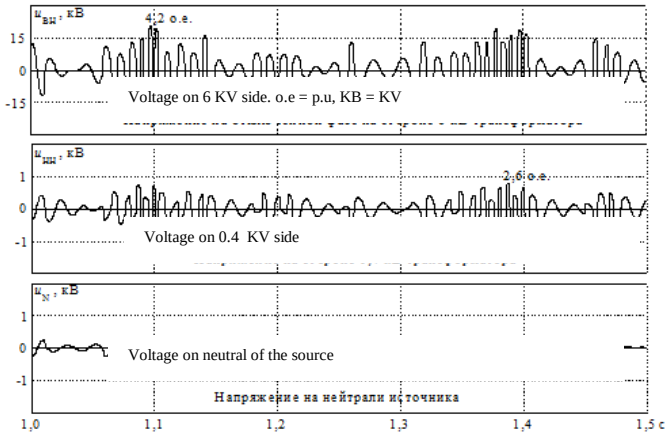

Fig. 2

If the unswitched on phase is connected to earth (switch B is closed in Fig. 1), which is a limit case, over voltage appearing as a result of ferroresonance will not differ from the case discussed above. The only difference is that insertion of reactor in the neutral will not eliminate overvoltage, because the current path will consist of non-linear inductance of the transformer and capacitive to earth in point of earth connection (switch B is closed).

In both cases, the insertion of resistor in the neutral of source supply will not affect the ferroresonance overvoltage. The most important factor in this case will be the loading of transformer at LV side. If the transformer is loaded with active load equals to 0.01 of its rated capacity the overvoltage as a result of ferroresonance will disappear.

4. Ferroresonance overvoltage as a result of unswitched-on phase on load side

In case of open phase operating condition on load side with connection to earth (refer to fig.1, where switch B2 is closed), ferroresonance overvoltage of 5 p.u. will appear on source side, while overvoltage of 2.9 p.u. will appear on load side. In this case overvoltage will appear also on the neutral of source supply. Monitoring of insulation by using an indicator of $3V_0$will indicate such a fault, but the large value of overvoltage (even for seconds) will damage voltage transformer and distroy the insualtion of the network. On of the effective measures to be taken in mitigating overvoltage will be insertion of active resistance in the neutral of power source.

Fig.3 shows ferroresonance process and overvoltages on source, load sides of transformer, and neutral of power source for 6/0.4 KV, Δ / Y to ground, 1000 KVA transformer, when capacitive current of the network is equal to 15A.

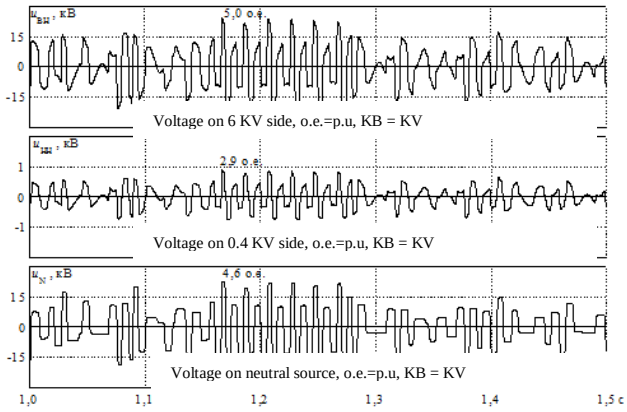

Fig. 3

The results of investigations and computer simulation show that certain measures should be taken to ensure that overvoltage as a result of ferroresonance is controlled and mitigated to safety levels. It is recommended to apply the following measures:

a. In order to avoid such open phase operating conditions it is recommended to protect the transformer with circuit breakers instead of fuses, specially for networks with high capacitive currents, or to make sure that all phases on the source side will be opened in case one of the fuses burns out.
b. The dangerous results of ferroresonance overvoltage in case of open wire on load side with drop-out to earth may be avoided if we insert a resistor or raector in the neutral of source supply.
c. Ir is recommended to connect permanently active load on the load side of transformer (0.4 Kv side) in the value of 5% 0f the rated capacity of transformer.

Conclusions

Open phase operating condition with and without connection to earth on source and load side of distribution 6/0.4 KV transformer were investigated by computer simulation.

In both cases a dangerous overvoltage as a result of ferroresonce will appear which might damage voltage transformers, insulation of the network and home appliances.

It is recommended to use circuit breakers instead of fuses on HV side to ensure interrupting of three phases in case of unswitched one of the phases. It is also recommended to insert resistor or raector in the neutral of source side. Also, the transformer must be loaded with active load, which is not less than 5% of rated transformer capacity. current with transformer parameters such as voltage impedance and rated current.

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