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## Protection of VTs against harmful effects of ferroresonance VT Guard Pro / VT Guard Pro-D



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### Technical background

Ferroresonance is a phenomenon usually characterized by over-voltages and very irregular wave shapes and is associated with the excitation of one or more saturable inductors through capacitance in parallel or in series with a nonlinear inductor. The saturable inductor is usually present in the form of an instrument transformer, power transformer or reactor which contains an iron core.

Ferroresonance of single-pole insulated transformers in an ungrounded network is one of the most common ferroresonance cases. Depending on the supply voltage, capacitance and inductance the oscillation can be either periodic (harmonic, sub-harmonic or with fundamental frequency) or aperiodic. The rated power of VTs is usually very low due to their metrological, rather than power supply function. Nominal primary currents in the transformer winding are typically of the order of single milliamps (at several up to tens of kilovolts). The so-called ferroresonance phenomenon can occur when VTs are connected phase to ground in an ungrounded network. Currents can occur that exceed nominal values by orders of magnitude, risking damage to the VTs.

There is an over-voltage factor of the VT that can in some cases reduce the risk of ferroresonance. According to the IEC standard the rated over-voltage factor is  $1.9 \times U_n / 8h$ . A higher rated over-voltage factor shifts the operating point towards lower flux values of the voltage transformer. It results in smaller sensitivity of the transformer to some kind of transients usually

initiating ferroresonance. Another option is the use of a damping resistor in the open-delta connection of auxiliary windings of the three individual voltage transformers (VTs). It is a simple solution that is mostly used, but it is not fully efficient in all cases. In many cases the resistance needed to efficiently damp ferroresonant oscillations should be very small but on the contrary draw too much current from the VT in the case of a simple network asymmetry, causing excessive load to the VT. Furthermore, such damping resistor is connected permanently to the VTs, which may affect of earth-fault protection, due to voltage drop in open-delta configuration, caused by the damping resistor.

All of the disadvantages mentioned above could be covered by one intelligent device called VT Guard Pro, which enables the application of damping with variable resistance, allows setting the voltage threshold and cooperates with protection functions by having the possibility to set a time delay for burden connection.

The ferroresonance phenomenon

The resonance of a circuit containing an inductance and a capacitance is a well known physical phenomenon. The simplest forms of this are series and the parallel resonant circuits Fig. 1.

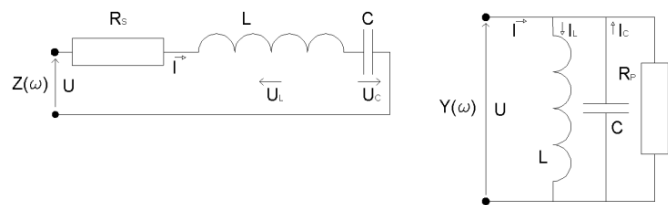


Fig. 1 – Series and parallel resonant circuits

In the series circuit, the equivalent impedance is the sum of the impedances of the individual components:

$$Z(\omega) = j\omega L - j\frac{1}{\omega C} + R_s$$

In the parallel resonant circuit the equivalent admittance is the sum of the admittances of the individual components:

$$Y(\omega) = j\omega C - j\frac{1}{\omega L} + \frac{1}{R_p}$$

The resonance pulsation is

$$\omega_r = \frac{1}{\sqrt{LC}}$$

in both cases.

At and near this frequency in the series circuit, voltages across the capacitor and the inductance can reach values that exceed the source voltage significantly. In the parallel circuit, it is the currents through these components that are similarly amplified. Such extreme values can damage the equipment if no remedial action is taken.

For known values of  $L$  and  $C$ , the resonant frequency can be predicted. Resonance related hazards can be avoided by maintaining an appropriate safety margin from the power supply frequency.

In the so-called ferroresonance phenomenon, however, resonance frequencies are more difficult to predict. The phenomenon occurs when the magnetic core of an inductive device is saturated, making its current-flux characteristic non-linear, see Fig. 2. Because of this non-linearity, resonance can occur at various frequencies.

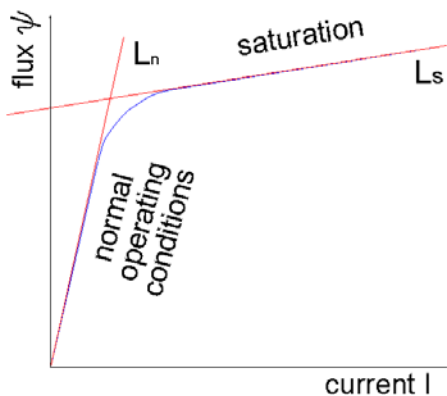


Fig. 2 – Non-linear characteristic of and inductive component with a saturable magnetic core.

In practice, ferroresonant oscillations are initiated by momentary saturation of the core of the inductive element

as a result of switching operations, for example. The effects of such resonance are further aggravated if damping is insufficient.

**Currents can occur that exceed nominal values by orders of magnitude, risking damage to the VTs.**

In many cases of non-transient resonance involving a saturated inductive element, some nodes in the equivalent network circuit are electrically floating (or connected to the fixed potential points through very high impedances). Such a situation is illustrated in the network of Fig. 3.

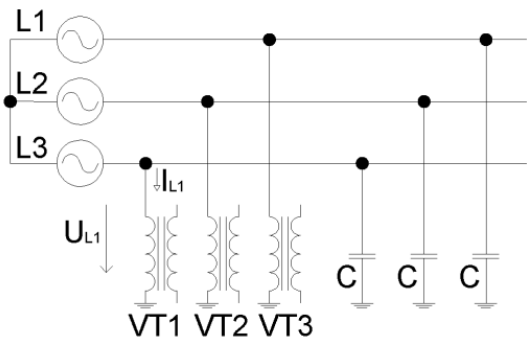


Fig. 3 – Ungrounded MV network with three single-phase VTs connected phase-to-ground

Although ferroresonance can also be initiated in other situations (e.g. capacitive coupling between parallel lines, ferroresonance between the VT and the power transformer's internal capacitance or single-phase disconnection in grounded networks) the configuration shown in Fig. 3 reflects a typical unearthed distribution system with single-pole VTs.

Despite that fact that the first publications on the ferroresonance phenomenon appeared at the beginning of the 20<sup>th</sup> century, no reliable criteria on the risk of ferroresonance have been formulated to this day. No universally applicable mitigation methods exist other than a damping resistor connected to the open-delta auxiliary windings of the three individual VTs.

**The compact design of modern voltage transformers and the high quality of the magnetic material (low losses) makes damp-ing difficult.**

Risk to equipment

Under normal operating conditions, the primary currents in the MV voltage transformers (VTs) are typically well below 10mA. In ferroresonance, the core of the VT operates in the deep saturation region and primary currents can reach amp values. The two orders of magnitude difference between normal and ferroresonant conditions leads to thermal damage to the primary winding if not appropriately damped.

The compact design of modern voltage transformers and the high quality of the magnetic material (low losses) makes damping difficult. The resistive load must have a low value to dissipate sufficient oscillation energy. Too small a value, however, draws too much power from the VT when a sustained zero-sequence voltage occurs (e.g. due to a ground fault that is not cleared), and so overloads the VT thermally. Selecting the right resistance is therefore crucial.

**Computer simulations and experiments show that in many cases the resistance needed to damp ferroresonant oscillations is very small. Such a resistor would, however, draw too much current from the VT in the case of a network asymmetry.**

**VT Guard Pro**

A new and unique protection approach has been developed by ABB, the VT Guard Pro device, which can effectively replace the conventional linear damping resistor. VT Guard Pro is connected to the open-delta circuit of three VTs as shown in Fig. 4.

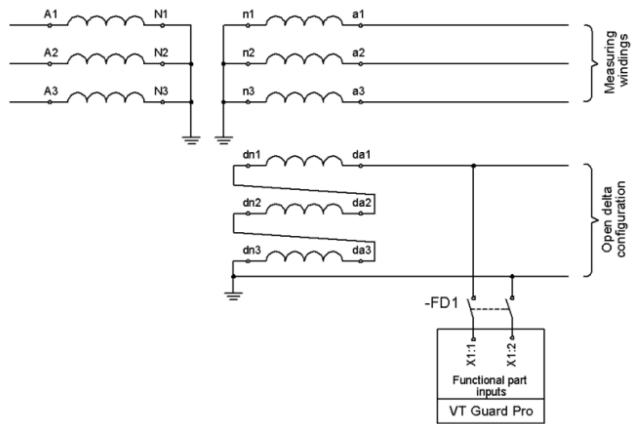


Fig. 4 – Connection of VT Guard in open delta configuration

Due to its small size and low power dissipation, it can be located in a low-voltage compartment of the MV switchgear and placed on a conventional DIN-rail, see Fig. 5.



Fig. 5 – VT Guard Pro, placed in LV switchgear compartment

When zero-sequence voltage occurs due to a natural system unbalance under normal operating conditions, the

device acts as a very high resistance and so does not drain power from the VTs. When the zero-sequence voltage exceeds a predefined threshold level, the device is activated and damps the ferroresonant oscillations with low ohmic burden within a small number of cycles.

**In case of a network ground fault condition the burden is periodically switched on and off so as not to overload the VTs.**

**VT Guard Pro – D** has in addition the diagnostic features which allow self-checking of its internal circuits. The device status is indicated visually and by auxiliary contact, which may be used in cooperation with superior systems (e.g. protection relays with binary inputs).

Moreover, both versions (VT Guard Pro and VT Guard Pro – D) have enhanced function which allows setting following parameters:

- threshold voltage (voltage when the device is activated and starts to damp ferroresonant oscillations)
- time delay (delay of connection of the low ohmic burden after device activation = exceeding threshold voltage)

**Threshold voltage setting allows using the VT Guard Pro devices in networks with different parameters (natural asymmetry). Time delay settings enable delaying damping action and provide better cooperation with earth-fault protection connected in open delta configuration as well.**

**Network tests of the VT Guard Pro**

The functional tests have been carried out in a network with three connected VTs according to Fig. 3. The VT Guard Pro was connected to an open-delta configuration of auxiliary windings of three VTs. Phase L1 has been directly connected to earth in order to simulate an earth-fault defect. Ferroresonance phenomena have been detected after clearing the earth-fault. The waveforms obtained in a circuit with VTs, are presented in Fig. 6. The figure is time-wise divided into following sections:

- 1) Normal state – Line to ground voltage ( $U_{L1}$ ) & current ( $I_{L1}$ ) have nominal values. Open-delta voltage ( $U_N$ ) shows natural network asymmetry.
- 2) Ground fault – phase L1 is connected to ground, primary voltage of corresponding VT ( $U_{L1}$ ) drop to 0V and open-delta voltage ( $U_N$ ) significantly increases, thus indicating earth fault.
- 3) Permanent ferroresonance – the ferroresonant oscillations were triggered by transient phenomena that originated from clearing the previous earth-fault state. Voltage  $U_{L1}$  and current  $I_{L1}$  significantly exceed nominal values and exhibit frequency of oscillations different from the natural network frequency.
- 4) Damped ferroresonance – VT Guard Pro activated and ferroresonance damped. System returns to the natural network operation.



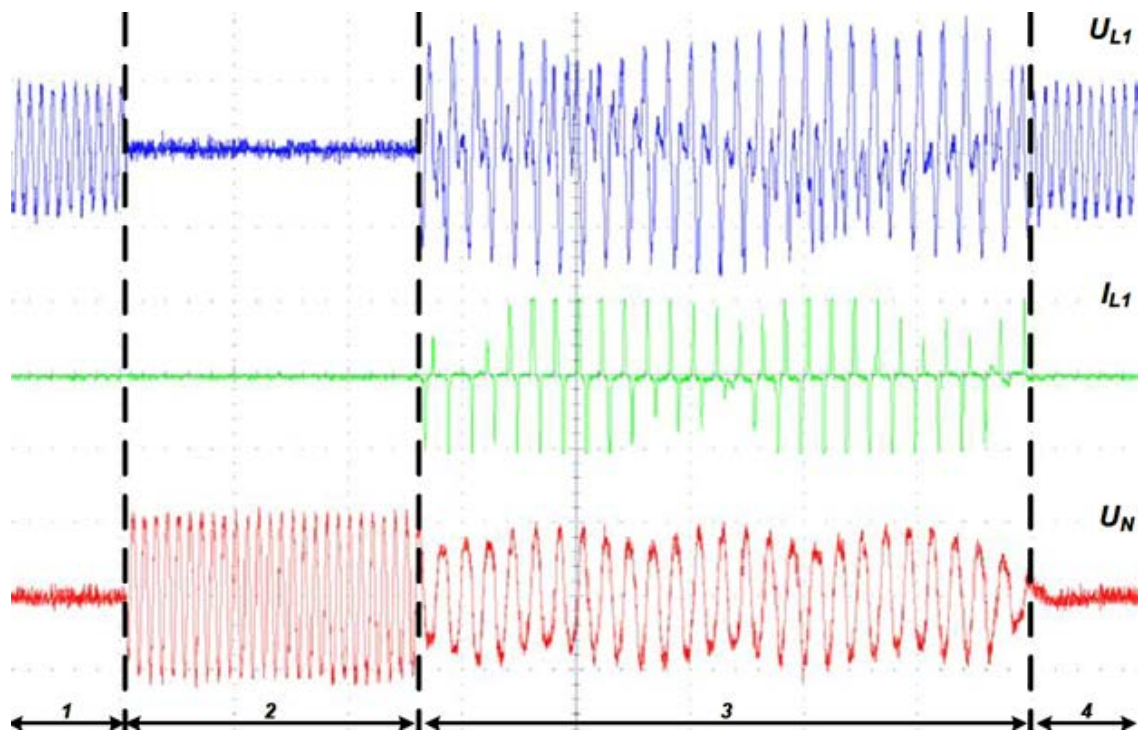


Fig. 6 – Functional test of the VT Guard Pro with three VTs  
 1- normal state, 2- ground fault, 3- permanent ferroresonance, 4- damped ferroresonance

#### References:

[1] Piasecki W., Florkowski M., Fulczyk M., Mahonen P., Luto M., Nowak W., Preiss O.: Ironing out ferroresonance - Ferroresonance prevention in MV voltage transformers, ABB review 4/2005.