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CONTROL OF FERRORESONANCE

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PURPOSE AND SCOPE

This Technical Guidance Note (TGN) provides recommendations on how to recognise and prevent ferroresonance on the National Grid transmission (Electricity) system. Where elimination through network design is not practicable, acceptable techniques of ferroresonance control are indicated. This document supports the policy on ferroresonance PS(T)020 and implements the recommendations made in TR(E) 398 for power transformers, quadrature boosters (QB), shunt reactors and electromagnetic (wound) voltage transformers.

PART 1 – GUIDANCE

1 BACKGROUND

Ferroresonance (FR) is a system over-voltage phenomenon involving the sustained electromagnetic interaction between an iron core reactance and shunt capacitance. Whilst the scenario can be avoided through design, a number of preferred economic circuit arrangements give rise to the condition. During the 1960's and 70's the high cost of technology led to the rationalisation of circuit breakers in the system. This drove the development of the mesh substation and the complex and integrated design of the UK transmission network including remote end switching and mesh DAR. The absence of circuit breakers, design complexity and double circuit overhead lines, provides an ideal environment for ferroresonance to occur. This non-linear condition can arise on the transmission system during network switching and can affect the security of the network.

Ferroresonance can ultimately destroy equipment such as, wound voltage instrument transformers and switchgear. Whilst, a number of WVTs have failed, so far it has not directly caused the failure of power transformers but is believed to be a contributing factor in the eventual failure mode, by exposing the unit to electrical and mechanical stress during the ferroresonance condition. The complexity associated with ferroresonance prone configurations increases the likelihood of over-voltage stressing (typically 60% of over-voltage failures are due to switching). This guidance document considers two scenarios:

- a) Power transformer ferroresonance (including QBs and shunt reactors) - units connected to double circuit overhead lines,

- b) Wound electromagnetic voltage transformer (WVT) ferroresonance – units connected to isolated sections of busbars (with circuit breaker grading capacitors).

Technical report TR(E) 398 'Implications of Ferroresonance on the Transmission System' expands on the asset damage and system complexity brought about through ferroresonance activity.

2 DEFINING FERRORESONANCE

Ferroresonance is the stochastic relationship between voltage and current which is dependent not only on frequency but also on a number of other factors such as excitation voltage magnitude, initial transformer magnetic flux and point on wave of the initiating switching incident.

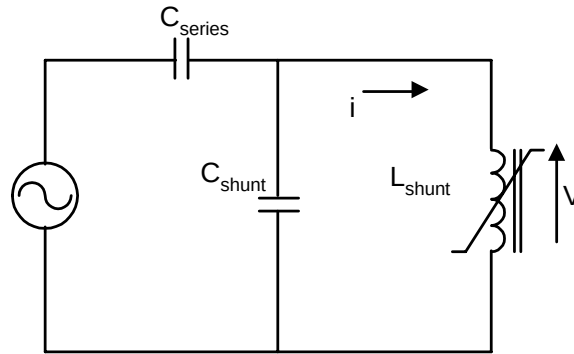


Fig. 1. Circuit elements necessary for ferroresonance

A circuit with the potential for ferroresonance requires a transformer (more specifically the non-linear inductance of the transformer magnetic iron core), some shunt capacitance (un-energised line or section of busbar, and an excitation source to sustain the oscillation (adjacent energised line or energised grading capacitor).

The shunt contribution is provided by the line to ground capacitance or the busbar to ground capacitance. The coupling can be obtained from the parallelism of a double-circuit overhead transmission line, the capacitive grading across an open circuit breaker or the capacitive and inductive coupling of a multi-limb power transformer. This is illustrated in Figure 1.

Ferroresonance is characterised as a temporary over-voltage condition with spiky current waveforms, typical of transformer magnetisation and core inrush.

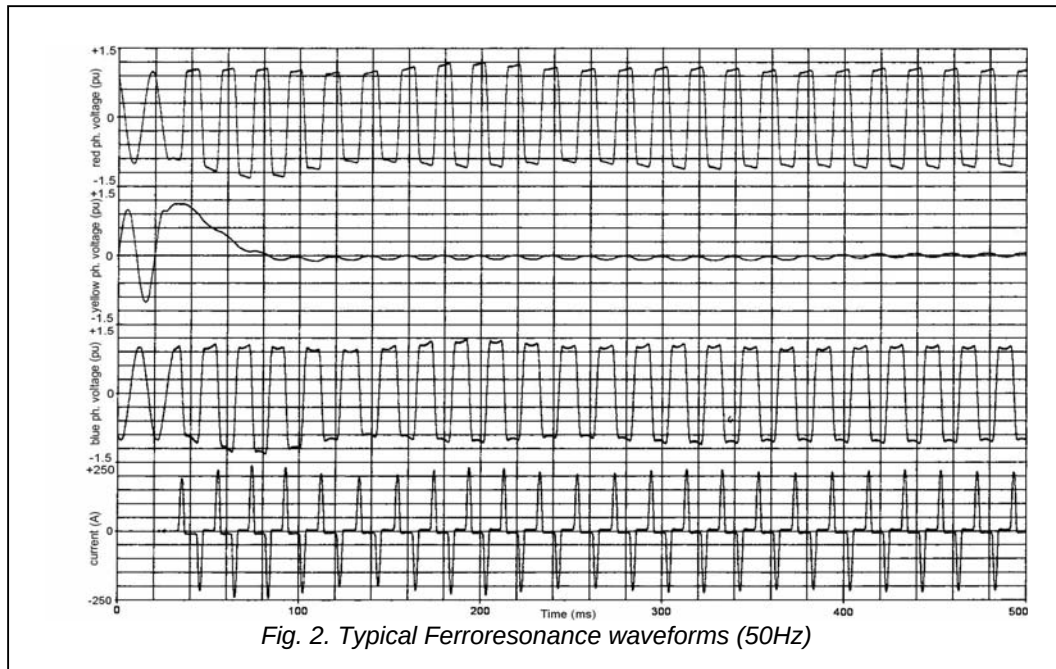


Fig. 2. Typical Ferroresonance waveforms (50Hz)

Ferroresonance should not be confused with linear resonance, which occurs when the inductive reactance is equal to then capacitive reactance. In linear resonance, the current and voltage are linearly related in a manner, which is frequency dependent.

3 FERRORESONANCE DETECTION

Power transformer ferroresonance results in 50Hz or lower frequency square voltage waves (see fig 2.), the more onerous conditions produce overvoltages above 1.2p.u. The voltage waveform is accompanied by inrush currents of amplitudes up to 350A_{pk}. The transformer itself will produce deep grumbling noises uncharacteristic of the normal 100Hz hum. The Buchholz may also start to gas as a result of internal overheating.

A Type Registered three phase ferroresonance detection relay is available. The operating principle of this relay type is to measure the voltage unbalance of **all** 3 phases. In practice, ferroresonance in a 3 phase power transformer will produce oscillations at both fundamental (50 Hz) and sub-harmonic frequencies. The ratio of the peak values of the voltages on the three phases will be approximately 1, -1/2, -1/2.

- a) The absolute peak voltage values are proportional to the ferroresonance frequency, 1p.u. or higher for 50Hz and 0.33 pu for 16⅔ Hz etc.
- b) Ferroresonance detection looks for a voltage ratio of 2:1:1, as would be theoretically expected for the worse case. However, in practice the voltage ratios may vary away from 2:1:1, especially for the 16⅔ Hz case.
- c) In some situations this may lead to the detection systems failing to recognise ferroresonance. Thus, the relay cannot be relied upon to reliably detect sub-harmonic modes of ferroresonance.

The back up relay is the SGT Bucholtz alarm, which will detect transformer oil gassing. However, this requires damage to have already occurred so is not acceptable as a preferred detection method.

Consideration should be given to the use of capacitive voltage transformers (CVTs) for ferroresonant voltage measurement. A CVT is designed and tested to give an accurate measurement of a sinusoidal voltage around 50 Hz. The accuracy of a CVT will drop if the signal frequency drifts away from 50 Hz. Furthermore, consideration must be given to the square wave response of the CVTs, and the sensitivity of the ferroresonance detection relay. The “low” frequency, sub-harmonic, ferroresonance produces very low voltage magnitudes which the relay may not pickup. However, the power transformer magnetic core will still saturate, with the consequent increase in thermal duty of its insulation material.

The detection of ferroresonance on non-three phase systems (typically traction supplies) is difficult and unreliable and requires special attention. TGN 175 provides additional guidance.

The following schemes are used to control ferroresonance when it is detected and are specified in NGTS 3.24.17 ‘Ferroresonance suppression’:

F1 Ferroresonance detection and alarm only scheme. There is no automated action. The system operator will need to initiate action to remove the condition.

F2 Ferroresonance detection and subsequent alarm (as in F1) followed by either lockout of the local delayed auto-reclose (DAR) function or inhibit switching or remote DAR.

F3 Ferroresonance detection and alarm and DAR inhibit (F2) followed by the automatic opening and closing (flapping) of a specially tested disconnecter to quench the FR. This is only initiated by a protection operation.

F4 Ferroresonance detection and alarm and DAR inhibit (F2) followed by the automatic closing and opening of a ferroresonance quenching earth switch to quench the FR. This operates for both manual and protection operations.

4 POWER TRANSFORMER FERRORESONANCE

This section provides recommendations on how to prevent ferroresonance occurring for new connections, system modifications or asset replacement where power transformers, quad boosters and reactors are installed. The Flow chart in Appendix A identifies the possibility of power transformer ferroresonance and the recommended solution. The following sections expand on the decision process.

Ferroresonance can be fully prevented in two ways. Ideally, by preventing it occurring in the first instance or secondly isolating the SGT from the condition once its detected.

The relative cost and complexity of circuit breakers is substantially less than the equipment installed the 1960's and 70's making the original drivers for mesh substations and remote end switching no longer valid. In addition, the network is becoming more complex, so wherever practicable, ferroresonance should be designed out or avoided through system configuration. Where this is not achievable an automated quenching scheme must be employed and secondary quenching made possible.

4.1 Control Through System Design & Configuration

The general policy is to install where practicable, a circuit breaker (or switch with **proven** strength and capability) between the HV terminal of a transformer and the overhead line which is providing the excitation source. This will prevent damage from over-voltages by removing the need for remote switching, reduce operational complexity and prevent ferroresonance occurring. The breaker will provide a safe and reliable disconnection of the transformer from the feeder.