TB 980 JWG A3/A2/A1/B1.44

Limitations in Operation of High Voltage Equipment Resulting of Frequent Temporary Overvoltages

The Technical Brochure of JWG A3/A2/A1/B1.44 deals with limitation in operation of high voltage equipment resulting of frequent temporary overvoltages (TOV). It classifies the duration and recurrence of the TOV in the electrical networks. For exemplary TOV parameters, the lifetime of the insulation for various equipment is evaluated. Apart from insulation ageing caused by TOV further possible limitations for equipment need to be considered. In typical applications, the network conditions are less severe as specified in standards. Hence, the recurring TOV can be typically mastered. Nevertheless, this is not a general rule. The users need to verify their specific network conditions for low-risk management of recurring TOV.

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Introduction

The distribution and transmission networks integrate huge amounts of renewable generation sources and experience changes in the load behaviour of the consumers. These changes impact the voltages in the grids. In numerous countries, frequent power-frequency temporary (short and long duration) overvoltages (TOV) are observed. Although the high-voltage equipment is tested according to equipment-relevant standards (e.g. IEC 62271 series), with this type of overvoltage, it is not clear whether recurring TOVs or longer-duration TOVs are also covered by these tests. Moreover, today, the maximum operating voltage (U_m), which is mostly equal to rated voltage U_r, is used as a design value to which numerous tests (e.g. slow-front, fast-front overvoltages) are referred. Frequent TOVs with amplitudes above U_m increase the probability of switching actions and short circuits at the time of an instance of TOV. Consequently, tested overvoltages referred to Um are lower as at the time of instance of TOV ($U_{TOV} > U_m$). For this reason, there is a need to consider in more detail the different limitations in applications of various equipment that may be exposed to TOVs.

Analysis of the network conditions and TOV characterisation

The network conditions that can lead to power-frequency TOVs have been listed and categorised in a novel way. "Long-duration power-frequency TOV" are longer than 2 s and typically require manual or automated action of the system operator. The resulting amplitudes can lead to 5 % - 10 % above Um. The "short-duration power-frequency TOV", typically in a time frame of 0.2 s to 2 s, depends on the regulation and automatic control of the voltage level. The last category is TOVs originating from some resonance phenomena in the grid. The comparison of different network connection and operation codes shows that there is no unified approach for the specification of the TOVs. They are rather dependent on the network type, country strategy and voltage levels. The survey conducted among TSO's and DSO's shows that the long-duration power-frequency TOVs are a reality phenomenon today. For the purpose of this work, the average or typical voltage surge equal to $U_{TOV}=1.05\times U_m$ has been defined.

The lifetime reduction of the equipment insulation subjected to continuous U_{TOV} can be very significant for most of the equipment considered. Hence, the increase of the continuous voltage and introduction of new voltage levels is not supported. The lifetime of the equipment insulation exposed to recurrent TOV should be considered. As long as the expected reduction in lifetime is minimal and acceptable from an asset management perspective it can be considered manageable.

Apart from insulation ageing, additional equipment-specific applications should be considered because TOV can restrict the application area of considered equipment.

Main Findings for considered equipment

Current and voltage instrument transformers

The TOV will lead to an increase in the short-circuit current. It should be verified by the user if the resulting current level remains below the tested values. Moreover, the TOV increases the risk of triggering ferro-resonance oscillations with inductive VTs. The application of designs with air gaps or with additional damping elements needs to be verified or considered. In particular, for GIS applications where the ratio of capacitance relation is unfavourable concerning triggering ferro-resonance oscillation, the resistive damping ability of VT is crucial. Finally, inductive VTs are frequently used for the discharging of non-grounded disconnected network parts. TOV will increase the amount of energy that needs to be discharged. Hence, the thermal ability of VT to withstand this stress should be verified. Low-power instrument transformers (LPITs) are not affected by ferro-resonance oscillations. The dielectric insulation coordination and ageing are subjected to the same criteria as the CTs and VTs.

Generators in power plants

In normal operation conditions, it is very unlikely that the generator will experience TOV since they typically deliver reactive power that reduces the voltages in their design range. Should the demand be higher than the generator can provide, the TOV at the connection point can be exceeded. However, it can be assumed that this is a rare emergency event. However, for generators connected to the network via a transformer with an off-load tap-changer, accelerated ageing due to frequent TOV can be expected. In the latter configuration, the excitation voltage of synchronous machine is used for voltage control. The TOV increases thermal losses, and more frequent thermal changes will accelerate mechanical and electrical ageing. The speed of this phenomenon depends on the duration and frequency of the TOV.

Switchgear

Generally, circuit breakers are tested with voltage surges related to U_r, which is equal to or higher than U_m. Thereby, no double voltage stresses, as the presence of TOV and TRV after fault, are considered by the circuit breaker test standards. This brochure has found that TOV events can have very long durations, so the failures at the time instance of TOV ought to be considered probable. In such a case, the reference for the voltage test would have to be changed from U_m to 1.05 × U_m (not currently defined by any standard).

However, the circuit-breakers are able to perform switching operations at the time instance of TOV events when the network/application parameters are more appropriate as tested according to standard.

For this reason, the users should verify the network parameters compared to the tested voltages, and thus, if circuit-breakers are likely to be subjected to long-duration TOV. The following checks have been considered as reasonable:

- Amplitude of short-circuit current is smaller as I_{SC}
- Pole factor of the network is smaller as 1.24 in solidly earthed systems
- Is the distance between resulting TRV, RRRV, PFRV and tested values appropriate?
- Check if the time constant of the network is lower than tested (typically 45 ms in EHV)
- I”k1E is at least 5 % smaller than I''_{k3} (in case of the nominal k_{pp})
- Check the voltage factor for the capacitive switching.
- Consider the Ferranti phenomenon for long OHL or OHL with cable sections
- Transformer fed faults may produce very high TRV and RRRV
- Consider application of controlled switching for transformers and reactors

Frequently, the involvement of the manufacturers can help to assess the ability of the circuit-breaker to perform its function at TOV time instance. The circuit-breakers are frequently tested with additional user-specific tests, which are more severe than those in the standards.

The GIS disconnectors in an old application require special attention because the TOV increases the VFTO (can exceed originally tested values). The users should verify this parameter if the GIS may be exposed to TOV. As a remedial measure, the switching of small capacitive currents with a disconnector can be avoided.

Cables

The used so far ageing models for cables are well understood and widely used. The test procedures performed in the pre-qualification phase allow one to conclude that the whole cable system (insulation, joints, terminations) will only insignificantly (if at all) age due to the application of power-frequency TOVs, as considered in this brochure. Should the cable be permanently loaded with a nominal current, a reduction of the nominal current of 0.5 % or an application of dynamic cable current rating can be considered.

Transformers

Generally, transformers are tested with much higher voltages, as considered for TOV. Hence, it can be expected that TOV as such will not influence the dielectric performance. However, frequent TOVs, especially caused by the higher inrush currents, overfluxing of the core and more frequent operation of the tap-changer, can speed up ageing processes. More intensive PD can also be generated. It should be considered, that the noise emission levels from the transformer at the instance of TOVs will be higher, which may be crucial for some urban areas. Transformers are tested for specific short-circuit currents. It should be kept in mind that the short-circuit current is higher at the time of instance of TOVs.

Surge arresters

For an operating voltage of 1.05 × U_S, no thermal overload of the surge arrester is expected. In reality, there can be parts of the network that are operated temporarily with a voltage of 1.05 × U_S and TOV due to earth faults and/or load shedding. These overvoltages must be taken into consideration for the surge arrester sizing. In such cases, the surge arrester needs to absorb more electric energy, which need to be included in the basic design. In some network parts, the preloading of the surge arrester before performing the voltage test is assumed. In networks where single events are expected, this test practice can be used.

Recommendations

For users – the considered and evaluated equipment is frequently capable of withstanding recurrent TOVs with acceptable risks. However, this is not the general rule, and the applications of the equipment need to be checked according to the above-mentioned dependencies and requirements. Involving the manufacturer and end users in the assessment process can prevent potential problems without having to take any remedial action at all.

For standardisation – the definition of the temporary over-voltage in the present insulation coordination standards requires an update. It should be clearly stated that today's standard tests performed cover some voltage stresses only. The permanent or recurrent operation at TOVs can lead to accelerated equipment ageing and should be named as such in the standards.

Outlook

Facing the large structural changes of distribution and transmission networks, the limitation in equipment application caused by recurrent TOV, discussed in brochure, can be overlapped by additional new phenomena as increasing short circuit ratio or non-power-frequency interactions between power electronic interfaced devices. The effort for appropriate management of complex energy networks is expected to increase in future. Due to the complexity, the users will further require technical guidance in application of high voltage equipment.