A NEW TOOL FOR LIVE, ON-SITE, HV INSTRUMENT TRANSFORMERS ACCURACY CHECK

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ABSTRACT

Metering accuracy is of essence in interconnections between Distribution and Transmission networks, in order to ensure market correctness; all components of measurement chains, from instrument transformers to meters, must therefore be calibrated. Instrument transformers role is crucial, since even tiny errors in voltage or current measurements, accumulated over a long period, will lead to a significant financial unbalance in energy trading. Up to now, instrument transformers are usually calibrated at the Manufacturer's along their operation range, keeping into account a wide range of standard conditions; after service installation no more accuracy checks are usually carried on, due to both technical and economical reasons: traditionally available calibration equipment and methodologies require service removal of instrument transformers. Recent studies and test campaigns however demonstrated that instrument transformer accuracy may deteriorate with ageing; moreover, as happens for meters, to all Parts involved should be granted at any moment the right and the possibility of verifying the accuracy of all components of measurement chains. Thanks to improvements in transducer technologies, appropriate metrological and live-line working procedures, new equipment tools purposely developed, in Italy was developed a methodology allowing a live, on-site verification of instrument transformer accuracy. This check can be performed without service outages and intervention on the busbar configuration, by means of live insertion of standard transducers; signals coming from standards and from equipment to be checked are compared, using a purposely developed software tool, keeping into account and getting round the possible presence of harmonics, random noise and other harsh environment disturbances. This approach is a powerful tool for on-site evaluation of the transformer accuracy, allowing identification of the voltage and current transducers, including burdens and signal cables, which no longer comply with the prescribed accuracy requirements and thus must undergo further laboratory investigations.

INTRODUCTION

Transformations in electric systems, and particularly market liberalisation, force the re-examination of concepts and praxis up to now taken for granted.
In vertically integrated utilities, voltage and current measurements in transmission and distribution networks interconnections aimed prevailingly to grant the correct and safe state of the electric system. In liberalised market, measurements undertake a new meaning, since economical transactions between parts involved in electricity trading are based on metering. A poor measurement quality could have economical repercussions, since even tiny errors accumulate over a long period.
A periodical check of instrument transformers (CTs, VTs, CVTs) used for metering would therefore be highly desirable from two points of view:

1. recent studies and laboratory tests [1] question transducer metrological features persistence with time not only for CVTs but also for inductive instrument transformers;
2. in order to assure electricity market transparency, all parts involved should be able to check at any time the whole energy measurement chains and not only, as now happens, low voltage components (meters, connection cables…).

Up to now technical, operational and economical burdens tied to a re-calibration of HV instrument transformers were so high that they could not be taken into consideration.
With traditional methods, a calibration would at least require service removal of instrument transformers and the consequent outage and unavailability of the relevant busbar: the operation would be in most cases too onerous.
Reference measurement systems and procedures for on-site, live, check of instrument transformers accuracy were therefore purposely developed: thanks to live working methods and tools adoption, the prototype equipment can be installed and the accuracy check carried on in substations without impact on HV network or busbar assets.
The prototype equipment such as the developed procedures and tools were tested in Rondissone (Italy) substation.

MEASUREMENT SYSTEM

The verification of instrument transformer accuracy is carried on by comparison with standards, as happens with traditional methods. In the present case, a split-core Rogowski coil and a capacitive-resistive voltage divider are used as reference transducers [2, 3].

Current measurement

The reference current transducer is a high-precision split-core Rogowski coil which enables the user to measure currents from 40 A to 4000 A.
A Rogowski coil is a special mutual inductor commonly used to measure transient and alternating currents. This coil is an amplitude linear device and does not suffer from saturation.
The proper selection of materials, the use of proprietary methods of coil design, fabrication practices and testing assure the very low position and temperature sensitivity values needed for the calibration of in-service CTs, until recently not achievable even with rigid, non-opening coils.
For live measurements within a 400 kV switchgear station, the bare coil must be provided with additional screening, fixations etc. and is therefore enclosed in an external housing assuring mechanical stability and electrical shielding, necessary for the use in high voltage environment.

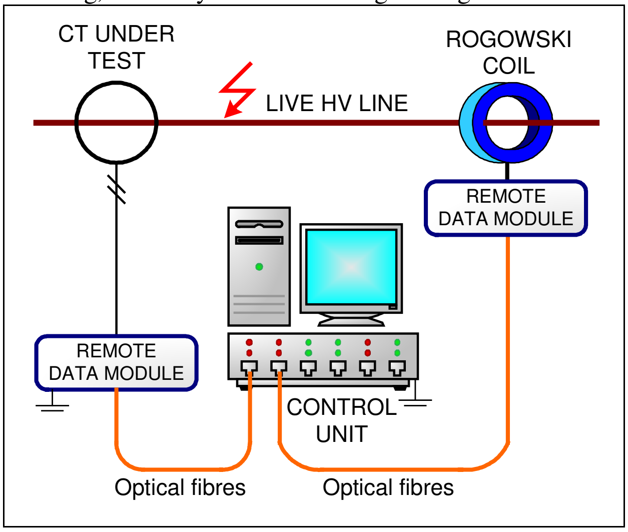

Figure 1 - The current measurement system

The coil can be easily opened and then safely clamped on a single conductor or on a twin bundle, according to solutions commonly used in the Italian grid substations.
In order to allow installation of the reference Rogowski coil, live working "bare-hand" techniques are used. The installation is performed by a man bonded to the live conductor, on a tower insulated from earth and provided with a crane for coil lifting at conductor height.
The current transducer at high voltage potential is connected to the local unit at ground potential by two optical fibres for data transmission and energy transfer.
The effectiveness of this connection methodology was demonstrated during field tests performed installing the Rogowski coil on a 400 kV line in Rondissone HV substation.

Voltage measurement

The reference voltage transducer consists of a two stage resistive/capacitive divider. At 400 kV the divider works with two stages on the high voltage side, and below 220 kV with one stage only.

Figure 2 - The Rogowski coil

Live-line voltage connection of the voltage divider to the HV network is more challenging compared to the Rogowski coil installation, since a galvanic contact and consequent absorption of a load current is needed to ensure proper divider operation. Special methodology and devices allowing a "smooth-step" connection were developed.
Steady-state value of the load current absorbed by the reference voltage divider is relatively low. However it is not negligible and any arcs generated during connection and disconnection operations may reach significant lengths in high voltage systems. Low capacitive current values (500 mA at least according to relevant IEC standards, even more in common practice) are usually interrupted and established using disconnectors. An insulated pole of an opened disconnector can be easily connected to the HV network, since capacitive charging current in this case is really negligible and such operation can be carried out using common live working distance techniques, insulating rods and ropes and a special cable reel device installed on the disconnector pole.
A solution foreseeing a voltage divider connected to a disconnector kept open, connected at no load with HV network and closed to allow measurement required anyway some improvements, to avoid capacitive divider long-term accuracy worsening due to arcs generated during every opening and closing: a current limiting resistor with a suitable resistive value is therefore inserted in series between the voltage divider and the disconnector during the

insertion process. A remote controlled integrated rotary disconnector can short-circuit the current limiting resistor during measurement. The rotary disconnector is mechanically connected with a rotating insulator column which is used also as mechanical support for the current limiting resistor.

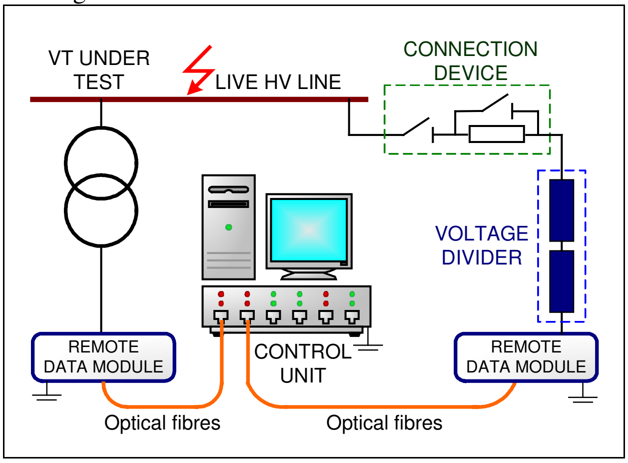

Figure 3 - The voltage measurement system

For measurements at the lower voltages, the upper part of the divider can be removed and the insulator column has to be replaced by a shorter one matching the height of the lower part of the divider All insulators are hollow core composite insulators filled with low pressured SF_6, to maintain the overpressure necessary to avoid the increase of humidity. This solution makes the equipment suitable for frequent assembling, disassembling and shipping operations, avoiding all problems tied to ceramic insulators fragility and weight.

The whole equipment (voltage divider and current limiting resistor) stands on a base provided both with wheels for short distance displacements and adjustable parking jacks. Inside the base the electrical control cabinet for the rotary disconnector and for the low voltage dividers as well as the overvoltage protection and the remote data module are placed.

After some preliminary laboratory experiments, this connection methodology effectiveness was demonstrated during field tests performed in Rondissone HV substation, both at 400 kV and at 220 kV.

Data acquisition and analysis system

Voltage and current signals coming from verified instrument transformers and standards are sampled and digitised by remote modules placed in the close vicinity of the transducers; optical fibres allow data transmission to a local module equipped with a data acquisition and analysis system. Data synchronisation is assured by the laser pulses generated by the local module used for remote modules power supply. Voltage and current transformers verification circuit diagrams are shown in Figure 1 and in Figure 3 respectively.

Figure 4 – The voltage divider: 400 kV configuration

Standards manufacturing aspects and data conversion, transmission and analysis system features were defined in order to make the tool suitable also for signals affected by harmonics, up to 3 kHz

Signals analysis and comparison methodology was implemented in a software tool allowing:

- accuracy check time-scheduling, in order to extend the verification to the significant instrument transformer operation range, taking advantage of daily load cycle
- discrimination of signal power frequency component useful for accuracy check from possible presence of harmonics, random noise and other harsh environment disturbances, if any.

Current/voltage signal files generated by data acquisition system are imported and processed by the software in order to perform ratio and phase angle errors calculation according to IEC relevant Standards [4-8] if, ideally, waveforms are sinusoidal, introducing also some tools to take into account typical situations occurring during on-site tests. The software tool evaluates a series of predetermined length-signal segments (typically ten power frequency periods): for each segment, peak and rms values as far as horizontal axis crossing points (signal zeroes calculation) and frequency range spectrum (absolute value and phase) are calculated.

Anyway, on site voltage and current signals are probably affected by noise and distortion. Signal segments are therefore processed using a digital filter in order to attenuate noise; a discrete Fourier transform based algorithm (DFT) is subsequently used to perform signal frequency analysis, allowing ratio and phase angle errors calculation harmonic

by harmonic.
Results are displayed in terms of processed signals spectra and signal peak values such as ratio and phase angle errors are shown in a suitable table.

SYSTEM CHARACTERISATION

Considering the operating range and ambient conditions, a complete metrological characterisation of the system has been almost completed.
Different tests are being performed in order to evaluate the proximity and temperature effects, short and mid term stability and the behaviour of the system in presence of harmonic distortion.
Results of a first test campaign on both the current and voltage measurement system were published in [3]
New results for the ratio and phase angle error of the current reference system (Rogowski coil and data acquisition system) are charted in Figure 5 and in Figure 6.
Those values were evaluated using a standard reference CT, and the test was repeated after some months to check also the long term stability of the system.
Dotted red lines show IEC 60044 0,1 class requirements [4-8] (± 0,1% for ratio and ± 0,15 crad for phase angle error respectively). As it can be seen from the charts the reference measurement system meets the 0,1 class requirements and has a good long term stability too.

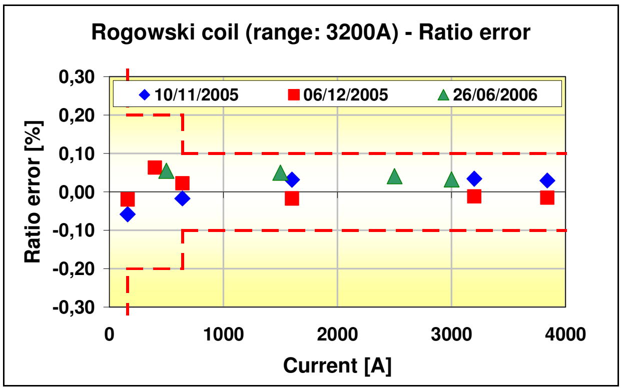

Figure 5 - Rogowski coil: ratio error

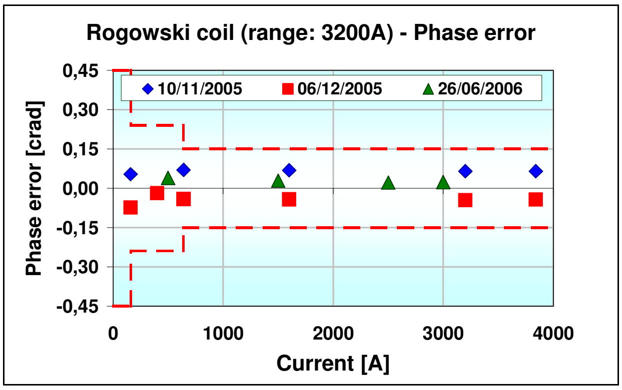

Figure 6 - Rogowski coil: phase-angle error

CONCLUSIONS

As long as new tests are being performed in order to complete system characterisation and to determine its long term stability, further research and engineering activities are currently carried on, in order to simplify and automate voltage divider live connection and Rogowski coil installation, making the whole on site, live accuracy test methodology found not only reliable but also cost effective, with significant advantages for a fair electricity market.

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