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Medium voltage measurements

Tradition dictates, that to measure a voltage in the medium voltage grid (10-36kV), a voltage measurement transformer is needed. A less costly approach, using nearly no space, fulfil the key voltage measurements needs based on capacitive voltage division.

In electronics, a capacitor is a device consisting of two conductors galvanically separated by a dielectric. Applying a time varying voltage to one conductor leads to a displacement of the charge in the other conductor via the electric field generated between the conductors in the dielectric.

The amount of charge depends on the physical configuration and properties of the conductors and the dielectric.

For a simple plate capacitor the capacity is calculated as:

$$C = \varepsilon_r * \varepsilon_0 * A / d,$$

where ε_0 is the vacuum permittivity, and ε_r describes the permittivity relative to vacuum, d the distance between the conducting plates and A the surface area of the plates.

An example is the capacitor used for live voltage indication in elbow connectors. The end plug is made of two metal parts and isolation (a dielectric) in between.

Illustration 1: Capacitive plug

The leftmost part in illustration 1 is attached to the high voltage side as you can see in illustration 2:

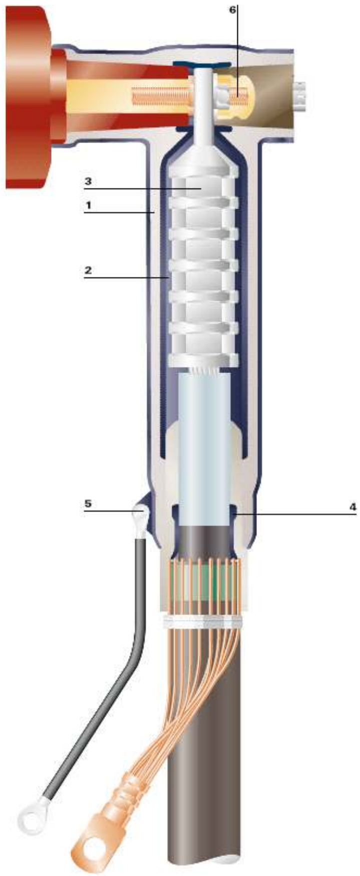

Illustration 2: Elbow connector

The capacity for such a plug is typically 1-2 pF, which is very small. The advantage of the low capacity is the small amount of charge, and sustained current, that can be transferred through a human. Assuming a maximum of 10 pF and a 50Hz varying voltage on a 36kV phase-to-phase line the initial discharge is less than 0.5mJ, and the sustained current thereafter less than 10uA. Both factors are well within what is considered a safe operating environment for humans (assuming that the actual medium voltage is fully shielded).

The voltage division

You can divide voltages by using two or more resistors. In a direct analogue to the resistor, you can divide voltage using capacitors. As stated above, it is safe to use end-plug capacitors to measure directly on the high voltage line. If you use a 1pF capacitor on the medium voltage side and a 10nF capacitor to connect to ground, the output voltage between the capacitors for with a 10.000 V input will be 10.000 / (10nF/1pF) = 1.0V with respect to ground. Such a voltage is very easy to measure.

The frequency response

As the division is made using only capacitors, the voltage division is independent of the frequency. This is an important feature, as we will have an interest in measuring all harmonics in the grid, often including the first 50 harmonics e.g. 50Hz * 50 = 2500 Hz.

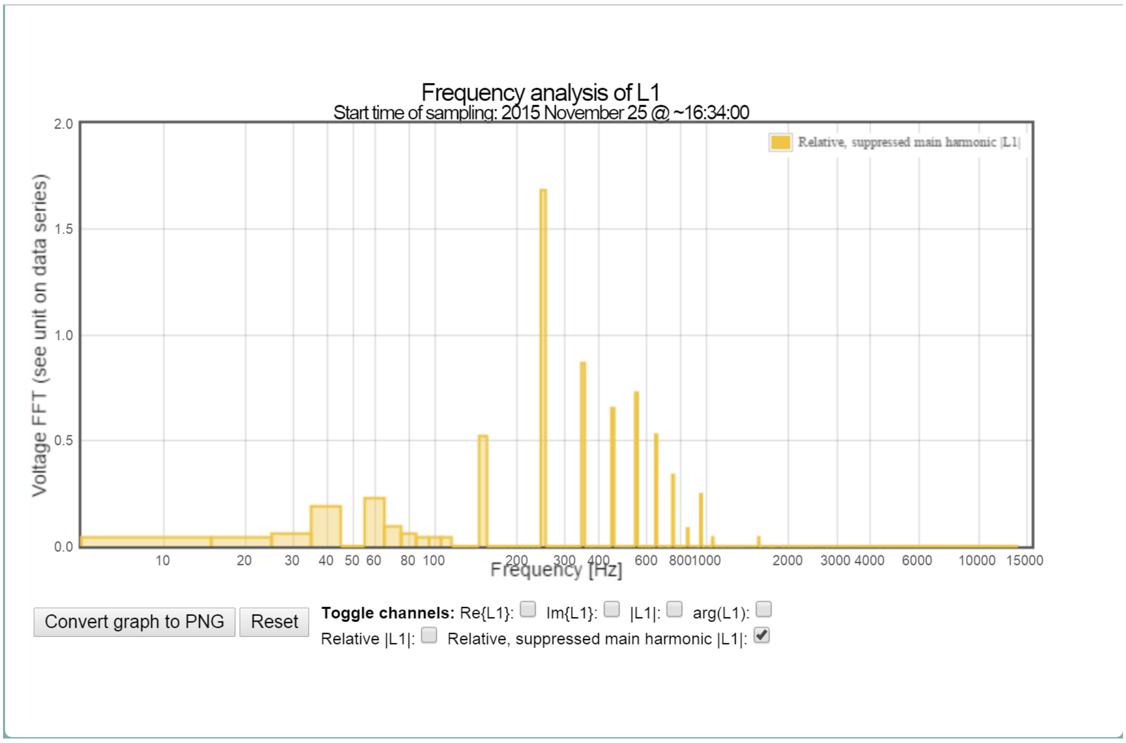

Illustration 3: Harmonics, where the main 50Hz component is suppressed, to better show the harmonics. The unit is as a percentage of the main component.

Precision

As we use a medium voltage capacitor made of two pieces of metal that are placed in a moulding form in the production, some deviations should be expected, typically in the range of a few percent.

The measurements can therefore not be used for metering as metering require much higher precision, like 0.1%.

The relative and repetitive precision is very high as well as the absolute precision obtainable if a device specific calibration is used. For the purpose of operational monitoring of the grid, the uncalibrated precision is better than strictly needed. Applications like frequency analysis (harmonics) and direction of faults, short circuits etc. does not necessitate an absolute precision better that 10%. Evaluation of reactive power losses in the grid will be easy to evaluate, assuming a simple current measurement method is also available.

The null voltage

The best reference for all voltage measurements is the earth. If the installation has a decent earth we can also measure the voltage on the null conductor, if available, even though it should be close to ground potential. For this reason, it makes sense to actually measure on 4 voltages; the 3 phase conductors and the null conductor.

Low voltage measurements
Sometimes it is difficult to get access to a medium voltage capacitor. Then measurement on the low voltage side is also an option. Instead of the 1-2pF medium voltage capacitors, the capacitor value must be much higher, but can also be physically smaller. In illustration 4 a capacitive low voltage connector is shown, where the needed capacitors are integrated in the red CEE connector.

Illustration 4: 400V capacitive connector

Smart Grid
Smart Grid applications for the medium voltage grid, must build on cost efficient sensor solutions such as the capacitive voltage measurement method in combination with transformer less current measurement. This will make it possible to produce small sensors to be placed in both new and existing substations.

Illustration 5: A combined current and voltage sensor. The capacitive voltage input is via the BNC connectors in the bottom.

The next article in this series will focus on 'Internet of Things' in relation to substation management.