USE OF VOLTAGE DETECTION SYSTEMS AS TRANSDUCER – PRACTICAL RETURN OF EXPERIENCE

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ABSTRACT

Voltage Detection Systems are more and more used for additional applications besides their historical use for voltage presence indication for the DNO staff. Equipped with a dedicated system which allows to access and measure the voltage at the middle of the capacitive divider inside it, they could be used as transducers for medium voltage measurements.

Based on preliminary investigations on the accuracy of VDS for voltage measurements and the potential use cases, two concrete applications have been tested at length and yielded mixed results. The use of VDS as a transducer for PMU measurements in MV cabinets is unfortunately not a valid use case due to the accuracy limit of the phase angle measurements, which is an order of magnitude higher than the observed magnitudes. Their use for directional relays phase angle measurements proved however successful and was validated in various test set-ups. This is due to much larger phase angle shifts expected in case of a fault, the limited accuracy of the phase angle measurements thus being high enough in this case.

INTRODUCTION

Voltage Detection Systems (VDS) have been present in the Medium Voltage (MV) networks since decades, but lately their use, previously limited only to the indication of voltage presence, is sometimes being extended to a voltage transducer. Although the accuracy of its measurements can and should be questioned, this new functionality would bring to the Distribution Network Operators (DNO's) a deeper visibility of their grid if connected to a dedicated metering devices.

Concrete applications can also benefit from this pre-installed equipment, without the DNO's having to purchase a lot of expensive voltage transducers instead. Two applications in particular have been investigated: Phasor Measurement Units (PMU's) in MV cabinets and directional relays. The details of the findings are detailed here after in this paper.

PRELIMINARY ACCURACY ASSESSMENT

Investigations on the use of VDS for MV measurements were carried out in laboratory thanks to a dedicated test set-up, which is illustrated in Figure 1. The channels CH1 to CH5 were recorded by a dedicated Yokogawa DL850® metering device.

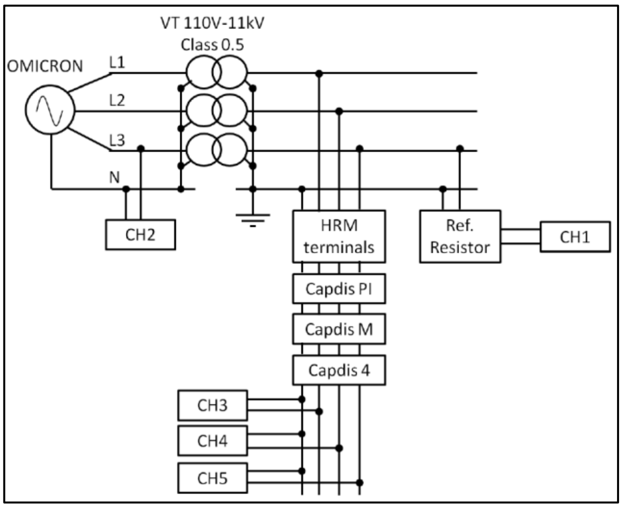

Figure 1: Schematic of the laboratory set-up used for VDS measurements accuracy investigation

The accuracy for harmonics, transients and voltage magnitude and phase angle measurements was estimated. It is worthy to mention that this setup determines the accuracy of the combined system of the VDS and the conditioning box attached (CAPDIS® complete system, as illustrated in Figure 3 and Figure 4).

The results for accuracy depending on the testing scenarios were comprised in the following intervals:

- Voltage RMS [V] : [-2 , 2] %
- Harmonics level [V] : [-1.5 , 1.5] %
- Phase angle [°] : [-1 , 2] °
- Transient rise rate [pu/s] : [0 , 2.4] %

These accuracy results can appear good or bad depending on the application considered for such measurements.

It is worthy to mention that similar measurements have been performed on-site in several DNO's MV cabinets with the objective of an on-site validation of the laboratory tests. The results in term of accuracy were similar to the ones shown here above.

APPLICATION 1: PMU IN MV CABINETS

The use of Phasor Measurement Units (PMU) in Medium Voltage networks is becoming more and more standard, with several concrete applications taking advantage of the additional observability brought by the long-term monitoring of voltage and currents phasors. For more information on the various applications of PMU's in MV networks, the reader can refer to [1].

Although MV substations are equipped with measurement transformer as dedicated MV/LV transducers, when desiring to install PMU's in MV cabinets one is faced with the absence of such transducers. The VDS is thus one possibility for such use case.

As illustrated in Figure 2 to Figure 4, a PMU can be connected to the VDS via a dedicated component such as the CAPDIS-4 voltage conditioning box. Such a component is required because of the exceptionally high impedance of the capacitive voltage divider inside the VDS, which prevents the use of conventional voltage measurement devices such as handheld multimeters due to their low internal impedance in comparison.

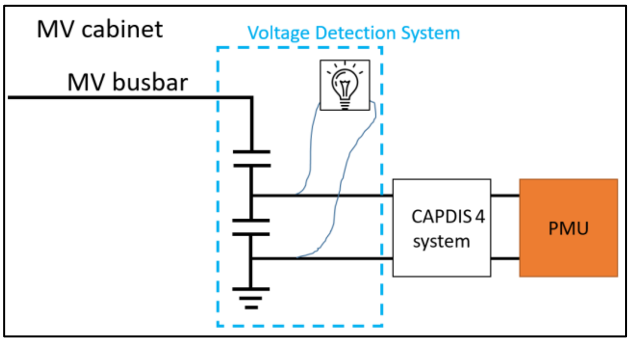

Figure 2: Schematic of the PMU connection to the VDS

When comparing the different sets of data in multiple Proof-Of-Concept (POC) architectures and network simulations via the NEPLAN® software (see [1] for more details), it has been observed that the VDS & CAPDIS-4 transducer induces a phase shift error of the order of about 1 degree. Unfortunately, this error seems erratic, being different from one VDS to the other and also from one moment to the other, thus pointing to a non-linear transducing ratio. A static correction thus seems non-feasible.

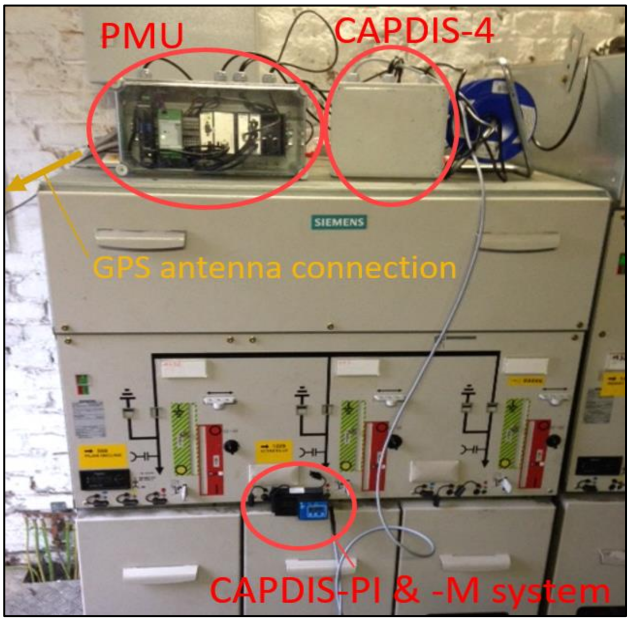

Figure 3: Example of PMU installation in a MV cabinet

Figure 4: CAPDIS-PI & CAPDIS-M system (VDS)

This accuracy limit was quite easily determined since the typical phase angle drop along a MV feeder is around 0.1-0.2 degree, while the measurements indicated up to 1.5 degree of phase angle difference between the beginning and the end of a feeder. The difference was thus quite obvious.

Conclusion of Application 1

The accuracy limit of the VDS & CAPDIS-4 transducer in view of the order of magnitude of the phase angle differences to be observed render this application non-feasible as such. Alternatives for accurate voltage measurements in MV cabinets fortunately exist (see [1] for more details). Using the MV/LV power transformer as transducer can provide better results in term of accuracy, although it remains insufficient in view of the order of magnitude of the phase angle variations to be observed and furthermore it brings an additional requirement for power measurement to monitor the MV/LV power flow. The use of a MV/LV resistive divisor could theoretically improve greatly the accuracy of the phase angle measurement, but it has not yet been tested in the field.

APPLICATION 2: DIRECTIONAL RELAYS

A second application investigated was the use of a VDS as a voltage transducer for overcurrent directional protection in MV substations. This alternative could be economically interesting compared to differential protection, which is quite expensive (price, cost of replacement policies, telecommunication dependence, etc.).

The directional protection requires a voltage measurement on the feeder bundles, but there are generally no measurement voltage transformers at the client side which can be used. Having in mind from the first application REX that the accuracy limit of a VDS in term of phase angle measurement is around 1 degree, one could reasonably hope that it would be largely enough for the determination of the direction of a current compared to the voltage.

Thanks to a laboratory setup, it has been decided to evaluate in practice the performance of a VDS for voltage measurement and its use for protective relays applications regarding different criteria:

- Reliability of the voltage angle measurement
- Capability of feeding several relays
- Phase-shift of the whole voltage measurement
- Stability of the measurement during transients in fault conditions

Reliability

To test the reliability of the voltage angle measurement, a comparison of trip angle values has been done by testing the tripping characteristic of a directional overcurrent protection relay in two different ways:

- Injecting voltage and current directly from an Omicron test set equipment into the relay.
- Injecting current directly from the same Omicron test set equipment and the voltage through an MV cell and a VDS + CAPDIS-4 system (see Figure 5 and Figure 6).

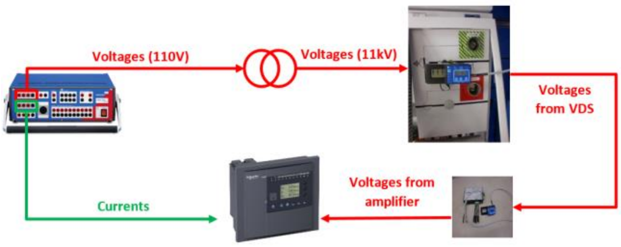

Figure 5: Injecting voltage in the relay through VDS+CAPDIS-4

Figure 6: Test bench used for VDS validation

The results of these tests showed very good performance of the VDS angle measurement, i.e. less than 1.6° for angle error regarding the tripping characteristic set in the relay. It is worthy to mention that this error results from the complete chain of measurement (VDS + CAPDIS-4) and the inner accuracy of the relay itself.

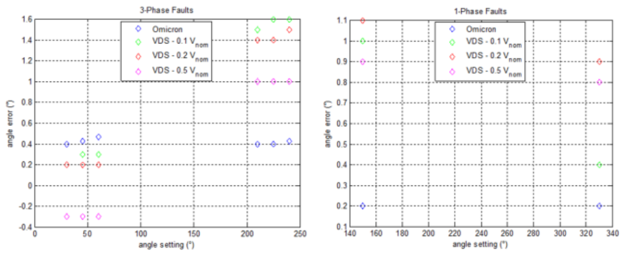

Figure 7: Tests results for 3-phase and 1-phase faults emulation

Capability of feeding several relays

One question that could come in a context of deploying such a solution in the MV-grids is the capability of the VDS to feed several protection relays. This property could be economically interesting for substations where all cells are not equipped with a VDS. To quantify the maximum number of relays that can be fed by one VDS, the burden of common relays has to be taken into account and to be compared with the rated power of the amplifier of the VDS used for signal conditioning (see Figure 8).

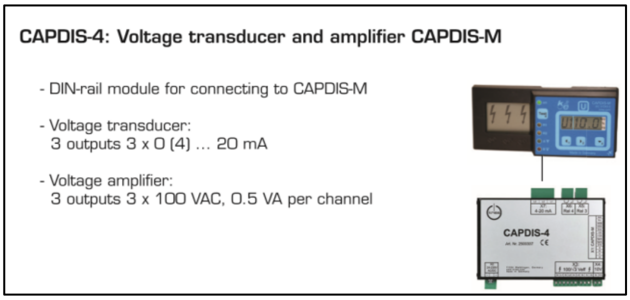

Figure 8: Rated power of CAPDIS-M system (per phase)

The voltage input consumption of a relay depends on each manufacturer. A measurement has been done for some relays in order to challenge the values given in the datasheet from the manufacturers (see Table 1). It can be observed that some datasheet are conservative in their consumption data.

Relay	Consumption in the datasheet	Mesured consumption
Siemens 7SJ64	0,3[VA] à 100[V]	100[V]*0,5[mA] = 0,05[VA]
ABB REF615	<0,05[VA]	100[V]*0,226[mA] = 0,0226[VA]
Micom P127 Alstom	44[kΩ] => 0,2273[VA]	100[V]*2,06[mA] = 0,206[VA]
7SJ82	<0,1[VA]	100[V]*0,5[mA] = 0,05[VA]
SEPAM S80 NPP	<0,015[VA] (pour les S80)	100[V]*150[µA] = 0,015[VA]
SEPAM S20	>100[kΩ] => <0,1[VA]	100[V]*134[µA] = 0,0134[VA]

Table 1: Relays burden comparison

As we can see, the consumption of the voltage input of a relay is really different from one relay to another. We must thus admit that it is not possible to give a quantitative answer to the question of the maximum number of relays fed by the same VDS. Most of the time, more than one relay can be connected to the same channel of the CAPDIS-M (up to 10 in several cases). But for some types, the burden is much higher. This point has thus to be checked for each application in function of the relays to be installed and connected to the same VDS.

Phase shift of the VDS & CAPDIS-4 measurement chain

In order to evaluate the phase shift naturally introduced by the VDS & CAPDIS-4 system without the potential error introduced by the relay, a 3-phase voltage of 230V was injected on the cell's terminals and it has also been measured. At the same time, the voltage output of the VDS has also been recorded. The results showed a global phase shift of 2.7° (see Figure 9). This test also demonstrates the good performances of the measurements for low voltages, although it tends to indicate that such voltage levels induce a lower accuracy.

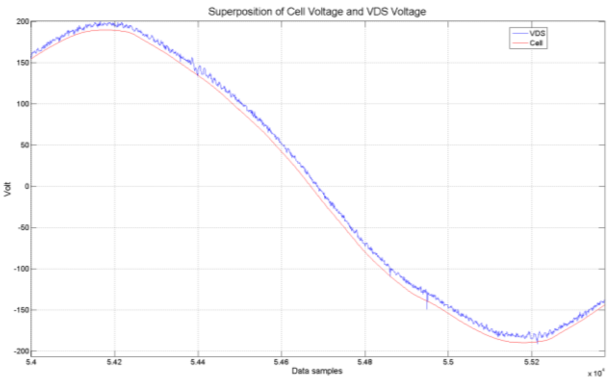

Figure 9: Phase shift introduced by the VDS

We can thus affirm here that the VDS introduces a phase shift that is acceptable for directional overcurrent protection applications.

Stability during fault transients

An interesting point to be analyzed is the behavior of the VDS during transients due to fault conditions. Therefore, a specific test setup has been used (see Figure 10).

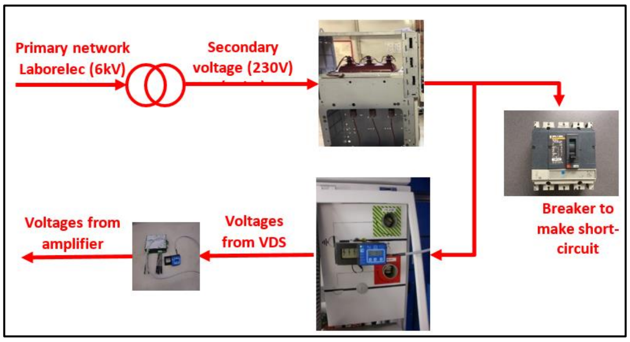

Figure 10: Lab setup for fault transients generation

As shown above, the VDS remains reliable for low voltage measurement. It has thus been decided to perform the tests directly from the secondary side of a transformer 6kV/230V. This 230V voltage has directly been applied on the terminals of the MV cell without any voltage transformer. The terminals were connected to a circuit breaker to generate short-circuits manually.

In order to limit the intensity of the short-circuit current to a range of 200A-300A, a relatively large impedance was placed before the circuit breaker. The reason of that limitation was to prevent the primary network from tripping because of the short-circuit and to keep on measuring.

The tests have been performed for a 3-phase fault and a 1-phase-to-earth fault. The measurements of the voltage on the terminals of the MV cell have thus been compared to the voltage given by the VDS in order to assess the behavior of the VDS during fault transients. Results are shown below in Figure 11 and Figure 12.

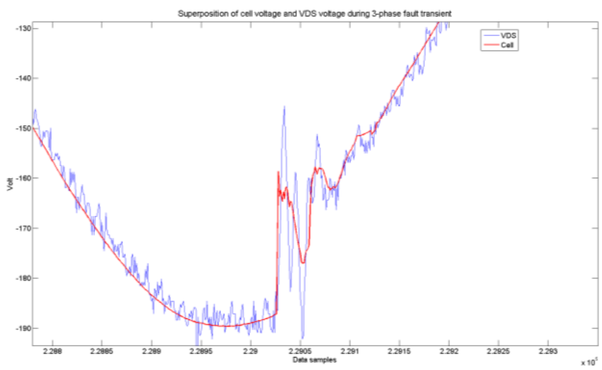

Figure 11: Measurement during 3-phase fault transient (VDS measurement in blue and cell voltage in red)

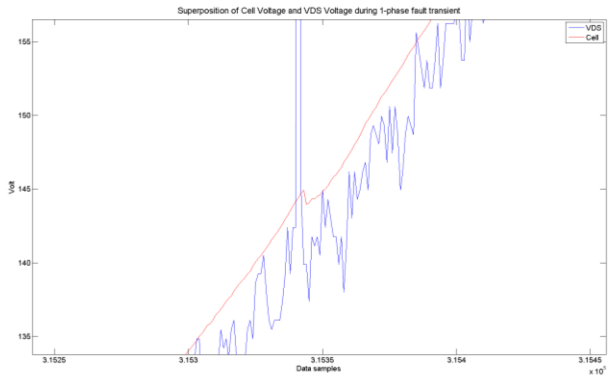

Figure 12: Measurement during 1-phase-to-earth fault transient (VDS measurement in blue and cell voltage in red, large zoom)

As we can see on these figures, the VDS measurement presents a short delay and some oscillations due to the capacitor voltage divider installed in the cell. However, we can appreciate a correct global behaviour of the VDS in terms of waveform and of dynamic response as well.

Conclusion of Application 2

All the tests have highlighted a very good global performance of the VDS for voltage measurement and its use for protective relays applications regarding different criteria. It can clearly been affirmed that the use of a VDS for that kind of application is an interesting alternative. An implementation of this solution on-site as a POC should be the very next step.

CONCLUSIONS

The use of VDS a voltage measurement transducers in MV cabinets has been tested in two different applications. The accuracy limit is of the order of magnitude of about 1-2 degrees for the phase angle measurement, which is high or low depending on the application considered. The return of experience obtained during field tests has proven that VDS can in some cases be used as voltage measurement transducers, while in other cases the accuracy is simply not high enough.

For PMU measurements, it has been determined that the accuracy is far from enough, since a typical phase angle drop along a MV feeder in Belgium is of the order of 0.1-0.2 degree. There is thus a full order of magnitude difference between the measurements accuracy and the observed magnitude. This application for VDS has thus been discarded. More details on PMU measurements in MV cabinets and other possible transducers can be found in [1].

Regarding the use of VDS-transduced measurements for directional relays yielded much better results, as it could have been anticipated. The accuracy is in this case largely enough, since the ultimate goal is to determine whether a current direction with respect to the voltage is fundamentally changed, which would be the case in case of a fault in the protected zone.. Indeed, during a fault, the position in the tripping characteristic is such that we are far from the boundary regions between trip and no-trip zones (i.e. much more than 2 degrees, the demonstrated VDS measurement error). The security and the dependability of the protections should thus be guaranteed with VDS for voltage measurement.

REFERENCES

[1] Q. Antoine, S. Uytterhoeven, L. Pellichero, 2019, "Applications of Phasor Measurement Units in distribution grids - Practical return of experience", C*IRED conference*, paper 232.