INTEGRATION CHALLENGES OF HIGH ACCURACY LPIT INTO MV RECLOSER

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ABSTRACT

This paper presents the lessons learned and challenges of developing an integrated solution of high accuracy Low Power Instrument Transformer (LPIT) into a medium voltage (MV) recloser. The challenges from a design, testing and end user acceptance will be presented. The main conclusion of this paper is that integration of typically separate network components requires careful design choices and testing beyond existing industry standards for LPIT and MV reclosers in order to achieve higher accuracy classes.

INTRODUCTION

With the drive for smarter and smarter grids, next generation network components, which have historically been only protective devices, are being called upon to perform tasks typically performed by multiple devices on a system. These tasks include intelligent diagnostic of the network status, smart network reconfiguration, power quality measurements, all at a high accuracy and reliability. A typical accuracy requirement for these applications is 0.5 class (±0.5 % magnitude, ±6 mrad phase) over temperature range -40° to +65°C with measurement systems made up of LPIT, cabling and controls [1]. Such requirements must be fulfilled by the whole measurement system.

In this light, a deep study of the propagation of uncertainty through the measurement system blocks has been required in order to verify whether the overall accuracy was achievable. It must be noted that uncertainty is due not only to the error contributions from each measurement block, but also to the contribution of other sources like the disturbances on the signal transmitting wires, the cross-talk effect, the temperature-dependent behavior of the wires and the strain capacitances in multiconductor cables.

This paper addresses the evaluation of the metrological performance of the presented MV recloser in presence of disturbances arising during its nominal operating conditions, with particular regard to situations when control and other sensor signals are carried in conductors close to conductors connecting the LPIT with the control unit. This situation occurs when signals are brought from the top to the bottom of the utility pole, from the MV recloser to control, carried by means of multiconductor control cable.

The paper is organized as follows: a description of the MV recloser with high accuracy LPIT, along with specifications of each item; design challenges and unknowns identified along the product's development; a test setup created to simulate real world conditions and effects on the performance of the MV recloser system; experimental results and comments on them. The paper ends with conclusions that can be drawn based on experimental results.

MV RECLOSER WITH HIGH ACCURACY LPITs

G&W Electric Co. and Altea, with the advice of the University of Bologna, developed an integrated solution of MV Recloser and LPIT to achieve high accuracy as a system. Shown in Figure 1 is the network device developed, a G&W Viper-LT MV Recloser with integrated Accusense high accuracy LPITs.

Fig. 1: G&W Viper-LT MV Recloser with Accusense high accuracy LPITs

This device is designed to be paired with a widely accepted recloser control available on the market, a SEL-651R2 Advanced Recloser Control. The MV recloser system is designed to a blend of industry, IEC, and IEEE standards of the individual components.

Accusense is a low power instrument transformer. It is a temperature compensated capacitive voltage divider with a Low Energy Analog (LEA) output and a transformation ratio of 5000:1 [V:V]. The accuracy meets 0.5 class per IEC 60044-7 "Instrument transformers - Part 7: Electronic voltage transformers" [2].

Viper-LT is a MV recloser rated for up to 27kV, 800A, 16kA symmetrical interrupting and reclosing. It is a maintence free, magnetic actuator controlled design. It is designed and tested per IEC 62271-111 / IEC C37.60 "IEEE/IEC High-voltage switchgear and controlgear - Part 111: Automatic circuit reclosers and fault interrupters for alternating current systems up to 38kV" [3].

SEL-651R2 is an advanced recloser control with multiple recloser interfaces, protection elements, automation packages, and communication interfaces. This device is shown in Figure 2. Although not specified by the manufacturer, its LEA voltage inputs are in line with IEEE C37.92, "IEEE Standard for Analog Inputs to Protective Relays From Electronic Voltage and Current Transducers" [4]. These inputs have 1MΩ input impedance, and are designed for voltage amplitudes up to 8V.

Fig. 2: SEL-651R2 Advanced Recloser Control

It can be seen from the system above, that each component is covered by its own IEEE or IEC standard and that there is no standard driving the integration or application of one device using another.

DESIGN CHALLENGES AND UNKNOWNS

The market demands for higher accuracy voltage measurements into MV reclosers led G&W Electric and Altea to develop an integrated solution. To achieve this with commercially available recloser controls, a multi conductor cable, or "control cable", is required to allow for the routing of the signals from the recloser to the control. This control cable length depends on the installation and lengths are typically between 10 and 100'.

This control cable includes current transformers wirings (CTs), recloser status signals (52A/B), magnetic actuator control wires and voltage measurements signals, in this case signals from Accusense LPITs. This concept is shown in Figure 3.

This multi conductor control cable poses challenges to ensure that the high accuracy LPIT voltage output will not be affected by the other signals within the same cable. Its immunity properties must be excellent in order to be immune to all other electric and magnetic disturbances arising in adjacent conductors. The CTs and magnetic actuator signals are especially challenging due to the nature of their signals, listed below:

Current Transformer is integrated into the MV recloser, and has a 1000/500:1 dual ratio. In MV recloser applications rated to 800A continuous and 12kA interrupting, the CT output can be as high as 1.6A continuous and 24A short time during faults.

Magnetic Actuator is the operator of the vacuum interrupter (VI) in the MV recloser, and it is directly controlled by the SEL-651R2 control. During a trip or close operation, the nominal voltage pulse applied to the magnetic actuator is 155VDC, with a peak current of 12A, for a pulse duration of approximately 60 ms.

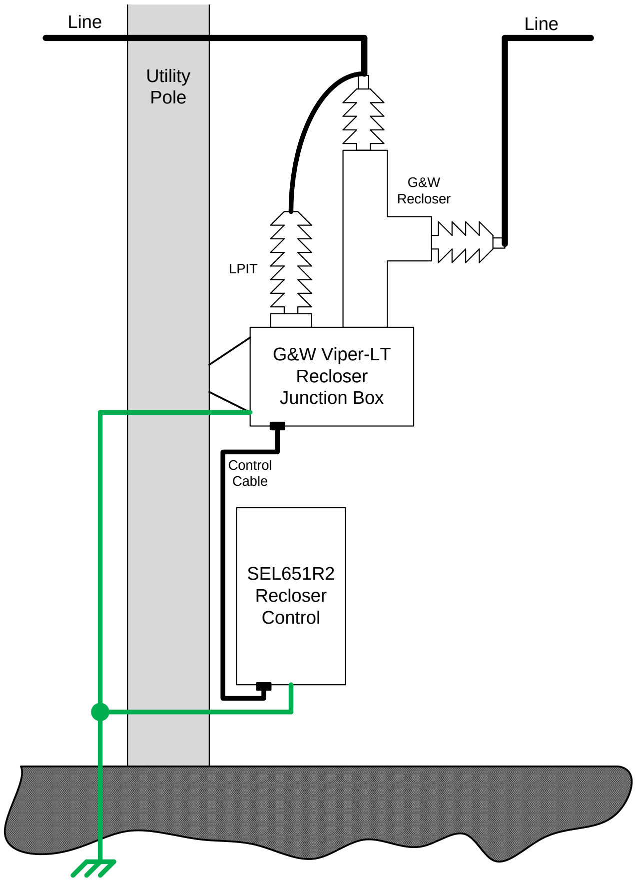

Fig. 3: Typical recloser installation

TEST SETUP

The effect of other signals in the multi conductor control cable on the high accuracy LPIT output required a test setup to confirm that the performance will not be compromised. To achieve this, a test setup was created to simulate an actual installation, using a three phase high voltage source and low voltage current source. A diagram of this test setup is shown in Figure 4.

This setup is particularly challenging because it requires the following, in addition to the LPITs, MV recloser, and recloser control:

- Adjustable three phase high voltage source with voltage regulation.
- Adjustable three phase current source with adjustable phase angles and current regulation.
- high accuracy voltage transformers to allow for phase angle references.

The created test setup allowed for testing the effects on high accuracy LPIT (Accusense) using short (10') and long (100') multi conductor control cable lengths, in the following setups:

- Effect from CT during nominal load current conditions of varying magnitudes and system power factors
- Effect from CT during fault current conditions of varying magnitudes and fault types
- Effect from magnetic actuators during trip, close, and reclose operations

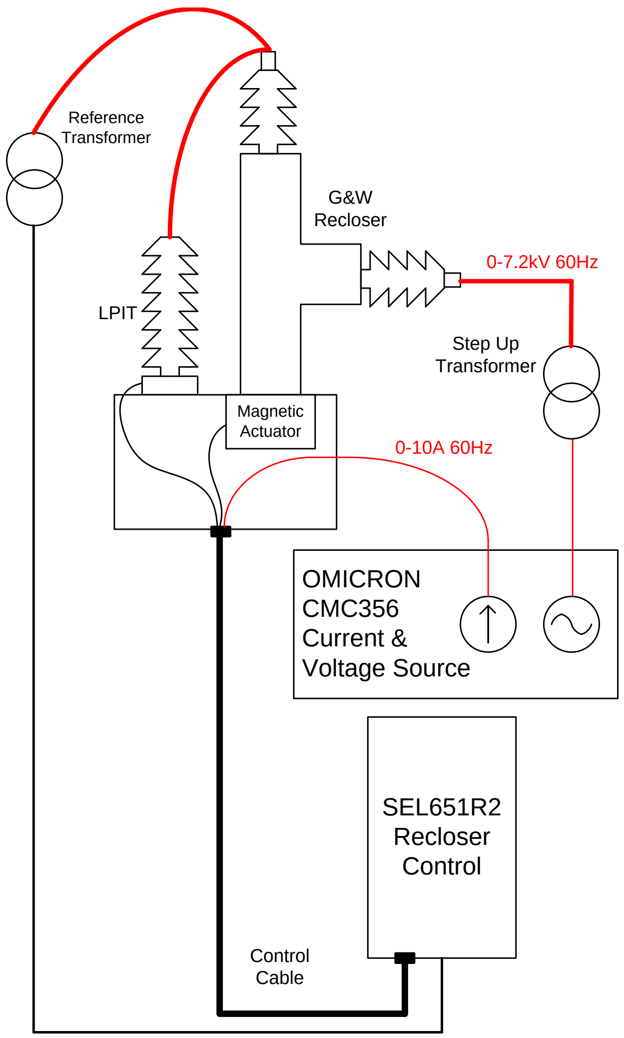

Fig. 4: Diagram of test setup created (Note: only one of the three phase system shown)

It should be noted that the test setup was created and designed for G&W Electric Co. Viper-LT with SEL-651R2. Other MV reclosers would require modifications to the test setup. This is an example of the challenges of performing testing at a system level. A Standard addressing such test procedures is still missing and is going to become necessary and of paramount importance in the near future due to the massive usage of LPITs in modern power networks.

SYSTEM CALIBRATION & SIMULATIONS

Before each performed test, a preliminary test has been carried out on order to calibrate the whole system made by Accusense LPITs, cable and Control. In particular, the voltage from Reference Voltage Source has been applied to both the reference transformer and the recloser. The magnitude and phase errors have been evaluated confirming that the whole system featured 0.5 accuracy class under normal operating conditions (no currents on the CT output conductors and no voltage or currents on the control conductors.)

The evaluation of errors that will be reported in the following has been performed according to the rules reported in the Guide to the expression of Uncertainty in Measurements, GUM [5]. In detail, the SEL-651R2 performed 100 readings for each test. This way the effect of random contribution to measurement uncertainty resulted filtered out. It has been verified that the standard uncertainty affecting the mean value of both magnitude and phase errors could be considered negligible with respect to the error values.

In order to also verify that the error values resulted consistent with what expected and no systematic errors were introduced in the procedure, a theoretical approach reported in [6] has been applied. This approach allows for evaluating the combined uncertainty in case of two items of the measurement chain connected in cascaded configuration. In the particular case the Accusense LPIT represented the first item while the cable represented the second one. As an example, Fig. 5 shows the simulation results for the ratio error.

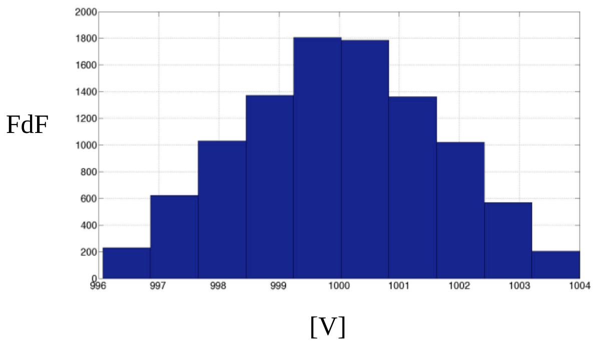

Fig. 5: Simulation results: frequency distribution function (FdF) of the instrument readings (SEL-651R2), rated voltage =1000V

The reference voltage was 1000V; the accuracy class for the Accusense LPIT was 0.5 and the cable had an effect on the ratio of 0.2% (as verified in separate tests). According to [7,8] two random variables with uniform distribution between ±0.5% and ±0.2% for the Accusense and cable, respectively, have been generated and a Monte Carlo simulation was run.

The mean value represents the estimate of the instrument (control) reading; the spread of the results is representative of the ratio error according to different ratio errors of the Accusense LPIT and cable. The frequency distribution is symmetrical. By considering the

95% of confidence level for the measurement results, the associated confidence interval is found to be in the range [996.9 – 1003.1] V. The combined standard uncertainty is then 6.2e-3. The conclusion is that the experimental values of the ratio error were expected to lie inside +/- 3.1e-3 with respect to the ideal case (zero ratio error). Similar considerations have been performed for the phase error evaluation.

EXPERIMENT RESULTS

The test setup was used successfully to determine the effect of the CTs and magnetic actuator on the LPIT performance. All testing was performed at 60Hz 3Φ unless otherwise noted.

Effects of CTs During Load Currents

During this test, the applied voltage was 4200V and the injected current was 1.6A. The phase angle was adjusted from +90° to -90° in 15° steps. The results are shown in Table 1.

Table 1: Results for effects of CT during load currents

Control Cable Length	Maximum Errors	
	Magnitude (%)	Phase (°)
Short (10')	0.005	0.01
Long (100')	0.1	0.06

The magnitude and phase errors using short (10') cable are considered negligible. Using a long (100') cable the errors increased as the phase angle increased, with the maximum errors at ±90°

Effects of CTs During Fault Currents

During this test, the applied voltage was 7200V and the injected current was adjusted up to 10A secondary. The number of phases with injected current was adjusted to 1Φ, 2Φ, and 3Φ phases. The results are shown in Table 2.

Table 2: Results for effects of CT during fault currents

Control Cable Length	Maximum Errors	
	Magnitude (%)	Phase (°)
Short (10')	0.01	0.01
Long (100')	0.27	0.17

The magnitude and phase errors using short (10') cable are considered negligible. Using a long (100') cable, the errors increased as the injected current and number of phases increased, with the maximum errors at 10A 3Φ phase.

Effects of Magnetic Actuator During Trip and Close Operations

During this test, the applied voltage was 7200V and the MV recloser was issued trip and close commands to interrupt and apply the high voltage to the LPIT. High accuracy voltage transformers were used as reference measurements during these operations.

The SEL-651R2 was used to capture event files which were analyzed for this test.

Short Control Cable (10') Results

The event files are shown below for the trip (Figure 6) and close (Figure 7) operation. Measurement errors by the SEL-651R2 have resulted to be negligible in either operation.

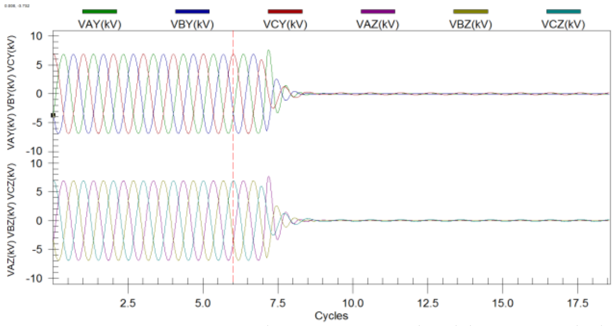

Fig. 6: Trip operating using 10' control cable. Top axis is reference measurement using 0.1 class PT. Bottom axis is high accuracy Accusense LPIT output.

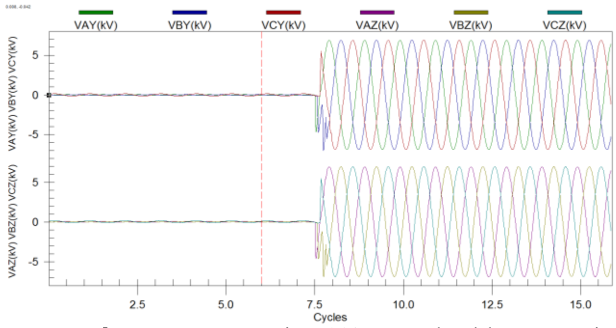

Fig. 7: Close operating using 10' control cable. Top axis is reference measurement using 0.1 class PT. Bottom axis is high accuracy Accusense LPIT output.

Long Control Cable (100') Results

The event files are shown below for the trip (Figure 8) and close (Figure 9) operation. Again measurement errors by the SEL-651R2 have resulted to be negligible in either operation.

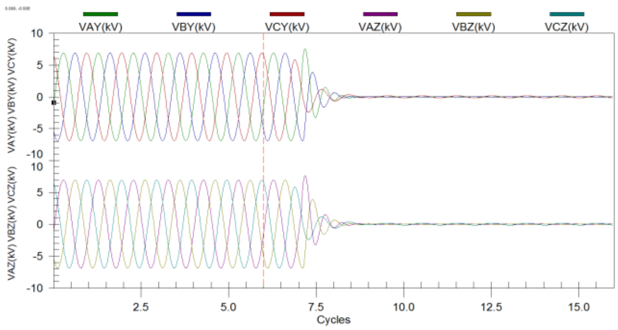

Fig. 8: Trip operating using 100' control cable. Top axis is reference measurement using 0.1 class PT. Bottom axis is high accuracy LPIT output.

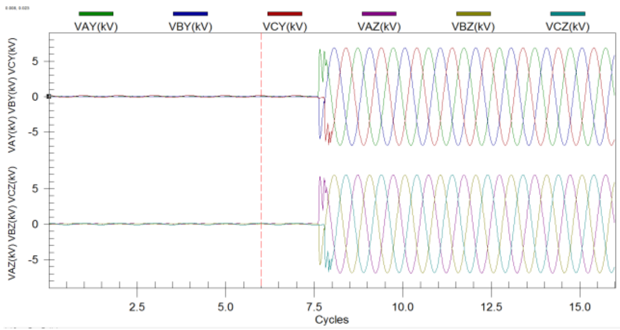

Fig. 9: Close operating using 100' control cable. Top axis is reference measurement using 0.1 class PT. Bottom axis is high accuracy LPIT output.

CONCLUSIONS

This paper presented an in depth investigation and analysis of the challenges of a high accuracy LPIT (Accusense) integrated into a MV recloser. Experimental results have shown that in extreme situations of cable length and fault current levels, the LPIT performance is influenced by the current transformers and magnetic actuator operation, but with careful design considerations it remains within published accuracy classes for the LPIT.

From this work, two main conclusions can be drawn. The first is that care must be taken into design choices by manufacturers and system integrators of equipment. At present there is no Standard in the industry that addresses the requirements of testing LPIT when integrated in the system so manufacturers and/or system integrators need to run validation testing above and beyond existing Standards. Typical design and construction of components including cables and junction boxes may or may not be adequate for higher accuracy systems depending on the requirements. Devices designed per existing Standards intended for simple "plug and play" may have unintended performance when integrated into a system.

The second conclusion is that to achieve a better accuracy class than 0.5 per IEC 60044-7 in an integrated design is extremely challenging and would require major design changes.

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