# RELIABLE DISTANCE PROTECTION

## Get precise line parameters with the CPC 100 + CP CU1

Distance protection and impedance-based fault location on overhead lines and power cables is being used at utilities all over the world. The $Z_1$ positive-sequence impedance and $Z_0$ zero-sequence impedance are significant characteristics of the protected line which must be understood precisely in order to make the relay decide whether to trip or not to trip with reliability. Sending out the line crew requires accurate knowledge of the fault location in order to keep the outage short. Therefore, fault locators that also depend on accurate line parameters are being used.

### Measurements or calculations?

Line parameters can either be measured or calculated, based on the geometry of the conductors and soil properties. When calculating line impedances, multiple simplification steps are taken which do not apply in the real world. Therefore, the results are often not precise enough. In particular, line-to-ground impedances, and therefore $Z_0$, are influenced by the physical characteristics that are present, such as metal pipes or neighbouring cables in the ground. This is why they are not sufficiently accurate when calculated. Furthermore, it is assumed that the soil has uniform resistivity which is usually not the case due to different soil properties in different layers of soil. However, a measurement reflects all factors and obtains true values.

Therefore, Anchorage ML&P, a utility in Anchorage, USA, has started to measure line impedances to verify and optimize distance relay parameterization. Although Anchorage ML&P uses line differential protection for its primary form of transmission line protection throughout its system, its backup protection is distance protection.

In May 2018 a 138-kV overhead line with a length of 4.4 mi / 7.1 km was measured. Overhead lines in Alaska are usually not equipped with a ground wire, as lightning is not a common occurrence. This means, that the entire fault current in the event of a single-line-to-ground fault (SLG fault) returns via soil and therefore via a path with unknown properties.

### Multi-functional test system

For the measurement, Anchorage ML&P used the CPC 100 as a multifunctional main unit which generates frequency variable test signals and measures current and voltage by applying digital filtering for effective noise suppression. This main unit was combined with the CP CU1 accessory, a coupling unit which ensures galvanic isolation between the line under test and the main unit. Additionally, the CP GB1 Grounding Box was used which comes with surge arrestors capable of diverting high fault currents in case of unexpected over-voltages from the line side.

Although, Anchorage ML&P originally obtained the CPC 100 + CP CU1 test system in order to verify the effectiveness of its ground grids by means of measuring the Ground Potential Rise, Step & Touch Potentials and Point-to-Point resistances, it saw the verification of its transmission line impedances as a benefit to the test system.

### Precise measurements

Seven loop impedances are being measured in order to determine the $Z_1$ positive-sequence impedance and the $Z_0$ zero-sequence impedance. This includes all three phase-to-phase loops, all three phase-to-ground loops and one loop where all three phases are shortened and measured to ground. Overall, the test took less than one hour. After the test, the dedicated Primary Test Manager software created a test report which comprised all of the relevant data:

- $Z_1$ positive-sequence impedance
- $Z_0$ zero-sequence impedance
- $k_0$ zero-sequence compensation factor
- Deviation between measured and calculated values for $Z_1$ and $Z_0$ if calculated values are available
- Actual zone reach based on present relay parameters
- Accuracy of the impedance-based fault locator based on present relay parameters

Table 1 compares the measured values for $Z_1$ and $Z_0$ which were derived from the measurement of the seven loop impedances with the calculated values. As expected, the deviation of the positive-sequence impedance is negligible as the positive-sequence impedance can be accurately calculated from the geometry of the conductor arrangement.

However, quite high deviations have been observed for the zero-sequence impedance. The X value of $Z_0$, which is the more crucial component aside from the R value, was previously determined to be almost 70% too high from the calculation based on the geometry and soil properties.

| Error calculation | | | | |
|---|---|---|---|---|
| | $Z_1$ | | $Z_0$ | |
| | R in Ω | X in Ω | R in Ω | X in Ω |
| **Measured value** | 0.722 | 1.938 | 1.095 | 5.067 |
| **Calculated value** | 0.740 | 1.940 | 1.450 | 8.500 |
| **Error (ref. to measured value)** | **2.54%** | **0.09%** | **32.42%** | **67.75%** |

Table 1: Comparison of measured and calculated values

In order to visualize the actual zone reaches and the accuracy of the impedance-based fault locator, the Primary Test Manager software allows you to enter relay parameters in order to produce the corresponding charts.

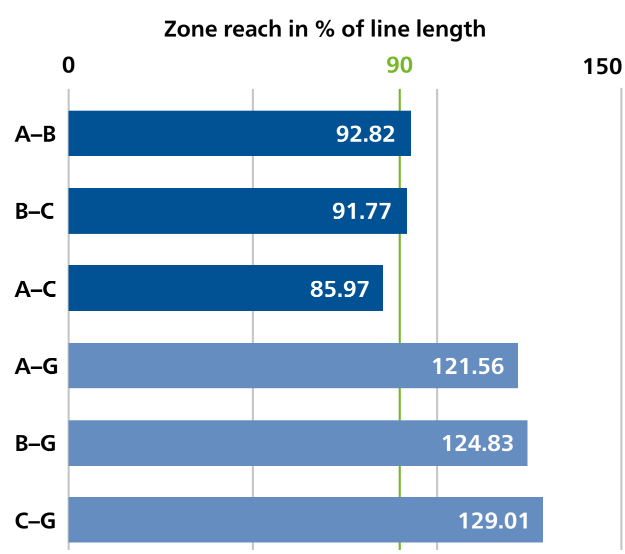
The primary X-value for the zone is entered in order to evaluate the zone reaches. In this particular case, zone 1 was subject to evaluation with a desired grading factor of 90%. This means that the X value is 90% of the X value of the calculated positive-sequence impedance. Furthermore, the $k_0$ zero-sequence compensation factor (magnitude $k_{0M}$ and angle $k_{0A}$) is entered per its definition in the SEL 311 manual:

$$k_0 = \frac{Z_0 - Z_1}{3 \times Z_1}$$

| Distance protection parameters | |
|---|---|
| **$X_1$ prim zone** | **1.746 Ω** |
| **$k_{0M}$** | **1.068** |
| **$k_{0M}$ in °** | 14.15 |

For phase-to-phase faults the reach is in the 90% range which is expected because there is almost no deviation between the calculated and measured $Z_1$.

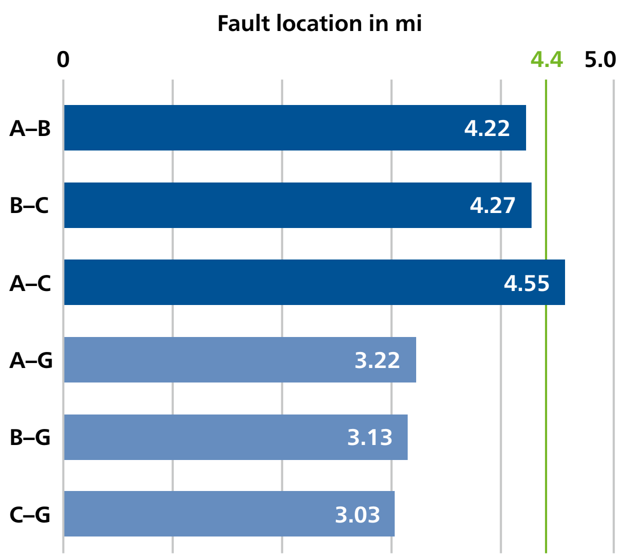
As expected, the zone reaches for phase-to-ground faults are far away from 90% which is caused by the zero-sequence compensation factor being derived from the calculated $Z_0$. In this case the relay would tend to overreach, which means that in the event of a SLG fault on the subsequent line (up to more than 120% of the measured line) the relay of the measured line would also trip, in addition to the relay which protects the subsequent line.



The per mile/km X value of $Z_1$ is required in order to evaluate the fault locator's accuracy. In this example a fault at 100% of the line length is examined which means, that the fault should correctly be seen at 4.4 mi / 7.1 km.

| **Fault locator parameters** | | | |
|---|---|---|---|
| **$X_1$, prim** | 0.446 Ω/mi | **Fault location** | 100% |

For phase-to-phase faults, again the fault location is very close to this value with the line's unbalance causing slight deviations. SLG faults however, are seen much closer to the relay due to improper $k_0$ settings. Although this line is rather short, the absolute deviation is already more than one mile / 1.6 km. In case line maintenance personnel are required to clear the fault, localizing the fault can be sped up tremendously, especially for longer lines which run through remote areas that might be difficult to access.




### Conclusion

The measurement demonstrates the lack of reliability of distance protection relays if inaccurate line impedances have been used to parameterize the relays. Accurate line impedances will increase the precision of calculating fault distances from stations in all types of scenarios.