DISTANCE PROTECTION RELAY IN ENERGY TRANSMISSION LINES

Purpose of the Experiment

- Recognition and use of the SEL 321 Distance Protection Relay.
- Understanding distance protection system based on impedance calculation during short circuit fault in power transmission lines.

Preliminary

- Give information about the working principle of distance protection relays.

1. Introduction

Distance protection is comprehensive short-circuit protection. The operation of the distance protection system is based on short-circuit impedance measurement. This impedance, measured at the time of failure, is proportional to the length of the protected line and allows the fault location to be detected. Distance protection applications are applied in transmission lines and interconnected distribution networks. Distance protection is used as the main protection for overhead lines, cables, and can also be used as backup protection for busbars, transformers and remote feeders.

1.1. Protection Zones and Coordination

In order to reduce the impact of faults in power transmission lines on the power system, the lines are divided into various zones in terms of protection system. These zones are called zone 1, zone 2 and zone 3. As seen in the figure, zone 1 covers approximately 80% of the line. Zone 2 covers 120% of the line (20% of the adjacent line if it is the same length). Although it is not widely used, the coverage area of zone 3 extends to line 3.

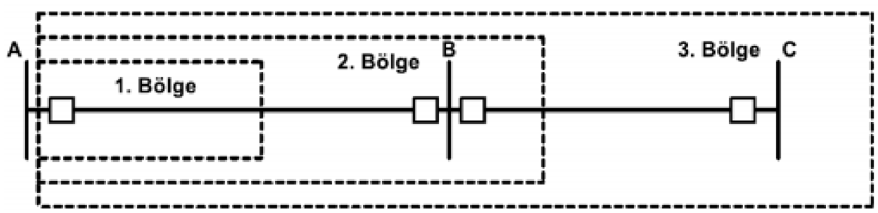


Figure 1. Protection Zones of a Distance Relay.

Figure 1 shows the zones for the relay connected to busbars A. If the fault is in zone 1, relay A will trip instantaneously (without any delay) will send trip signal to the circuit breaker to break the power. In case of fault in Zone 2, it will send a trip signal with a time delay of approximately 0.3-0.5 s. Thus, in case of faults in zone 1 of relay B, if relay B cannot do its job, relay A will take on the role of backup protection. In case of fault in the 3rd region of Relay A, it will send the necessary trip command with a delay of approximately 0.8 s. Thus, there will be no line part that is not protected, and relay coordination is ensured.

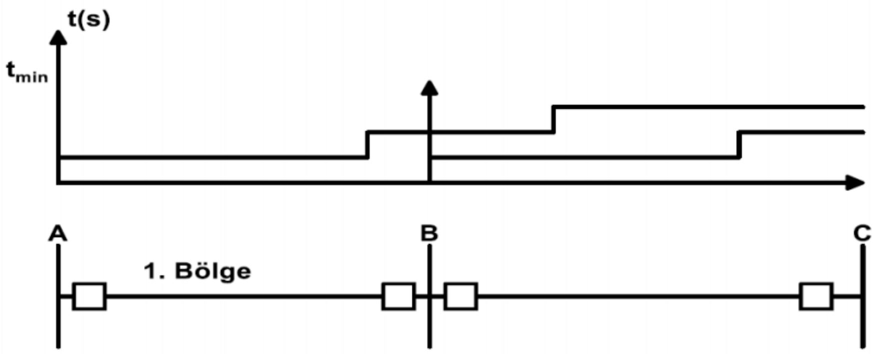


Figure 2. Time stages of the distance protection relay

1.2. Parameters and Equipment related to Distance Protection

The operating voltage of the line and equipment protected by distance relays is usually in the order of kV, in addition to this, the current in the equipment during system failures or breakdown is in the order of thousands of Amperes. Levels of primary demand voltage and current; Voltage and current are reduced by using measurement transformers to protect workers and equipment from high voltage and to provide proper insulation for relays, measuring instruments and other tools. The reduced levels of voltages are 120 V or similar value. In the primary circuit, the nominal current circulates, while in the secondary circuit, the reduced levels of currents circulate (5A or 1A). voltage and current transformers serve as the link between relays and power circuits.

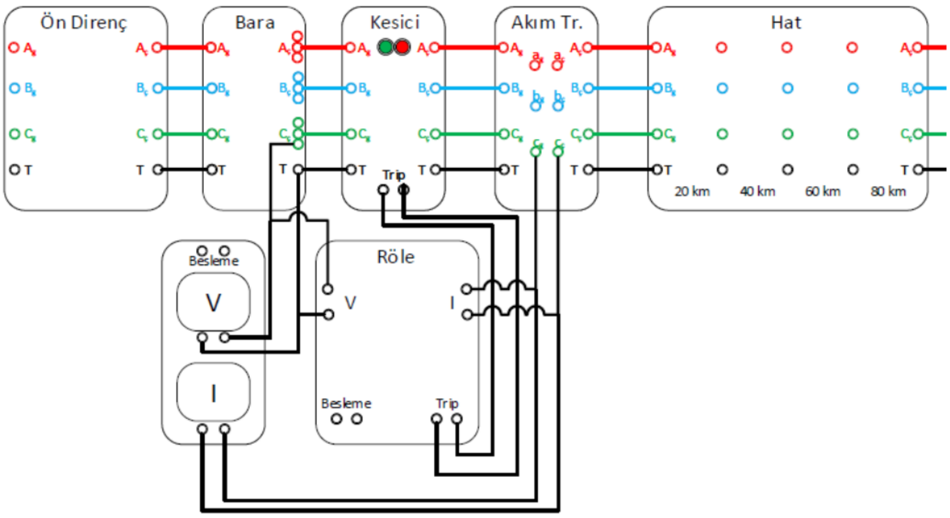


Figure 3. Experiment wiring diagram

In the event of a fault, bus voltage levels decrease and currents in the affected circuits rise during system faults and disturbances. The relay uses the information from the system to decide whether or not to trip the circuit breaker. When the tripping conditions of the circuit breaker are active, the relay completes the circuit that energizes the breaker's trip coil.

Figure 3 illustrates the experiment wiring diagram. In this configuration, the phase-to-ground voltage of phase C is applied to the relay's voltage input, while the phase current, obtained through the current transformer, is supplied to the relay's current input. Based on these measured quantities, the relay issues a trip signal to the circuit breaker under fault conditions, thereby ensuring line protection.

1.3. Distance Protection Relay Measuring Principle

The term 'impedance location of a line' is frequently used in the context of distance protection and describes the fundamental principle on which distance protection systems operate. Figure 4 illustrates a distance protection relay on a transmission line subject to a three-phase fault. The fault current is supplied by the source and is typically much higher than the currents observed during normal operation. The voltages and currents applied to the relay are derived from the bus voltages and the line currents, scaled according to the ratios of the voltage and current transformers. The phase voltages and line currents applied to the relay are expressed in the equations given below.

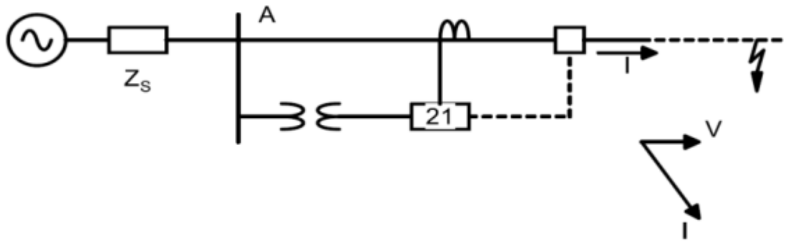


Figure 4. Distance protection of the transmission line.

$$V_{rA} = \frac{V_A}{N_{vt}}$$

$$I_{rA} = \frac{I_A}{N_{ct}}$$

VA : Busbar A phase voltage

VrA : A phase voltage applied to the relay

Nvt : Voltage transformerwater ratio

IA : Line A phase current

IrA : Phase A current applied to the relay

Nct : Current transformerwater ratio

The following equation calculates the ratio of the phase A voltage to the phase A current applied to the relay. This ratio represents the impedance value.

$$\frac{V_{rA}}{I_{rA}} = \left(\frac{N_{ct}}{N_{vt}}\right).\left(\frac{V_A}{I_A}\right) = N_r.\,m.\,Z_1$$

m : Distance between busbar and fault [km]

Z1 : Impedance of the line [Ω/km]

Nr : Impedance ratio stabbed by the relay

For the relay, Nr is constant since the current and voltage transformer ratios are determined during the design stage and remain unchanged. If the protected transmission line is homogeneous, its line impedance, Z1, is also constant. Because both Nr and Z1 are fixed, the impedance calculated by the relay for faults along the line depends on the fault location (distance). Fault current is generally lagging the voltage by about 60–85 degrees, depending on the line characteristics. Therefore, the calculated impedances are inductive and lie in the first quadrant of the complex R–jX plane. In this plane, the impedances define a straight line, commonly referred to as the *impedance locus of the line*. For a high-voltage transmission line, this locus is illustrated in Figure 5. It should be noted that when a fault occurs within the protected section of the line, the impedances observed by the relay are located in the first quadrant.

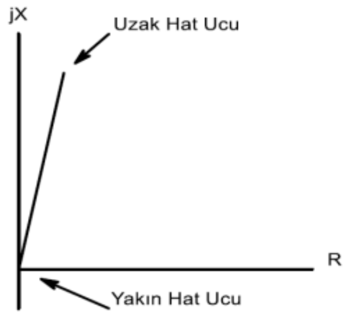


Figure 5. Faulted Line Impedance Region as Seen by the Protective Relay

1.4. Transmission Line Model

The transmission line model consists of three lines rated at 77 kV and 100 A, with lengths of 80 km and 60 km, respectively. In modeling the transmission lines, the π-equivalent model has been employed. The 77 kV, 100 A system has been scaled down to 220 V and 5 A using a scaling factor. The line impedance values are Z=3.8∠65° for the 80 km line and Z=2.85∠65° for the 60 km line.

In the experiment, short-circuit fault points will be created on the transmission line models, and the distance protection relay is expected to detect the fault location. To control the excessive current resulting from short-circuit faults in the transmission lines and to prevent potential damage to the grid, a resistive module has been included to serve as current limitation.

2. Distance Protection Relay Used

The distance protection relay used in the experiment is the SEL-321 model (Figure 7.) manufactured by Schweitzer Engineering Laboratories.

Figure 7. SEL 321 Distance Protection Relay

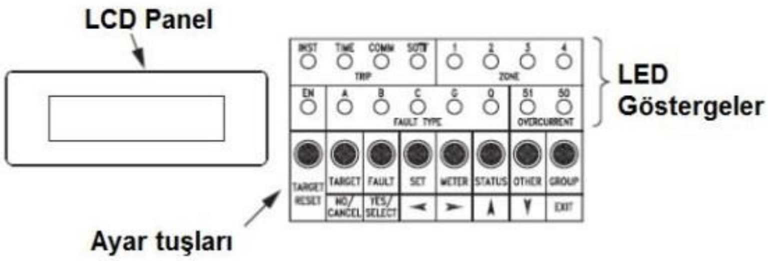


Figure 8. Relay instrument panel

The SEL 321 can be programmed using a computer via the RS232 serial port. It has 8 contact inputs and 16 contact outputs.

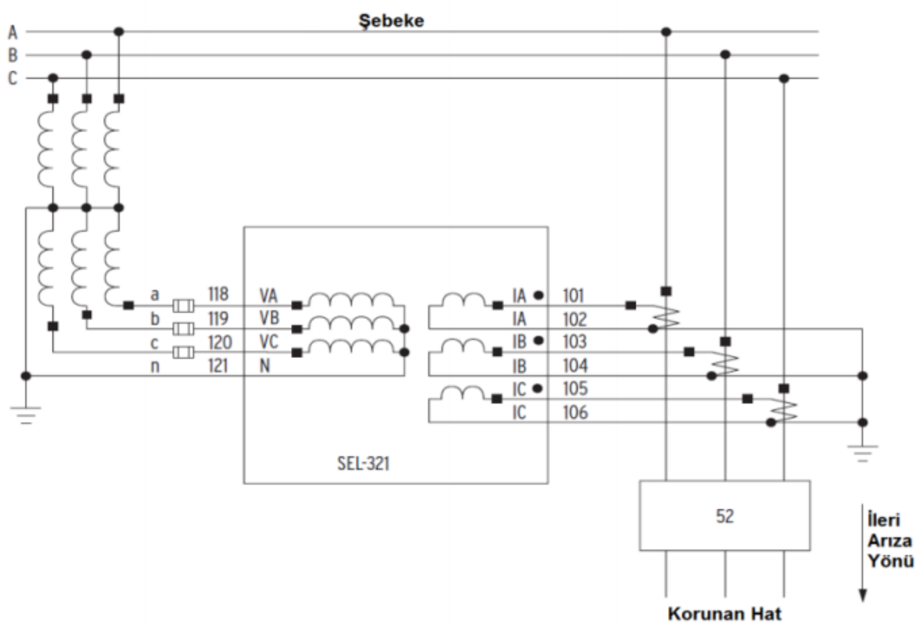


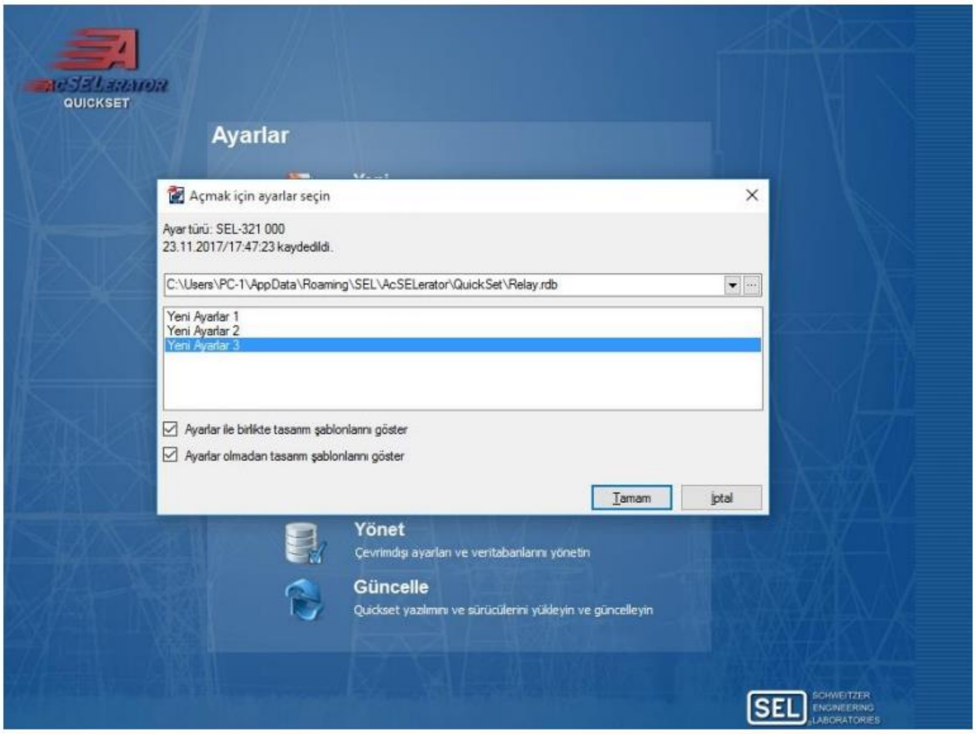
Figure 9. Connection of the SEL-321 Relay to the Grid and the Protected Transmission Line.

2.1. Conducting the Experiment

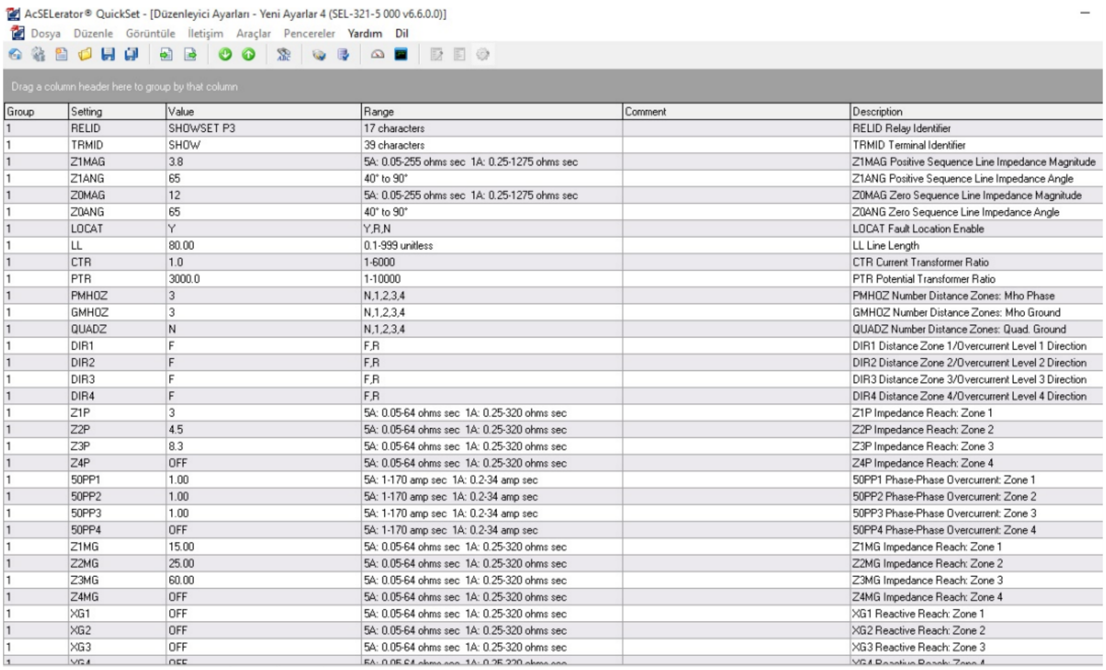
1. On the desktop 

icon Clicking SEL Company Acselerator program to run it.

2. On the screen that opens, click on the >>File >> Open tab.
3. Select the relevant settings on the screen and turn them on.



The following screen will open where the relay settings will be entered.



Group	Setting	Value	Range	Comment	Description
1	RELID	SHOWSET P3	17 characters		RELID Relay Identifier
1	TRMID	SHOW	39 characters		TRMID Terminal Identifier
1	Z1MAG	3.8	5A: 0.05-255 ohms sec 1A: 0.25-1275 ohms sec		Z1MAG Positive Sequence Line Impedance Magnitude
1	Z1ANG	65	40° to 90°		Z1ANG Positive Sequence Line Impedance Angle
1	Z0MAG	12	5A: 0.05-255 ohms sec 1A: 0.25-1275 ohms sec		Z0MAG Zero Sequence Line Impedance Magnitude
1	Z0ANG	65	40° to 90°		Z0ANG Zero Sequence Line Impedance Angle
1	LOCAT	Y	Y,R,N		LOCAT Fault Location Enable
1	LL	80.00	0.1-999 unitless		LL Line Length
1	CTR	1.0	1-6000		CTR Current Transformer Ratio
1	PTR	3000.0	1-10000		PTR Potential Transformer Ratio
1	PMHOZ	3	N,1,2,3,4		PMHOZ Number Distance Zones: Mho Phase
1	GMHOZ	3	N,1,2,3,4		GMHOZ Number Distance Zones: Mho Ground
1	QUADZ	N	N,1,2,3,4		QUADZ Number Distance Zones: Quad. Ground
1	DIR1	F	F,R		DIR1 Distance Zone 1/Overcurrent Level 1 Direction
1	DIR2	F	F,R		DIR2 Distance Zone 2/Overcurrent Level 2 Direction
1	DIR3	F	F,R		DIR3 Distance Zone 3/Overcurrent Level 3 Direction
1	DIR4	F	F,R		DIR4 Distance Zone 4/Overcurrent Level 4 Direction
1	Z1P	3	5A: 0.05-64 ohms sec 1A: 0.25-320 ohms sec		Z1P Impedance Reach: Zone 1
1	Z2P	4.5	5A: 0.05-64 ohms sec 1A: 0.25-320 ohms sec		Z2P Impedance Reach: Zone 2
1	Z3P	8.3	5A: 0.05-64 ohms sec 1A: 0.25-320 ohms sec		Z3P Impedance Reach: Zone 3
1	Z4P	OFF	5A: 0.05-64 ohms sec 1A: 0.25-320 ohms sec		Z4P Impedance Reach: Zone 4
1	50PP1	1.00	5A: 1-170 amp sec 1A: 0.2-34 amp sec		50PP1 Phase-Phase Overcurrent: Zone 1
1	50PP2	1.00	5A: 1-170 amp sec 1A: 0.2-34 amp sec		50PP2 Phase-Phase Overcurrent: Zone 2
1	50PP3	1.00	5A: 1-170 amp sec 1A: 0.2-34 amp sec		50PP3 Phase-Phase Overcurrent: Zone 3
1	50PP4	OFF	5A: 1-170 amp sec 1A: 0.2-34 amp sec		50PP4 Phase-Phase Overcurrent: Zone 4
1	Z1MG	15.00	5A: 0.05-64 ohms sec 1A: 0.25-320 ohms sec		Z1MG Impedance Reach: Zone 1
1	Z2MG	25.00	5A: 0.05-64 ohms sec 1A: 0.25-320 ohms sec		Z2MG Impedance Reach: Zone 2
1	Z3MG	60.00	5A: 0.05-64 ohms sec 1A: 0.25-320 ohms sec		Z3MG Impedance Reach: Zone 3
1	Z4MG	OFF	5A: 0.05-64 ohms sec 1A: 0.25-320 ohms sec		Z4MG Impedance Reach: Zone 4
1	XG1	OFF	5A: 0.05-64 ohms sec 1A: 0.25-320 ohms sec		XG1 Reactive Reach: Zone 1
1	XG2	OFF	5A: 0.05-64 ohms sec 1A: 0.25-320 ohms sec		XG2 Reactive Reach: Zone 2
1	XG3	OFF	5A: 0.05-64 ohms sec 1A: 0.25-320 ohms sec		XG3 Reactive Reach: Zone 3
1	XG4	OFF	5A: 0.05-64 ohms sec 1A: 0.25-320 ohms sec		XG4 Reactive Reach: Zone 4

On this screen;

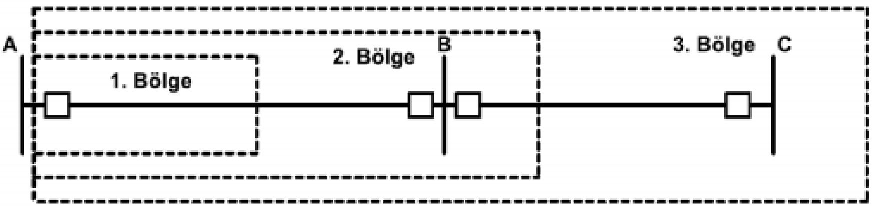
4. Z1MAG is the impedance amplitude of 80 km line. Enter this value as 3.8 ohms.
5. Z1ANG is the impedance angle of the same line. Enter this value as 65 degrees.
6. The LL value is the line length. Enter this value as 80 km.
7. CTR is the current transformer ratio. Since the current transformer used in our experiment is 5:5, this value will be 1.
8. PTR is voltage transformer ratio. Enter this value as 3000.

Three zones are defined in distance protection to reduce the impact of faults in power transmission lines on the power system.

Zone 1: Covers 80% of the line.

Zone 2: Covers 120% of the line.

Zone 3: covers 120% of the adjacent line, in addition to the entire line. In this way, in addition to protection on the adjacent line, backup protection is also provided on the third line.



Setting the Protection Zone Impedance Values from the Parameters of the 80 km Line:

Z1P: 3 ohms (80% of the line)

Z2P=4.5 ohms (120% of the line)

Z3P=8.3 ohms (entire line 1+120% of line 2)

Entering protection time:

The protection time for Zone 1 is instantaneous tripping.
For Zone 2, enter the Z2PD value as 50 cycles. Since one cycle corresponds to 0.02 seconds, 50 cycles equal 50×0.02=1 second.
For Zone 3, enter the Z3PD value as 100 cycles. One hundred cycles correspond to 2 seconds.

After the relay settings are configured, the connection diagram is established as shown below.