APPLYING THE PERMISSIVE OVERREACHING TRANSFER TRIP OF SEL 311L DISTANCE RELAY TO PROTECT THE TRANSMISSION LINE

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Abstract - Vietnam's electricity system has been increasingly invested in development, meeting the growth rate of energy consumption demand in all socio-economic aspects. In particular, the energization and commission of solar and wind power plants greatly affect the stability and safety of the Vietnam power system. To improve the system's stability when incidents occur, one of the current solutions is to coordinate relay calibration settings which have a rapid reaction time at all voltage levels. To meet the above requirements, an option is to use Intelligent Electronic Device (IED) with fast processing speed, reduced latency, and multiple functions with intelligent algorithms. In addition, the solution to coordinate the protection areas between IEDs is being concerned. This paper presents the coordination of Permissive Over-Reaching Transfer Trip (POTT) interlock function of SEL 311L relay for power transmission lines to reduce the fault clearing time compared to the traditional calculation method.

Key words - Transfer Trip; POTT**;** substations; tranmission grid 220kV; relay SEL 311L.

1. Introduction

In recent years, the demand for electricity in all fields such as industry, civil, transportation and agriculture has grown rapidly. This forces the power industry to build more power plants as well as improve and develop the grid structure at all voltage levels. Among types of power sources, solar and wind power plants have relatively low stability due to their dependence on environmental conditions such as solar radiation and wind speed [1]–[3]. The uncertainty in the generation capacity of these types of sources has a great impact on the ability to work safely and stably in the entire power system [4]. Besides, the number of nodes of the power system increases, the rings are formed and expanded, making the grid structure increasingly complex. All factors mentioned above will push the managers and operators of the power system to change the traditional thinking in developing operating scenarios when considering the stable working capacity of the power system.

IEDs based on digital relay platform with high-speed communication are currently a great advantage to improve the stability of the power system by significantly reducing the occurrence of incidents on the grid [5]. However, it is important that we take advantage and apply the advanced functions integrated in the digital relays in a reasonable manner such as the interrupt transfer function in the digital distance relay. SEL 311L is one of the digital distance relays used very commonly in the Vietnamese power system to protect transmission lines, so the article focuses on the application of the POTT interlock transmission function of SEL 311L.

2. Digital relay SEL 311L

SEL 311L is a digital relay from Schweitzer Engineering Laboratories. The block diagram of the functions integrated in the relay is shown in Figure 1 in the form of a code according to the ANSI standard and listed as Table 1. Relays are integrated with both distance protection function (21) and differential protection (87) and play a major protective role for current transmission lines [6].

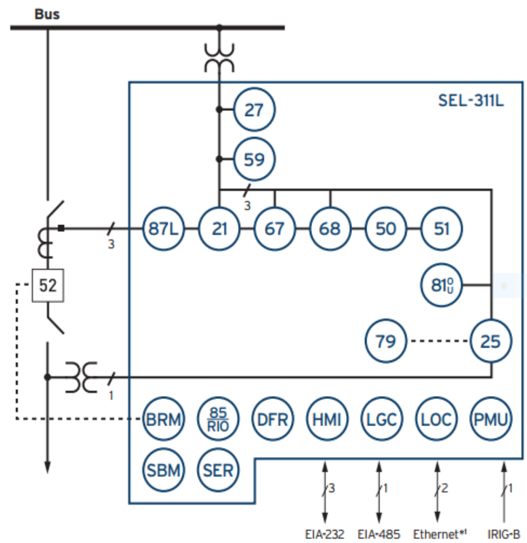

Figure 1. *SEL 311L block diagram*

Table 1. *ANSI function code of SEL311L [6]*

Code (ANSI)	Function
21	Distance protection
87	Differential protection
50/51	Overcurrent protection
25	Synchronization protection
27/59	Under/over voltage protection
67	Directional overcurrent protection
79	Single-and Three-Pole Reclosing
81(O/U)	Over/Under frequency protection
85 RIO	SEL mirrored bits Communications
DRF	Event Reports
HMI	Human machine interface
LGC	Logical coordination function
MET	High speed measurement function
PMU	Phase synchronization measurement
SER	Sequential event record
LOC	Fault location (21L)

2.1. Distance protection

Consider the principle diagram of distance protection for transmission line with two sources as shown in Figure 2.

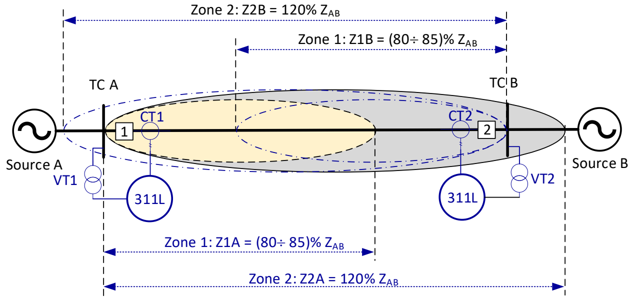

Figure 2. *Principle diagram of distance protection SEL 311L for transmission line with two sources*

Like other distance relays, the SEL 311L carries out protection functions through positioning and coordinating zones of protection. The working principle of distance relays is based on the method of comparison between the preset impedance value and the impedance value measured at the time of consideration. The protection is activated when the measured impedance value is less than the preset impedance corresponding to the time set for each protection zone. The impedance of the distance relay at bus bar A and B is determined by the following expression:

$$\begin{cases} \text{TC A: } Z_{MA} = \dfrac{\dot{U}_A}{\dot{I}_{AB}} \quad [\Omega] \\ \text{TC B: } Z_{MB} = \dfrac{\dot{U}_B}{\dot{I}_{BA}} \quad [\Omega] \end{cases} \tag{1}$$

For SEL 311L, it is usually divided into four protection zones. This paper considers only two protection zones that affect the interlock function as follows:

a. Zone 1: The function of Zone 1 is to eliminate faults with the fastest possible time, so the time set for Region 1 is selected as 0 seconds. The protection length of zone 1 located at bus A and bus B is determined within (80 - 85)% of the length of line AB, corresponding to the total impedance set for the Phase-Phase short-circuit according to the following expression [7]:

$$\begin{cases} Z1A = (80 \div 85)\% * Z_{AB} \quad [\Omega] \\ Z1B = (80 \div 85)\% * Z_{AB} \quad [\Omega] \end{cases} \tag{2}$$

b. Zone 2: The task of zone 2 is to protect 100% of the length of the section AB and to reserve for a part of zone 1 in the direction from bus B to source B. Region 2 of SEL 311L is located at bus A and bus B is calculated according to the expression (3) for Phase - Phase short circuit [7]:

$$\begin{cases} Z2A = 120\% * Z_{AB} \quad [\Omega] \\ Z2B = 120\% * Z_{AB} \quad [\Omega] \end{cases} \tag{3}$$

The time of zone 2 is calculated in combination with other adjacent protection at bus B (considering 311L located at bus A) and at bus A (considering 311L located at bus B). This time value is calculated using the expression (4) [7]:

$$\begin{cases} t_{Z2A} = \max\{t_{BVi\_TCB}\} + \Delta t \quad [sec] \\ t_{Z2B} = \max\{t_{BVj\_TCA}\} + \Delta t \quad [sec] \end{cases} \tag{4}$$

where:

- t_{BVi_TCB}, t_{BVj_TCA} are the time-action values of the other protection i set at bus B, and the other protection j is located at bus A.

- Δt is the protection selective time, usually equal to 0.3 [sec].

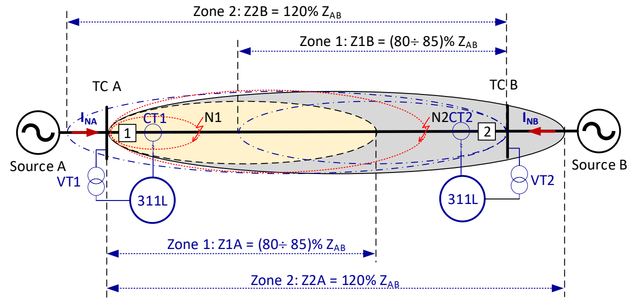

Figure 3. *Faults at zone 1 and zone 2*

When a short circuit occurs at N1 (Figure 3) about 10% of the length of the segment AB, SEL 311L at the side bus A and bus B determine the impedance measurement according to Equation (1). Then:

- SEL 311L at bus A: N1 is determined at its zone 1 (Figure 3). As $Z_{MA} < Z1A$, SEL311L sends TRIP signals to circuit breaker [1] at the beginning of line AB. The fault elimination time t_c is calculated as equation (5).

$$t_c = t_{rl} + t_{Z1} + t_{tt} + t_{MC} \quad [sec] \tag{5}$$

where:

+ t_{rl}: processing time of relay SEL 311L, approximately 0.75 cycle, that is 15ms [].

+ t_{Z1}: zone 1 preset time (0 giây).

+ t_{tt}: communication time (calculated from the replay output to the control box of circuit breaker, usually (1÷2)ms in a local substation).

+ t_{MC}: circuit breaker reaction time, depending on different types. For example, circuit breaker SF6 LTB-D from ABB has t_{MC} = 2 cycles (40ms) [8].

From equation 5, the elimination time at the bus A is:

$$t_c = 15 + 0 + 2 + 40 = 67 \quad [ms]$$

- SEL 311L at bus B: N1 is determined at its zone 2 (Figure 3). As $Z_{MB} < Z2B$, 311L sends TRIP signal to circuit breaker [2] at bus B after the preset time t_{Z2B}.

Because the t_{Z2B} time must be coordinated with other protections located at bus A, this greatly increases the t_c short-circuit time (hundreds of milliseconds) compared to 67 milliseconds of zone 1 at bus A. This does not satisfy the maximum withstand time short-circuit current of 1 second of the switching devices according to the provisions of Circular 25/2016 TT-BCT.

To overcome the disadvantages mentioned above, users can use the POTT function of SEL 311L to reduce the tripping time when faults are in zone 2.

2.2. Permissive Overreaching Transfer Trip of SEL 311L

Consider the principle diagram of POTT intermittent transmission of relay SEL 311L located at the bus A and bus B as shown in Figure 4 [9]. As analyzed in section 2.1, it is shown that if the transfer mode between two relays is not applied at both ends, when the short circuit is about 10% from the bus bar A, the elimination time is long and endanger the equipment as well as affects the stability limits of the power system.

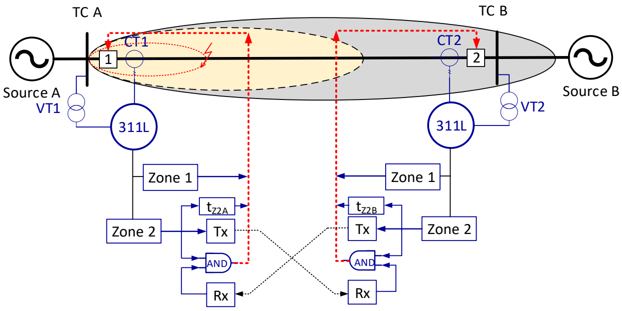

Figure 4. *POTT scheme of SEL 311L*

When using the POTT transmission as shown in Figure 4, a short circuit occurs at 10%L_{AB} in zone 1 of the 311L relay at the bus A, Zone 1 sends the TRIP signal to activate circuit breaker 1. The short-circuit current due to power supply A is eliminated after 67 ms. At the same time, because the short circuit is also in Zone 2 of 311L at bus A, Zone 2 sends the interrupt signal to the Tx signal transmitter transmitted by the Rx signal receiver of the 311L relay on the bus B via fiber optic communication channel. Relay 311L at the bus B will check whether the short-circuit problem actually occurs or not through the signal of Zone 2. Now because Rx and Zone 2 at the 311L bus B relay have signals, so input the AND set at high threshold, AND sends signal to circuit breaker 2 at the bus B. The time to eliminate fault by circuit breaker 2 when using POTT interlock transmission function is determined as follows:

$$t_{cMC2\_POTT} = t_{rl} + t_{Z1} + t_{ttA-B} + t_{MC2}$$
$$= 15 + 0 + 2 + 20 + 40 = 87 \text{ [ms]}$$

where t_{ttA-B} is the communication time from bus A to bus B, this simulation is 20ms.

It is obvious that the fault elimination time is reduced significantly when POTT is applied.

3. Calculation of model testing

Consider the diagram of the power system for calculating and testing the POTT function as shown in Figure 5.

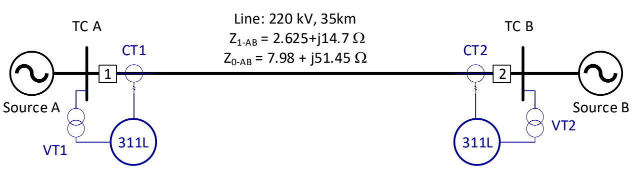

Figure 5. *Diagram of testing power system*

The data of the system used for simulation is as follows

- Short circuit power of source A: 2500 (MVAsc); source B: 2000 (MVAsc).

- Transmission line length: 35km, voltage level: 220kV.

- Line type ACSR-400 with positive impedance: r_{01} = 0.075 Ω/km; x_{01} = 0.42 Ω/km; b_{01} = 2.74*10^{-6} Csim/km; zero impedance: r_{00} = 0.228 Ω/km; x_{00} = 1.47 Ω/km; b_{00} = 1.781*10^{-6} CSim/km.

- Coefficient referred to the secondary side:

$TR = n_I/n_U = 0.6$

3.1. Parameter calculation of SEL311L

Transmission line impedance referred to the secondary side is calculated as follows:

- Positive and negative impedance:

$$Z_{1-AB} = Z_{2-AB} = (r_{01} + jx_{01}) * L_{AB} * TR$$
$$= 8.96\angle 79.87^0 [\Omega];$$

- Zero impedance:

$$Z_{0-AB} = (r_{00} + jx_{00}) * L_{AB} * TR = 36.85\angle 82.53^0 [\Omega];$$

Preset impedance and time of SEL 311L at bus A are calculated as follows:

- Zone 1 preset impedance is determined around 80% L_{AB}:

$$Z_{1A} = 0.8 * Z_{1\_AB} * TR = 0.8 * 8.96\angle 79.87^0 * 0.6$$
$$= 7.17\angle 79.87^0 [\Omega];$$

- Zone 1 preset time is 0 second.

- Zone 2 preset impedance is determined around 120%L_{AB}:

$$Z_{2A} = 1.2 * Z_{1\_AB} * TR = 1.2 * 8.96\angle 79.87^0 * 0.6$$
$$= 10.75\angle 79.87^0 [\Omega];$$

- Zone 2 preset time calculated by equation (4) is 0.3s.

- Zone 3 preset impedance is calculated to protect bus A in reverse direction (around 10% L_{AB}):

$$Z_{3A} = 0.1 * Z_{1\_AB} * TR = 0.1 * 8.96\angle 79.87^0 * 0.6$$
$$= 0.9\angle 79.87^0 [\Omega];$$

Protection characteristic limitation:

- Minimum load impedance:

$$Z_{L\min} = 0.8 * TR * \frac{0.9 * U_{dm}}{\sqrt{3} * I_{dm}}$$
$$= 0.8 * 0.6 * \frac{0.9 * 220000}{\sqrt{3} * 900} = 60.69 [\Omega];$$

- Fault ground resistance without power fluctuation, with 20% safety range:

R_{Gmax} = 0.8*60.96 = 48.77 [Ω]

- Minimum fault ground resistance is equal to phase-ground arc resistance and tower ground resistance, around 40 [Ω].

R_{Gmin} = 40*0.8 = 32 [Ω]

Other fault resistances are determined in table 2 [10].

Table 2. *Fault resistance values*

R_{SC}	Min	Max	Zone 1	Zone 2	Zone 3
R_G	32	48.77	35	40	9

Ground coefficients K_{01}, K_{02}:

$$K_{01} = K_{02} = \frac{Z_0 - Z_1}{3 * Z_1} = \frac{(0.228 + j1.74) - (0.075 + j0.42)}{3 * (0.075 + j0.42)}$$
$$= 1.04\angle 3.5^0$$

Let $K_{01} = K_{02} = 1.04\angle 3.5$

That is:

$K_{01Mag} = K_{0Mag} = 1.04$; $K_{01Ang} = K_{0Ang} = 3.5^0$; t= 0 s.

Setting parameters of SEL 311L at bus B are calculated similarly.

3.2. Settings and simulation results

Testing systems are carried out in the Relay protection lab at faculty of Electrical Engineering, University of Science and Technology – the University of Danang as in Figure 6 [11].

Figure 6. *SEL digital relay testing systems in the LAB*

a. Parameters' setting of SEL 311L

Using software AcSELerator QuickSet provided by SEL, all the above calculated parameters for SEL 311L relays are set, specifically:

- Select Phase Distance in Group1/Set 1 (Figure 7) to enter Phase-Phase protection parameters as in Table 3:

Table 3. *Phase-phase fault preset impedance*

Z1P [Ω]	Z2P [Ω]	Z3P [Ω]
7.17	10.75	0.9

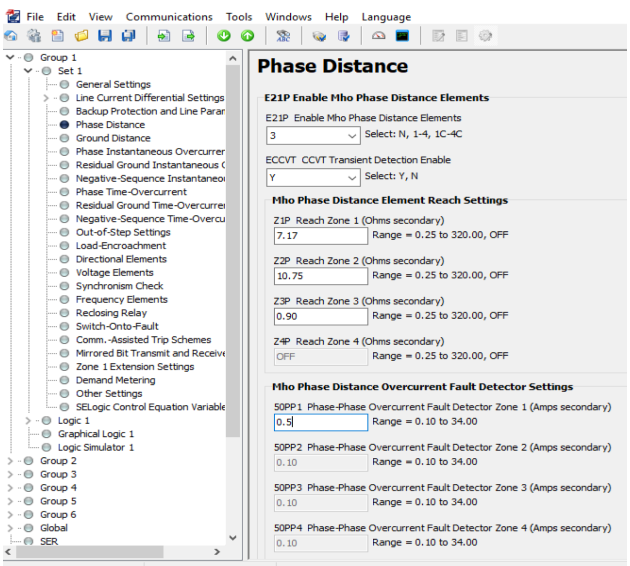

Figure 7. *Phase-phase distance protection settings*

- Select Ground Distance in Group1/Set 1 (Figure 8) to set phase-phase protection parameters as in Table 4:

Bảng 4. *Phase-Ground preset impedance settings*

Z_{1MG} [Ω]	Z_{2MG} [Ω]	Z_{3MG} [Ω]	R_{G1} [Ω]	R_{G2} [Ω]	R_{G3} [Ω]
7.17	10.75	0.9	35	40	9

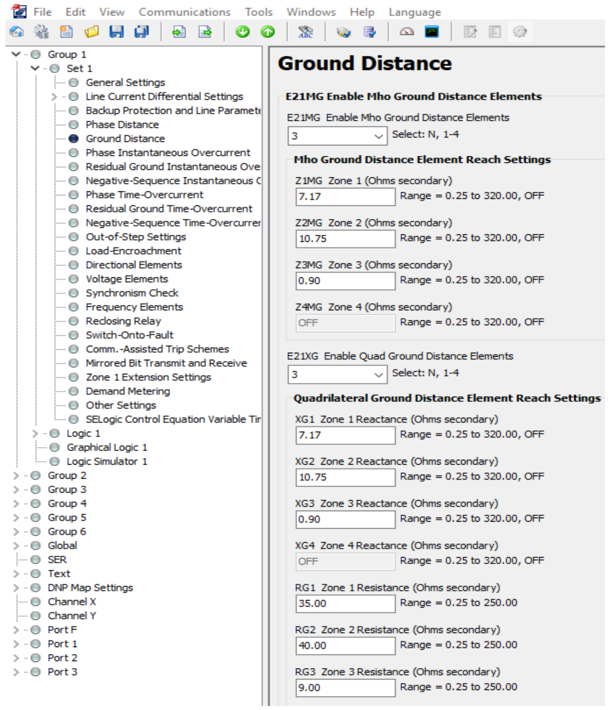

Figure 8. *Phase-Ground distance parameters settings*

- Set the transmitting and receiving addresses for communication between two SEL 311L relays as in Table 5:

Table 5. *POTT transmitting and receiving address activation*

Switch 4	Switch 3	Rx Address	Switch 2	Switch 1	TxAddress
OFF	OFF	1	OFF	OFF	1
OFF	ON	2	OFF	ON	2
ON	OFF	3	ON	OFF	3
ON	ON	4	ON	ON	4

- Select the mode for the Outputs of SEL 311L on both ends as in Table 6:

Table 6. *Output settings*

Switch	Message 1	Message 2
Switch 5 (OUT1, OUT2)	FAST (OFF)	SECURE (ON)
Switch 6 (OUT3, OUT4)	FAST (OFF)	SECURE (ON)
Switch 7 (OUT5, OUT6)	FAST (OFF)	SECURE (ON)
Switch 8 (OUT7, OUT8)	FAST (OFF)	SECURE (ON)

After setting all the data for SEL 311L, proceed to save and write to the relay's memory.

b. Testing results

Use the Omicron adapter to transmit the distance function and simulate the device according to the calculated zones and set up the relay to conduct the simulation when the short-circuit problem occurs at about 10% L_{AB} position. The simulation results are as follows:

- The current wave diagram is recorded for a phase-phase short circuit in SEL311L relay at bus A as shown in Figure 9.

From the wave graph recorded in Figure 9, it is shown that the fault occurs at time t = 230ms. When the incident occurs at about 10% L_{AB} position, the currents in phase A and phase B increase to maximum value I_{max} = 17.5 kA.

- Simulation experiment without activating the POTT function: The experiment results show that the time of

Zone 2 of SEL 311L set at bus B is 300ms, the total time to eliminate fault is 359.2ms (Figure 10).

- Activating the POTT function of the SEL 311L relay with the same location of short circuit: The simulation results in Figure 11 show the time to eliminate short-circuit incidents after 59.9ms.

- Thus, through experiments with practical devices, it has been shown that the protection method using POTT interlock between two distance relays reduces significantly the short-circuit elimination time. That is from 359.2 ms to 59.9 ms accordingly.

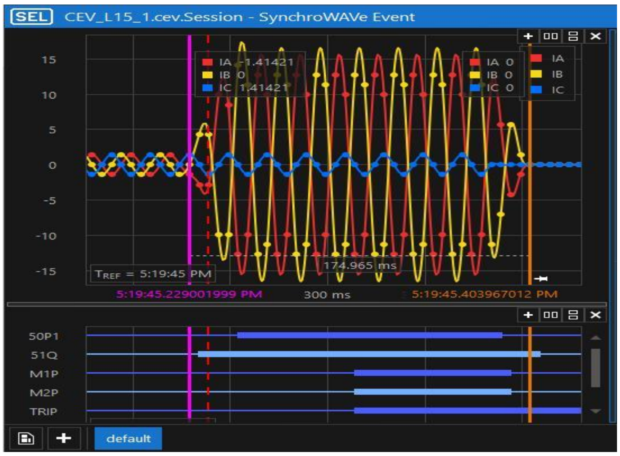

Figure 9. *Phase-phase fault simulated results*

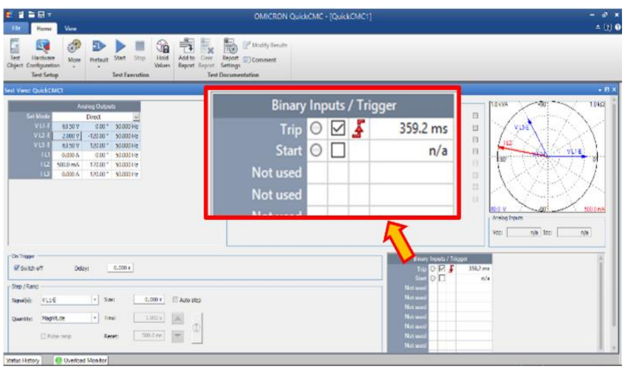

Figure 10. *Reaction time of zone 2 distance protection without POTT*

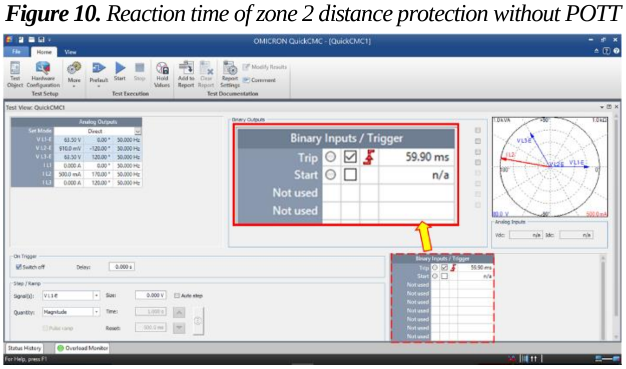

Figure 11. *Reaction time of zone 2 distance protection with POTT*

4. Conclusions

From the calculations and experiment results on the actual SEL 311L relay device, the paper proves the effectiveness of the protection method using POTT as one of the interlocking transmission methods of the digital relays. This means that for the 110kV or higher power grid of Vietnam Power Systems, the application of intermittent transmission functions of digital distance relays is an effective and necessary measure to improve the fast elimination of short-circuit incidents. As a result, this enhances the reliability and stability of the power system.

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