



Development of Wide-Area Protection and Coordination for Electrical Transmission Systems with Distributed Generation

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ABSTRACT

This paper presents a tool for the development of Wide-Area Protection and Coordination (WAPC) for electrical transmission systems. The development of the WAPC tool could be used to solve the protection relays miscoordination problems and decreases the mal-operation of protection relays. This tool was developed by writing DIgSILENT Programing Language (DPL) script in DIgSILENT PowerFactory software. The proposed tool has been implemented in the 115 kV transmission systems of the Provincial Electricity Authority of Thailand (PEA). Moreover, the existing transmission systems with distributed generation (DG) have been studied. In this paper, it will be shown the development of the WAPC tool can assist the protection engineer to set the protection relays more correctly and effectively.

1. INTRODUCTION

Provincial Electricity Authority (PEA) is responsible for distributing electricity to various areas of Thailand. The electrical transmission systems of the PEA are operated in many schemes for supplying the electricity to many areas with different demands, for example, radial operation and closed-loop operation. The electrical transmission systems are wide and large scale. Consequently, the designing of protection scheme is very difficult. So, the protection schemes are designed in a variety of schemes. Protection systems include many protective devices and must be coordinated correctly. The designing of this protection scheme is called "Wide-Area Protection and Coordination (WAPC)".

Generally, WAPC need a big database management system for a large amount of the protective device's data. In addition, the electrical transmission systems may change the electrical configuration or the electrical transmission systems installed the distributed generation (DG) which affects to the protection setting value. The additional fault current of DG may require changing the settings of the network protection relays. The protection device settings must be regularly monitored and updated for protective devices are coordinated correctly. However, when the system has many protective devices, it takes a long time to audit and improve. Therefore, it is imperative to have an

automatic tool to determine. The automatic tool shall be easy to use, effective and automatically.

The case study of RED ELÉCTRICA de ESPAÑA [1] shows the results of developing wide area protection and coordination in Barcelona, Spain. The relay miscoordination cases before developing WAPC are 16%. After the readjusting process, only 1% of the transmission miscoordination and 1% of the simulations are cases where the miscoordination cannot be solved because of system topology or constraints in the protection technologies installed. B. Barman [2] has presented a guideline for the WAPC analysis process and discusses some potential challenges that may be encountered. It is important to distinguish the difference between coordination analysis and a full protection evaluation. M. Chen et al. [3] has presented a distance relay-based wide-area backup protection (WABP) algorithm for transmission lines. The proposed WABP collects the statuses of zone 2 and zone 3 distance relays in local substation and immediate neighboring substations. However, this algorithm cannot determine primary protection. P. Maneerat et al. [4] has proposed the method to monitors and evaluates the performance of primary and secondary protection elements for PEA's 115 kV closed loop transmission lines in Chiang Mai area. The method is developed by DPL script in PowerFactory software. However, this method determines only close-loop structure and cannot determine wide and

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large-scale systems. In this paper, the proposed tool was developed from the old tool [4]. The new proposed tool could be used to solve the protection relays miscoordination problems with many types of transmission and distribution systems such as radial, loop and existing system with DG.

This paper presents a tool for the development of WAPC for electrical transmission systems. The tool was developed by writing DPL script in DIGSILENT PowerFactory software. This tool is used to analyze and reconfigure the settings of miscoordinated relays. Our objective is to create an automatic computational tool, which is flexible and takes less time to determine miscoordination problems. The proposed tool has been implemented in the 115 kV transmission systems of PEA. Moreover, the existing transmission systems with DG have been studied. In this paper, it will be shown the development of WAPC tool can assist the protection engineer to set the protection relays more correctly and effectively.

2. WIDE-AREA PROTECTION AND COORDINATION

Zone of Protection [5]

The selection of the reach settings and tripping times for the various zones of measurement enables correct coordination between distance relays on a power system. Basic distance protection will comprise instantaneous directional Zone 1 protection and one or more time-delayed zones. Typical reach and time settings for a zone distance protection [6] are shown in Fig. 1.

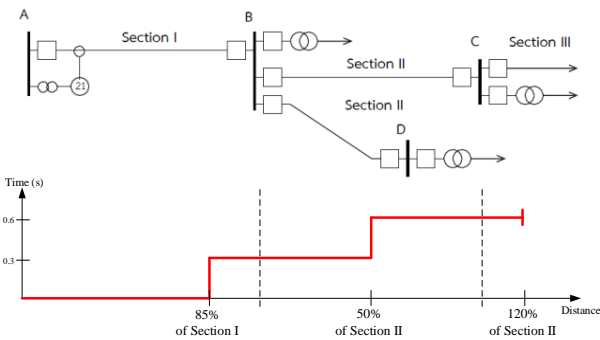


Fig. 1: Typical reach and time settings for a zone distance protection.

Zone 1: Set the reach impedance up to 85% of the line impedance section I

Zone 2: Set the reach impedance 100% of the line impedance section I + 50% of section II. (the shortest line that connects to next substation or load.)

Zone 3: Set the reach impedance 100% of the line impedance section I + 120% of the line impedance section II. (the longest line that connects to next substation or load.)

Zone 4 reverse: 15% of Zone 1 reach.

Zone 2 and zone 3 shall not exceed 100% of line impedance section I + 80% of transformer impedance at the remote end

Time setting

Zone 1: Operating time = Instantaneous

Zone 2: Operating time = 300 ms

Zone 3: Operating time = 600 ms

Zone 4 reverse: Operating time = 600 ms

Impact of DG on A Distance Relay [7]

Distance relays are often used on 115 kV overhead lines, and a generator connected within the protected zone of these impedance relay may reduce the reach of the relay. The distributed generator acts to support the network voltage so appearing to increase the impedance to the fault seen by the relay. The relay then calculates that the fault is further away, outside the zone of protection and so will not operate. This can be explained using Fig. 2.

Assume that before the distributed generator is connected, the setting of the distance relay is $(Z_1 + Z_2)$. After DG is connected, the voltage seen by the relay and current through the relay for a fault within its zone of protection is given by:

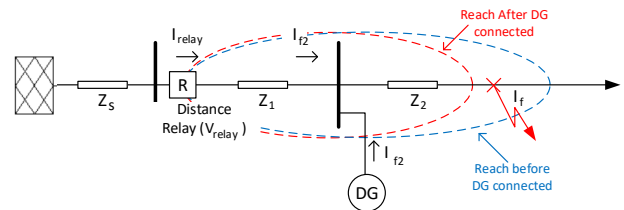


Fig.2: The relay operates outside the zone.

$$V_{relay} = I_{f1}Z_1 + (I_{f1} + I_{f2})Z_2 \quad (1)$$

$$I_{relay} = I_{f1} \quad (2)$$

Thus, impedance seen by the relay:

$$\frac{V_{relay}}{I_{relay}} = Z_1 + \left(1 + \frac{I_{f2}}{I_{f1}}\right) Z_2 \quad (3)$$

$$\frac{V_{relay}}{I_{relay}} = (I_{f1} + I_{f2}) \left(\frac{I_{f2}}{I_{f1}}\right) Z_2 \quad (4)$$

Since the impedance seen by the relay within the original protected zone of zone 1 is now increased above the setting of the relay, the distance relay will not provide protection for the entire zone, thus under-reaching its protected zone. Therefore, the reach and time settings for a zone distance protection with DG are shown in Fig. 3.

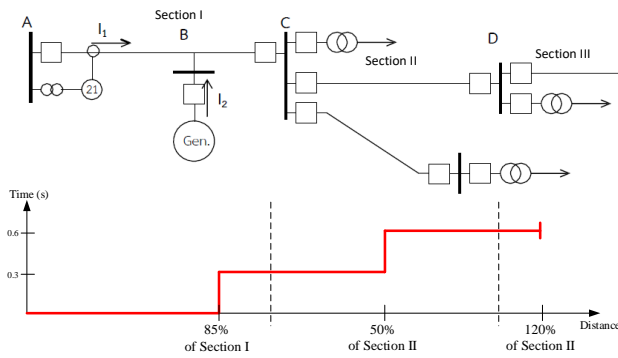


Fig. 3. The reach and time settings for a zone distance protection with DG.

Zone 1: Set the reach impedance up to 85% of the line impedance section I (A to C)

Zone 2: Set the reach impedance 100% of the line impedance section I ($Z_{AB} + (1 + I_2/I_1)Z_{BC}$) + 50% of section II ($(1 + I_2/I_1)Z_{CD}$). (the shortest line that connects to next substation or load.)

Zone 3: Set the reach impedance 100% of the line impedance section I ($Z_{AB} + (1 + I_2/I_1)Z_{BC}$) + 120% of the line impedance section II ($(1 + I_2/I_1)Z_{CD}$). (the longest line that connects to next substation or load.)

Zone 4 reverse: 15% of Zone 1 reach.

3. WIDE-AREA PROTECTION AND COORDINATION (WAPC) TOOL

DIgSILENT Programming Language (DPL) [8-9]

The DIgSILENT Programming Language (DPL) serves the purpose of offering an interface for automating tasks in the DIgSILENT PowerFactory program. By means of a simple programming language and in-built editor, the user can define automation commands (scripts) to perform iterative or repetitive calculations on target networks, and post-process the results. The structures of DPL are like to C++ language. The principle structure of DPL is shown in Fig. 4.

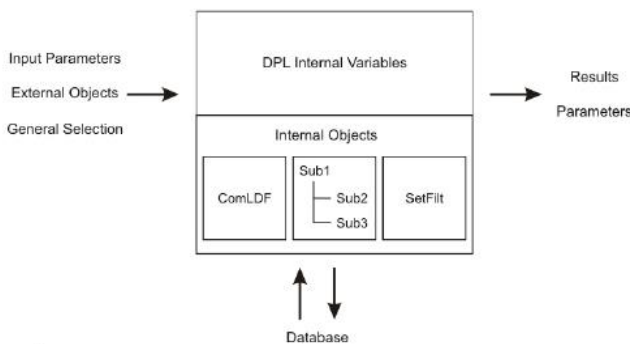


Fig. 4. The structure of DPL.

The DPL command is the central element, which connects different parameters, variables or objects to

various functions or internal elements and then outputs results or changes parameters. The input to the script can be predefined input parameters. Next, the DPL script will run a series of operations and start calculations or other functions inside the script. It will always communicate with the database and will store changed settings, parameters or results directly in the database objects. Almost every object inside the active project can be accessed and altered. During or at the end of the execution of the DPL script, the results can be output or parameters of elements may be changed.

WAPC Tool

The WAPC tool is the automatic tool shown in Fig.5 composed of three parts including an input section, analyze section, and report section.

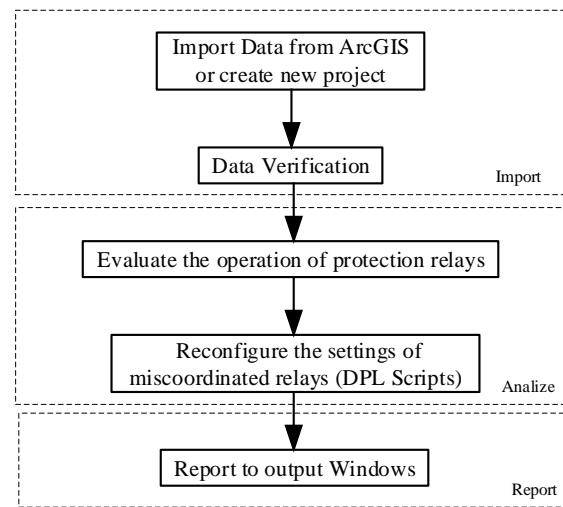


Fig. 5: Flowchart of the WAPC tool.

Transmission and distribution systems studied can be created in PowerFactory software and saved in the *.pfd file format. In addition, spatial and network data of the transmission and distribution systems can be exported from ArcGIS software using the GIS Import/Export Tool, which was developed by ESRI and PEA [10]. The exported data will be saved as in the *.dgs file format, which can be directly imported to PowerFactory. The calculation engine, named “Wide-Area Protection Coordination”, was developed by programming DPL script in PowerFactory software for determining the protection relays miscoordination problems and reconfigure the settings of miscoordinated relays. Finally, the report is shown in output windows of PowerFactory.

The Proposed WAPC Algorithm

The flowchart of the purposed WAPC algorithm is illustrated in Fig. 6. Firstly, the users must input the parameters such as the relay setting criteria (tripping time of each zone, reach of each zone, etc.) and the protection

boundary. The users must select the path of transmission and distribution systems within protection zones to input the protection boundary. If the users do not select the path, the program does not know the protection zones and the structure of system. Then, the program checks the setting of measurement unit of relay such as the polarizing element and the starting element, which was contained in relay model. If the polarizing element and the starting element have not been set, the program will calculate new setting parameters. For the polarizing element, the program will assume the k_0 value of polarizing element automatically to be close to the k_0 value of the line. The example assuming k_0 value of polarizing element is shown in Fig. 7. For the starting element, the program will calculate the starting current value around 125% of load flow current (current flowing through the relay) The example calculating starting current value of starting element is shown in Fig. 8.

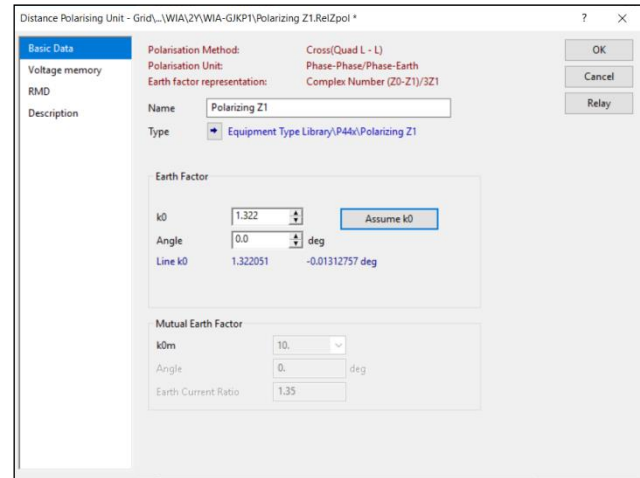


Fig. 7: The assuming k_0 value of polarizing element.

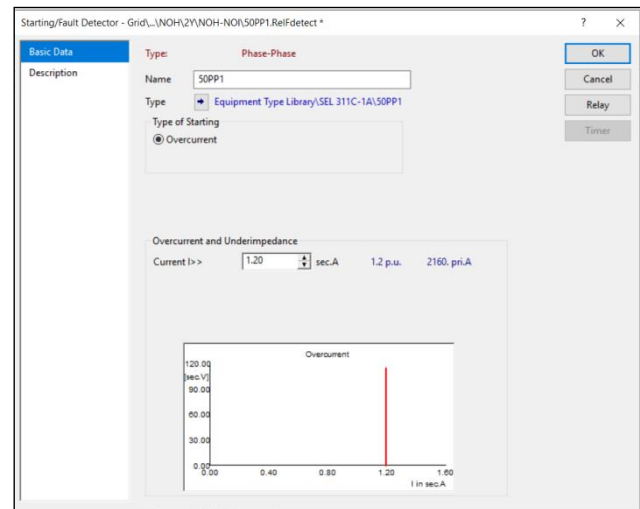


Fig. 8: The starting value of starting element.

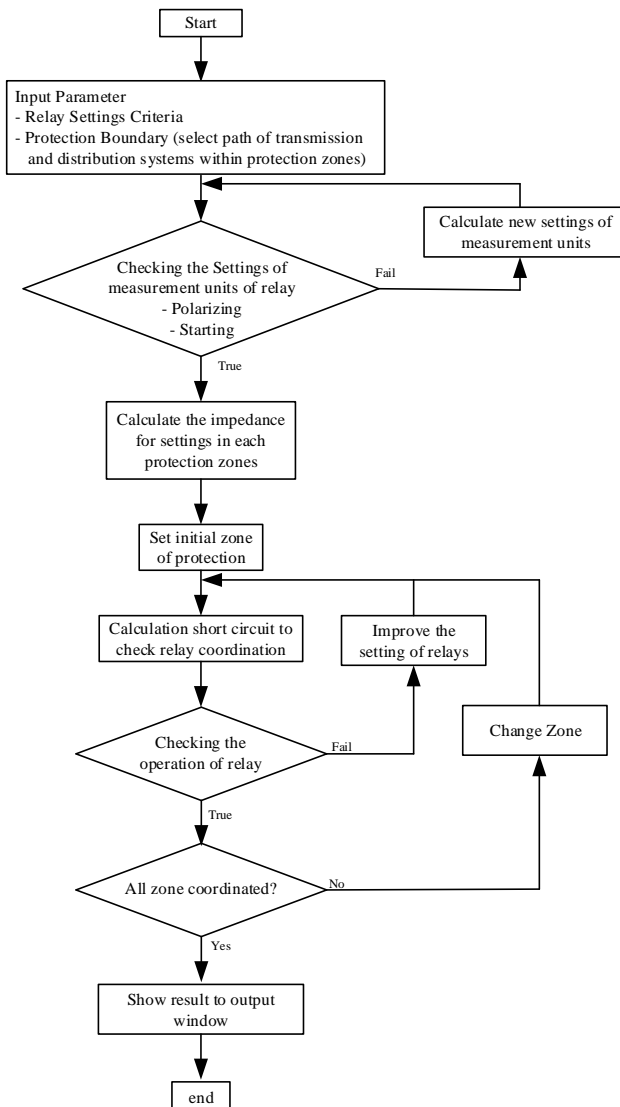


Fig. 6: Flowchart of the purposed WAPC algorithm.

Next step, the program will calculate the impedance for settings in each protection zone. If the structure of system has the tap line point between 2 substations, the program will calculate by the total of impedance between 2 substations in the path, which the users is selected. Then, the program calculates the settings for initial zone by run single-phase to-ground short circuit sweep to collect the minimum fault current (at the boundary of the zone) through acceptable fault resistance in the zone. If the impedance of ground relay is set to comply with the relay setting criteria, calculate 3-phase short circuit sweep to recheck the settings. Unless the settings of ground and phase of each zone are related, the program will improve the setting again. The relay settings of other zones will repeat the same process. Finally, if all of the settings are set to comply with the criteria, the program will export the results for completed settings to the user.

4. CASE STUDY AND RESULTS

Radial System

A 115 kV transmission system of the PEA central 1 region, the source of the system is from AT1_EGAT substation by Electricity Generating Authority of Thailand (EGAT) that delivers the power through Ang Thong 1 (ATA) substation to Bang Pahan (BPI) substation and Bang Phra Khru (BPH) substation shown in Fig. 9 is used as a radial system case study. This 115 kV transmission line provides electricity to the urban area of Ang Thong province and Phra Nakhon Si Ayutthaya province. This transmission system was created on DIGSILENT PowerFactory software. There are 5 buses, and 8 main distance relays.

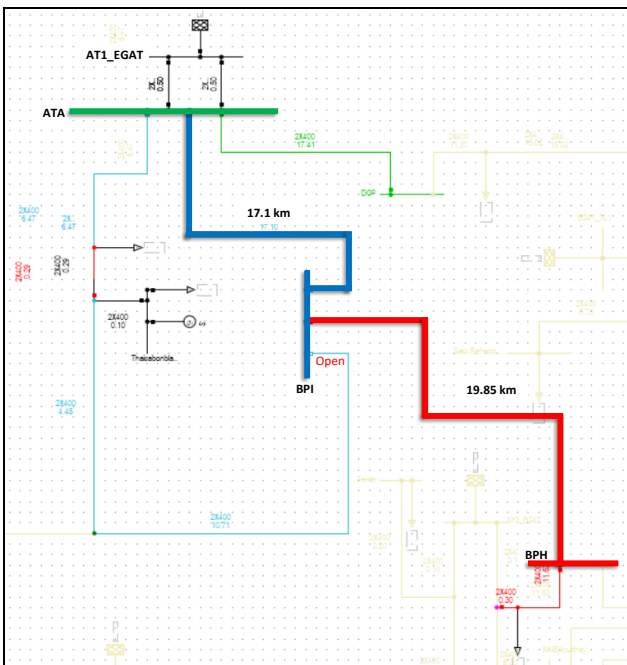


Fig. 9: A transmission system of the PEA central 1 region (used in radial case study).

The WAPC tool was applied to transmission system of the PEA central 1 region. Some constant parameters used in the simulations are shown in Table 1. These constant parameters were entered to DPL command window shown in Fig.10.

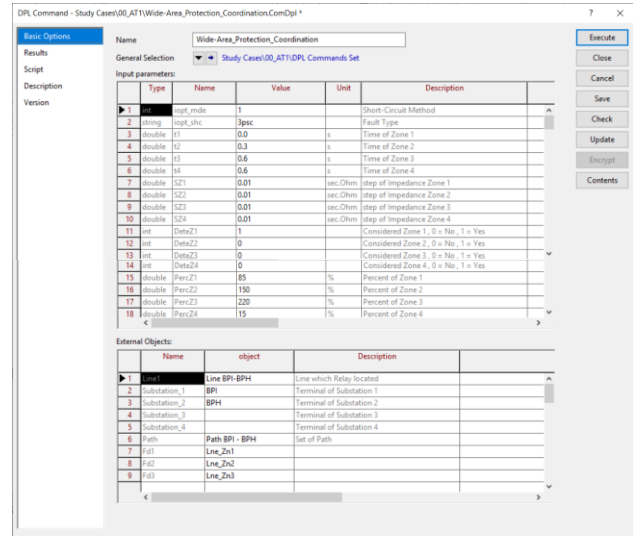


Fig. 10: DPL command window.

The time-distance path between ATA substation to BPH substation before using the tool shown in Fig 11 show the distance relay, which is connected at ATA substation has underreach problems (circle in Fig 11). The reach impedance of zone 1 was set at 54.6% of the line impedance section I (line ATA to BPI (17.1 km)). The reach impedance of zone 2 was set at 100% of the line impedance section I (line ATA to BPI (17.1 km)) and 23.7% of the line impedance section II (line BPI to BPH (19.85 km)). The underreach problem can cause miscoordination problems in radial system.

Table 1: The Parameters Use in the Simulations

Parameter	Value
Time of Zone 1	0 s
Time of Zone 2	0.3 s
Time of Zone 3	0.6 s
Time of Zone 4	0.6 s
Percent Impedance of Line Zone 1	85% of line section I
Percent Impedance of Line Zone 2	100% of line section I + 50% of line section II
Percent Impedance of Line Zone 3	100% of line section I + 120% of line section II
Percent Impedance of Line Zone 4	15% of line section I (Reverse Zone)

After using the WAPC tool, the proposed tool could be used to solve the underreach problems shown in Fig 12. The reach impedance of zone 1 was set up to 85% of the line impedance section I. The reach impedance of zone 2 was set up to 100% of the line impedance section and 50% of the line impedance section II. Consequently, the WAPC

tool could be used to solve miscoordination problems in radial system.

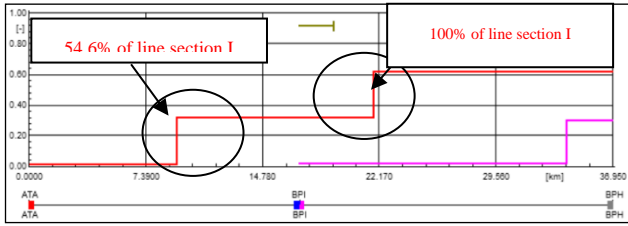


Fig. 11: Time-distance path ATA – BPH before using the tool.

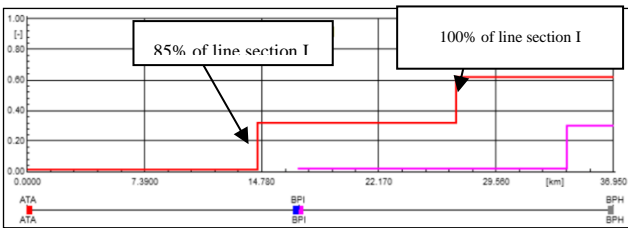


Fig. 12: Time-distance path ATA – BPH after using the tool

Closed-Loop System with DG

A 115 kV transmission system of the PEA Southern 1 region, the source of the system is from RB2_EGAT substation by EGAT that delivers the power through Ratchaburi 2 (RBB) substation to Photharam (PTR) substation, Damnoen Saduak (DNA) substation and Pak Tho (PTH) substation shown in Fig. 13 is used as a closed-loop system case study. This 115 kV transmission line provides electricity to the urban area of Ratchaburi province. In this case, a DG is located at Ratchaburi 3 (RBCx) temporary substation, which connected to tap-line between RBB and PTR substation. This transmission system was created on DIgSILENT PowerFactory software. There are 4 buses, and 8 main distance relays and 1 tap line point.

The constant parameters used in the closed-loop system case study simulations are equal to the constant parameters used in the radial system case study simulations shown in Table 1.

The time-distance path between RBB substation to PTH substation before connection of a DG shown in Fig. 14 show the distance relays are coordinated correctly. The reach impedance of zone 1 was set at 85% of the line impedance section I (line RBB to tap line point (3 km) + line tap line point to PTR (20.9 km) = 23.9 km). The reach impedance of zone 2 was set at 100% of the line impedance section I (line RBB to tap line point (3 km) + line tap line point to PTR (20.9 km) = 23.9 km) + 50% of the line impedance section II (line PTR to DNA (19.85 km)).

The time-distance path between RBB substation to PTH substation after connection a DG shown in Fig. 15 show the distance relay, which is connected at RBB substation

has underreach problems. The DG acts to support the network voltage and current so appearing to increase the impedance to the fault seen by the relay. The relay then calculates that the fault is further away, outside the zone of protection and so will not operate.

After using the WAPC tool, this tool could be used to solve the underreach problems. Fig. 16 show the R-X diagram of a relay at RBB substation after DG connected. The new relay impedance parameters was calculated automatically by the tool. The new relay impedance parameters can be used to set the relay correctly. Consequently, the WAPC tool could be used to solve miscoordination problems in transmission system and assist the protection engineer to set the protection relays more correctly, effectively and takes less time to determine.

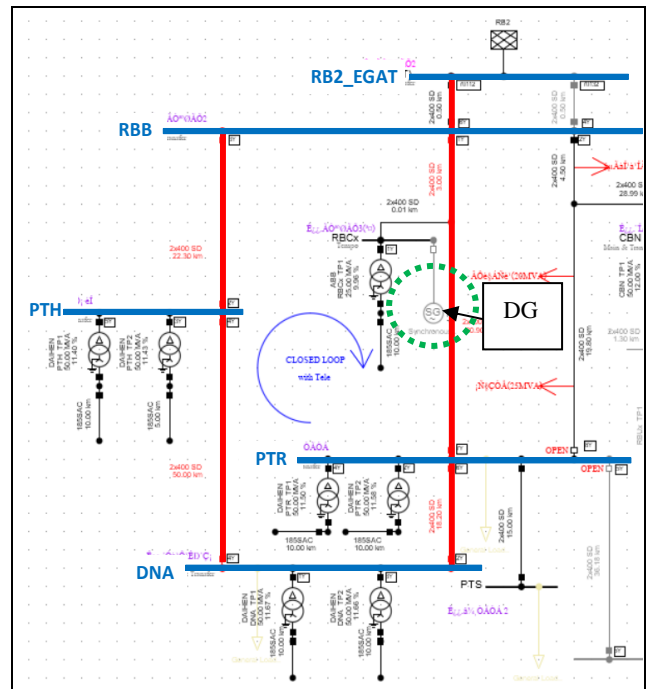


Fig. 13. A transmission system of the PEA southern 1 region (used in closed-loop case study)

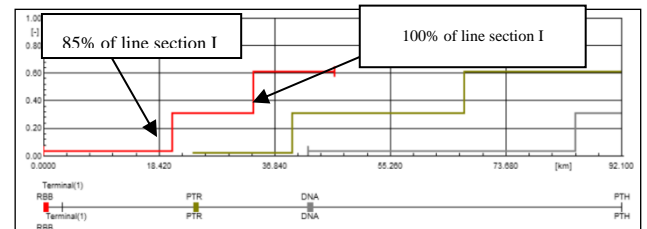


Fig. 14: Time-distance path RBB – PTH before DG connected.

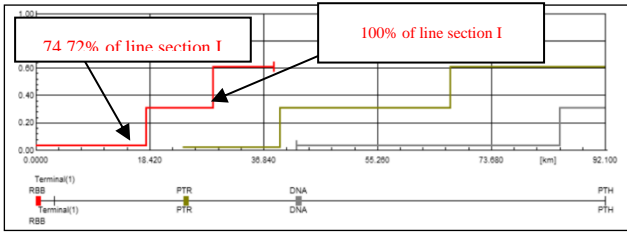
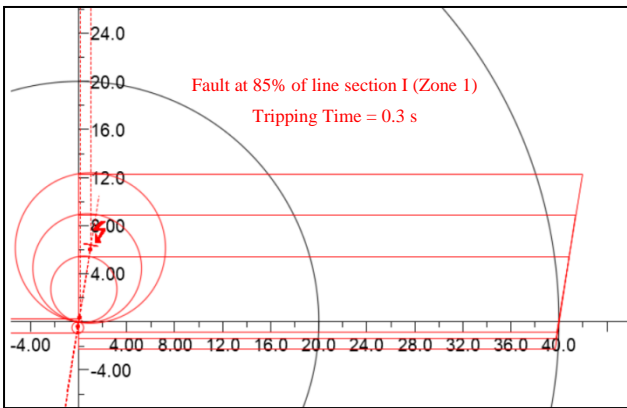
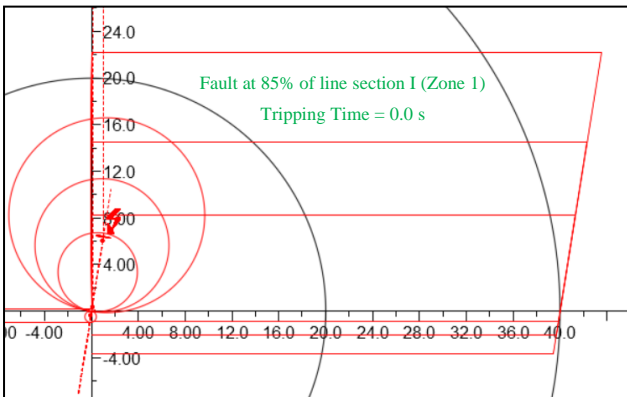


Fig. 15: Time-distance path RBB – PTH after DG connected.



(A)



(B)

Fig. 16: R-X Diagram of a relay at RBB substation after DG connected (A) Before using the tool (B) After using the tool.

5. CONCLUSION

This paper presents a tool for the development of Wide-Area Protection and Coordination (WAPC) for electrical transmission systems. The development of the WAPC tool could be used to solve the protection relays miscoordination problems and decreases the mal-operation of protection relays. This tool was developed by writing a DPL script in DIgSILENT PowerFactory software. The proposed tool has been implemented in the 115 kV

transmission systems of PEA. Moreover, the existing transmission systems with DG have been studied. In this paper, it will be shown that the development of the WAPC tool can assist the protection engineer to set the protection relays more correctly and effectively. Even though, some cases cannot be solved regarding the complexity of system topology or the limitations in the established protection elements. The outcomes of this study can be used by system engineers as well as researchers for operating protection systems. The future research will be focused on the possible protective levels related to this class of protection coordination.

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REFERENCES

- [1] Pérez, CP, Castillo, I. and Martin, J. 2017. Protection Coordination in the Transmission System and Boundaries – A Wide Area Coordination Study. In *Western Protective Relay Conference*. 18 October.
- [2] Barman, B. Clack and J. Padaca, V. 2015. A Practical Guide to Performing Wide-Area Coordination Analysis. In *51st Annual Minnesota Power Systems Conference*,. 10-12 November.
- [3] Chen, M. Wang, H. Shen, S and He, B. 2017. Research on a Distance Relay-Based Wide-Area Backup Protection Algorithm for Transmission Lines. In *IEEE Trans. Power Delivery*. 2017; 32(1):97-105.
- [4] Maneerat, P. Premrudeepreechacharn, S. Supannon, A. 2018. Development of Wide Area Protection & Coordination for PEA’s 115 kV Closed Loop Transmission Lines in Chiang Mai Area. In *2018 53rd International Universities Power Engineering Conference (UPEC)*,. 4-7 September.
- [5] Rush, P. (2011). *Network Protection & Automation Guide*. 2nd Edition, Alstom Grid.
- [6] Power System Protection Division of PEA (2016). *Criteria Setting of Distance Relays for Provincial Electricity Authority*.
- [7] Rush, P. Jenkins, N. Ekanayake, J.B. and Strbac, G. (2010). *Distributed Generation*. The Institution of Engineering and Technology (IET).
- [8] DIgSILENT GmbH. *DIgSILENT PowerFactory 2018 User Manual*. Gomaringen, Germany; 2018.
- [9] DIgSILENT GmbH. *DIgSILENT PowerFactory Advance Tutorial DIgSILENT Programming Language (DPL)*. Gomaringen, Germany; 2017.
- [10] Environmental Systems Research Institute Thailand (2009). *Network Analysis and Power Flow Modeling*.