



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

Autthaporn Supannon^{1,*}, Suttichai Premrudeepreechacharn¹, and Piyadanai Pachanapan²

ARTICLE INFO

Article history:

Received: 18 March 2020

Revised: 29 June 2020

Accepted: 7 July 2020

Keywords:

Wide-Area Protection and Coordination (WAPC)

Protection relays

DIgSILENT Programming Language (DPL)

DIgSILENT PowerFactory

ABSTRACT

This research presents a computational tool for development of Wide-Area Protection and Coordination (WAPC) for electrical power transmission systems. This tool could be used to clarify the protection relays miscoordination. This tool was designed by developing DIgSILENT Programming Language (DPL) script, which is build-in function in DIgSILENT PowerFactory v.2018 software. The proposed tool has been applied to the Provincial Electricity Authority (PEA)'s 115 kV electrical transmission systems. Moreover, the existing transmission systems with distributed generation (DG) have been studied. In this paper, it will be shown the development of WAPC tool can help the protection relay engineer to set-up the relays correctly, effectively and decreased the man-day time of engineers.

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 added fault current of DG may change the network protection relays setting parameters. 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. 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 backup protection distance relay combined with wide-area (BPWA) algorithm for electrical transmission system. The proposed of BPWA is to collect the conditions of zone 2 and zone 3, which are the backup zones of distance relays in substation. However, this algorithm cannot determine primary protection. P. Maneerat et al. [4] has proposed the method to audits and reconfigures the primary and secondary protection relay for 115 kV PEA's closed-loop transmission system in Chiang Mai province. The method is created by DPL script in PowerFactory software. However, this method determines only close-loop structure and cannot determine wide and

¹Department of Electrical Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai, 50200, Thailand.

²Department of Electrical and Computer Engineering, Faculty of Engineering, Naresuan University, Phitsanulok, 65000, Thailand.

*Corresponding author: Autthaporn Supannon; Phone: +668-7542-8066; E-mail: autthaporn_su@cmu.ac.th.

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

This research presents a tool for the development of WAPC for electrical transmission systems. The tool was designed by creating DPL script, which is build-in function in DlgSILENT PowerFactory software. The developed tool is used to audit and reconfigure the settings of miscoordinated relays. The objective of this research is to develop an automatically calculated tool, which is flexible and decrease man-day time to clarify relay miscoordination problems. The proposed tool has been applied to 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 help the protection relay engineer or technician to set-up the relays correctly, effectively and decreased the man-day time of engineers.

2. WIDE-AREA PROTECTION AND COORDINATION

Zone of Protection [5]

The corrected settings of the reach impedance and relay tripping times for any zones on distance relay could be helped network coordinated correctly. Typical distance protection will consist of Zone 1, which is instantaneous zone and anyone or more zones. Typical reach and tripping time settings for the zone of distance protection [6] are shown in Fig. 1.

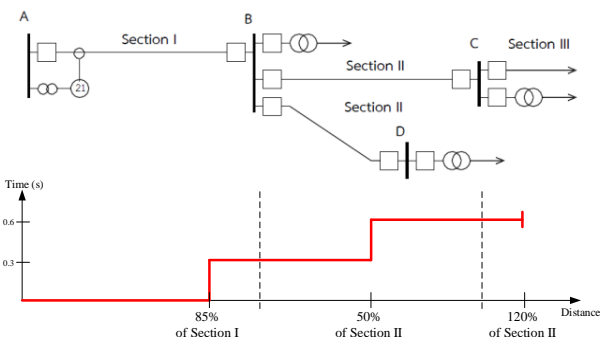


Fig. 1: Typical reach and time settings for a zone distance protection.

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.

For zone 2 and zone 3, the impedance seen by relay could not over than 100% of line section I (A to B) + 80% of impedance transformer at the receiving 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]

Typical distance relays are used in 115 kV transmission system, and a DG connected within the zone of protection of these distance relay may reduce the reach impedance of the relay. The DG acts to increase the network voltage so appearing to reinforce the impedance seen by the distance relay. The relay calculated that the fault is faraway, outside the protection zone and so will not tripping. This can be shown in Fig. 2.

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

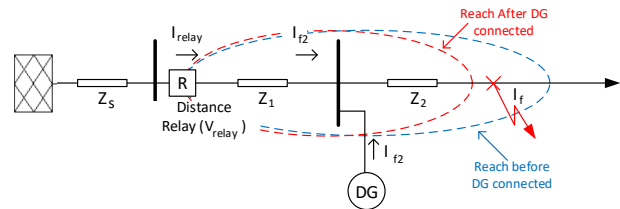


Fig.2: The relay operates outside the zone.

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

$$I_{relay} = I_{f1} \tag{2}$$

Thus, impedance seen by the relay:

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

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

The impedance values seen by the distance relay within the range of the original first protected zone is now added over the relay setting, the distance relay will not maintain protection for the zone. Therefore, the reach impedance and tripping time settings for a zone distance protection with DG are shown in Fig. 3.

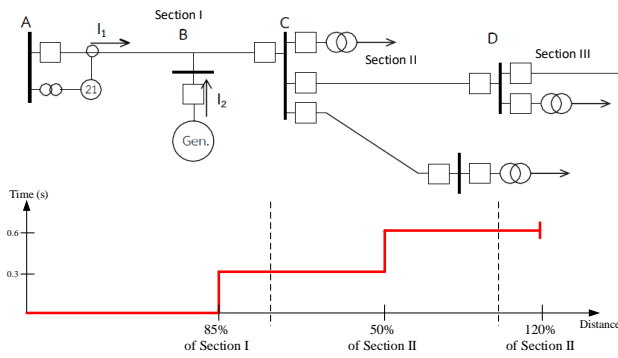


Fig. 3. The reach and time settings for a zone distance protection with DG.

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) is used for the interface and automatically calculated in the PowerFactory program. By denotes of a simple programming language and built-in task, the automation commands can be defined by utilizer to create iterative process or re-calculated on activate systems and final operation results. The structures of DPL are relish to C++ language. Fig. 4 shows the DPL principal structure.

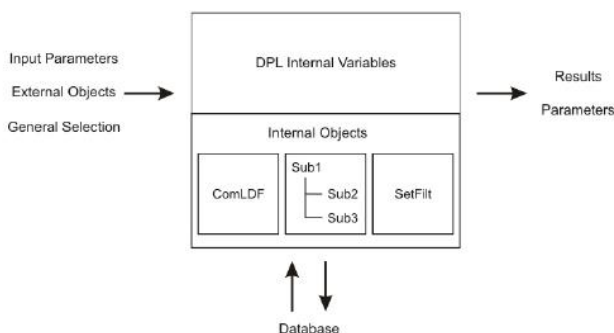


Fig. 4. The structure of DPL.

The DPL command is the key component, which joins different parameters, variables or objects to different functions or internal components and then shows the results or reconfigures parameters. The inputting parameter

on command windows or the defining some parameter on the script can be predefined input parameters of the calculating engine. After execute DPL script, an operations series and initial calculations or other internal functions of the script will be operated. the database will be always communicated and stored the changed parameters, settings or results in the database objects directly. Nearly all objects within the activated project can be gotten to and modified. After finished or in-progress of the execution of the DPL script, the output windows can be shown the changed result parameters or output of elements.

WAPC Tool

The WAPC tool is the automatic calculated tool shown in Fig. 5 combined with three parts including an input initial parameter section, analyze section, and report section.

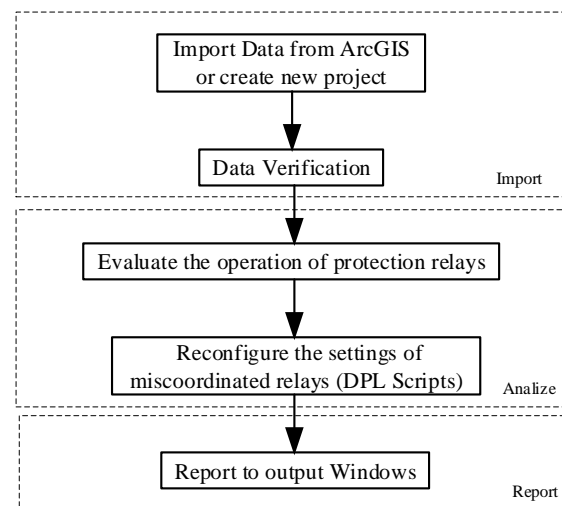


Fig. 5: Flowchart of the WAPC tool.

The PowerFactory software can design the electrical transmission systems case studies and save their cases in the *.pfd file format. Furthermore, the PowerFactory software can communicate with the transmission systems data in the GIS software by using the GIS Import/Export function created by PEA and ESRI [10]. The data which communicated between PowerFactory and GIS software will be recorded as in the *.dgs file type, that can be directly communicated with PowerFactory. Next, the developed DPL scripts, named “Wide-Area Protection Coordination”, was designed by writing DPL script in PowerFactory software for calculating the distance relays miscoordination problems and reconfigure the settings of miscoordinated relays. Finally, the output windows of PowerFactory will be show the results.

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.

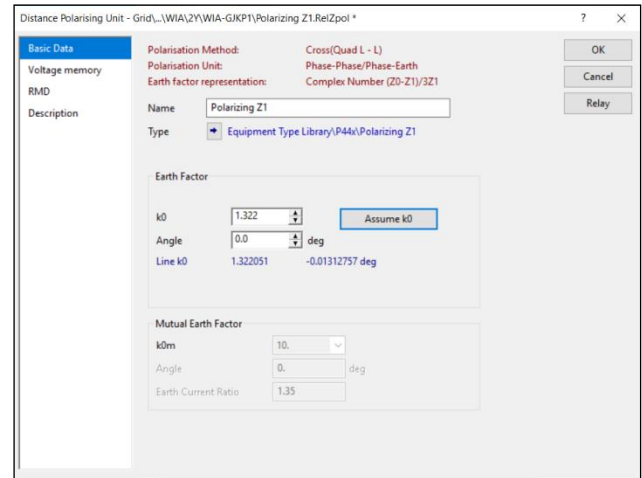


Fig. 7: The assuming k_0 value of polarizing element.

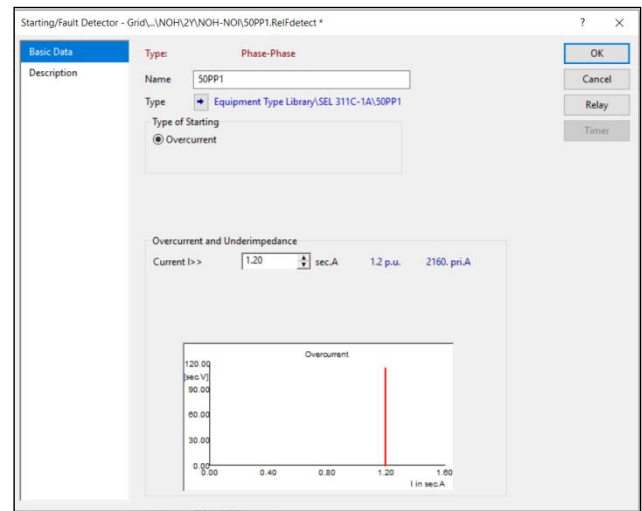


Fig. 8: The starting value of starting element.

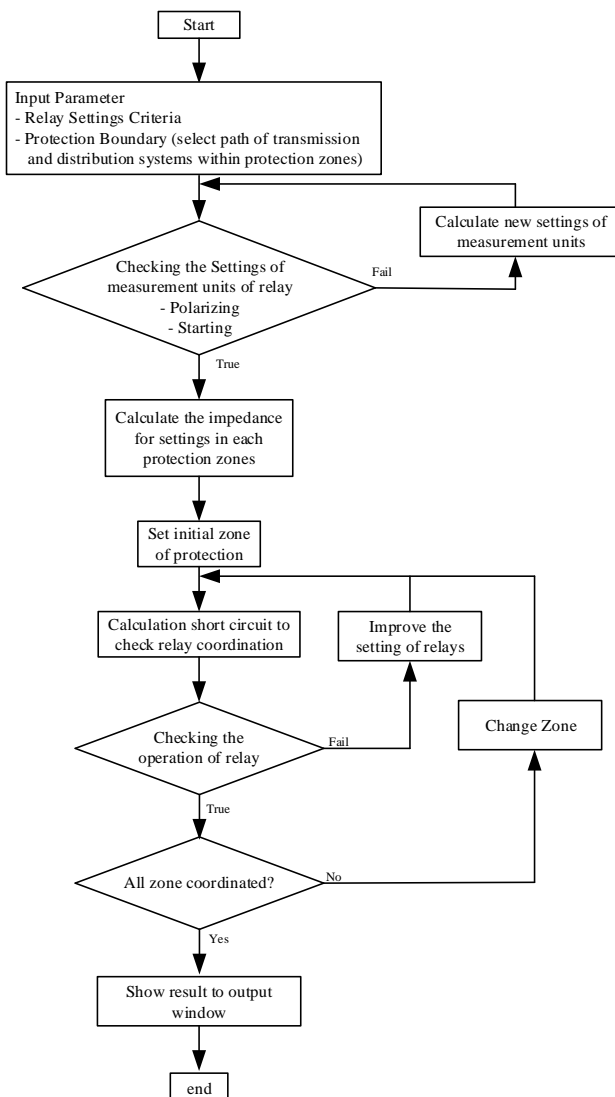


Fig. 6: Flowchart of the purposed WAPC algorithm.

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 settings are calculated for initial zone by calculated single-phase to ground fault to determine the minimum short-circuit current (the defined element within this zone) through tolerable fault resistance in the zone. After the calculation of the ground impedance relay is solved correctly, 3-phase short circuit will be calculated to re-audit the phase impedance relay settings. If the ground and phase impedance relay settings of all zones are solved correctly, the setting will be improved again. The relay settings of new zone will be re-calculated the same process. Finally, if all setting parameters is applied with the settings criteria, the results will be shown the completed settings parameters.

4. CASE STUDY AND RESULTS

Radial System

A 115 kV transmission system of the PEA central 1 region, the main source of this system is generated by AT1_EGAT substation owner by Electricity Generating Authority of Thailand (EGAT) that transfers 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 electric power to the 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.

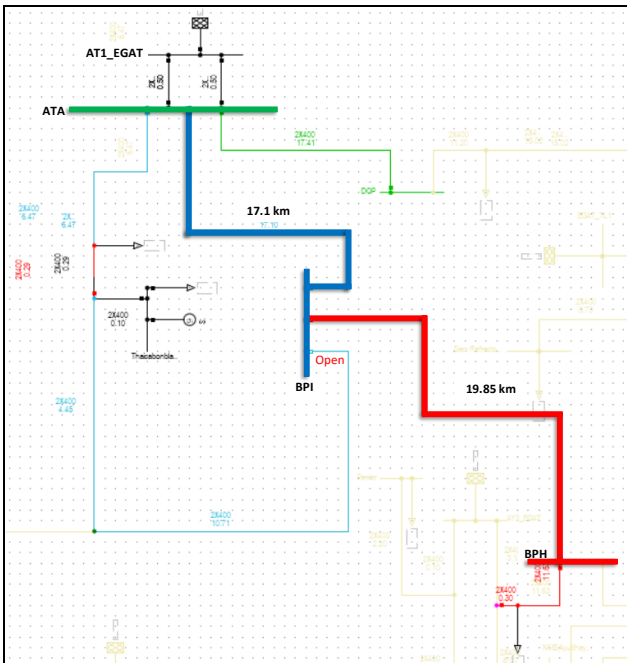


Fig. 9: A transmission system of the PEA central 1 region (used in radial case study).

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

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 section I (line ATA to BPI (17.1 km)) line impedance. The reach impedance of zone 2 was set at 100% of the section I (line ATA to BPI (17.1 km)) line impedance and 23.7% of the section II (line BPI to BPH (19.85 km)) line impedance. The underreach problem can cause miscoordination problems in radial system

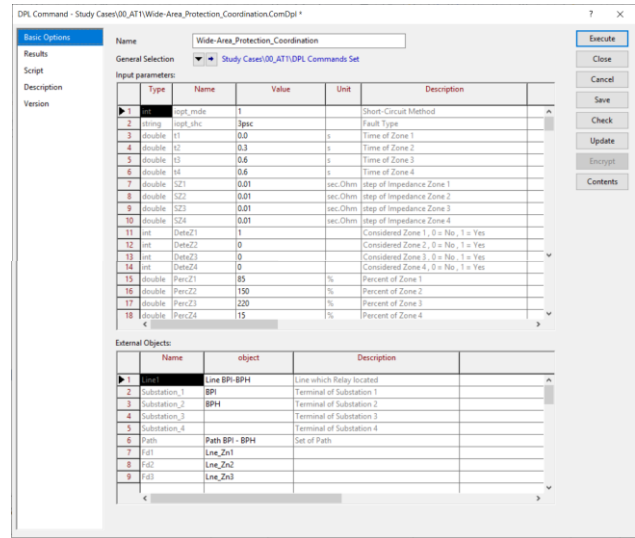


Fig. 10: DPL command window.

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 section I line impedance. The reach impedance of zone 2 was set up to 100% of the section I line impedance and 50% of the section II line impedance. Consequently, the WAPC tool could be used to clarify miscoordination problems in radial system.

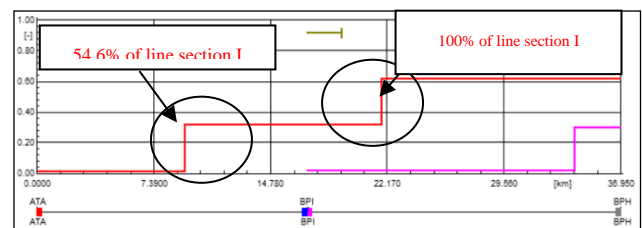


Fig. 11: Time-distance path ATA – BPH before using the tool.

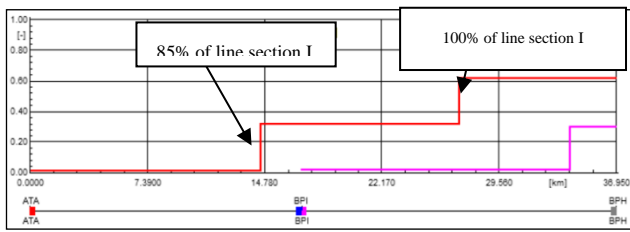


Fig. 12: Time-distance path ATA – BPH after using the tool.

Closed-Loop System with DG

A 115 kV power transmission system of the PEA Southern 1 region, the source of this system is from RB2_EGAT substation by EGAT that transfers 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 system provides electric power to some districts 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 DlgSILENT 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 section I (line RBB to tap line point (3 km) + line tap line point to PTR (20.9 km) = 23.9 km) line impedance. The reach impedance of zone 2 was set at 100% of the section I (line RBB to tap line point (3 km) + line tap line point to PTR (20.9 km) = 23.9 km) line impedance + 50% of the section II (line PTR to DNA (19.85 km)) line impedance.

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 reinforce the system voltage and current so appearing to expand the impedance to the fault seen by the distance relay. The relay then determines that the fault is faraway, outside the protection zone and so the relay 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 the relay at RBB substation after DG connected. The new relay impedance parameters were 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 clarify miscoordination and failure problems in closed-loop

transmission system with DG and help the engineer or technician to design the settings of protection relays more correctly, effectively and takes less time to determine.

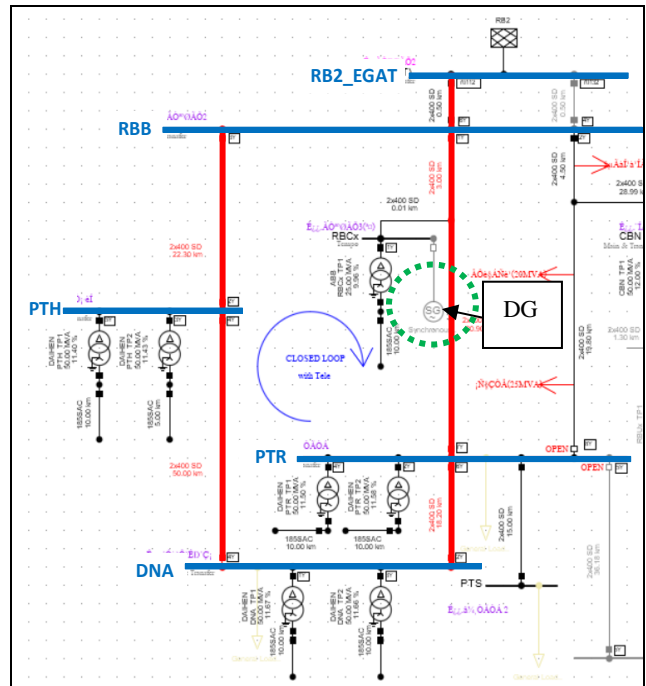


Fig. 13. A transmission system of the PEA southern 1 region (used in closed-loop case study).

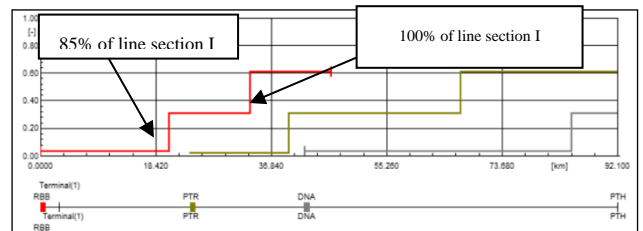


Fig. 14: Time-distance path RBB – PTH before DG connected.

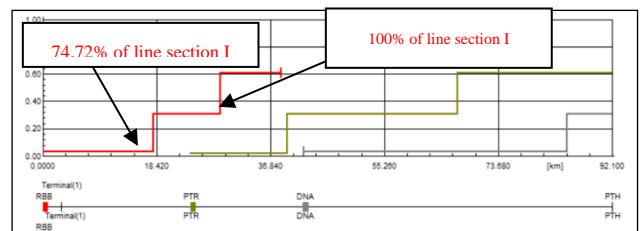
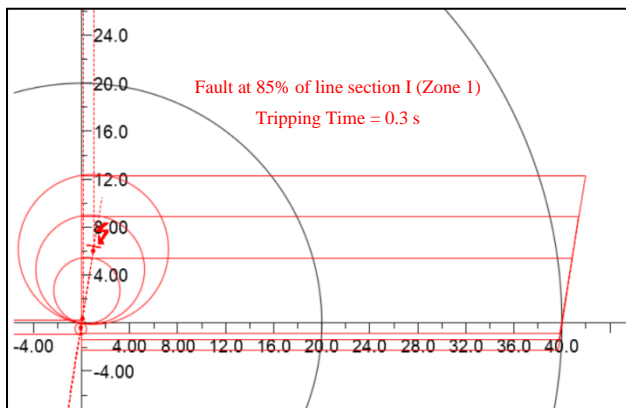
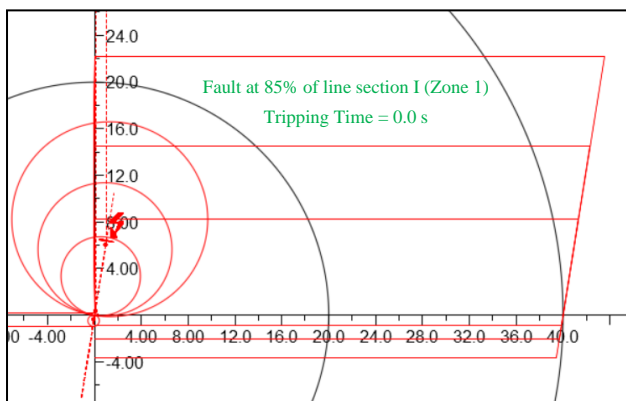


Fig. 15: Time-distance path RBB – PTH after DG connected.



(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 development of Wide-Area Protection and Coordination (WAPC) for electrical transmission systems. The development of WAPC tool could be used to solve the protection relays miscoordinated and decrease the failure tripping of distance relays. This tool was created by designing DPL script, which is build-in function in DIgSILENT PowerFactory software. The proposed tool has been implemented in the PEA's 115 kV transmission systems. Moreover, the existing transmission systems with DG have been studied. In this paper shows that the development of WAPC tool can help the engineer or technician to set-up the distance relays correctly, effectively and decreased the man-day time of engineers.

Although, there are some failure cases that cannot clarified caused by the complex of closed-loop system scheme or the reservations in the entrenched protection relay elements. The benefits of this research can be used by electrical engineers or technician for operated protection relay systems. The future research will be focused on the possible protective classes related to the class of protective relay.

ACKNOWLEDGMENT

The authors would like to thank PEA for technical support and Graduate School and Faculty of Engineering, Chiang Mai University for financial support.

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*.