Development of wide-area protection and coordination for PEA electrical transmission systems

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Abstract

This paper presents the methodology of development wide-area protection and coordination (WAPC) for Provincial Electricity Authority (PEA) electrical transmission systems. The methodology of development WAPC consist of three main parts: the database management system, the evaluated operation of relays and the reconfiguration of miscoordinated relays. DIgSILENT Stationware software is used as a database management software and DIgSILENT PowerFactory is used as an analysis software. This proposed method could be applied to solve miscoordinated relays and to manage data. The proposed method has been implemented in the 115 kV southern 1 region of PEA transmission systems. The test results show the proposed method could be implemented to improve relay coordination. The method is easy to use, flexible and saving time.

Keywords: Wide-Area Protection and Coordination (WAPC), miscoordinated relays, DIgSILENT Stationware, DIgSILENT PowerFactory

1. Introduction

Currently, the electrical transmission systems of the Provincial Electricity Authority (PEA) contain with various types and characters such as radial and closed loop operation. In recent years, the distributed generation (DG) from renewable energy sources has been undergoing consideration for connected directly to PEA transmission system, which cause the control and monitoring system of the power grid to be more complex. Consequently, the designing of protection schemes is very difficult. The protection schemes are designed in a variety of schemes due to many protective devices are located within the transmission system and they should be coordinate correctly. This designing of protection scheme is called “Wide-Area Protection and Coordination (WAPC)”. A WAPC system needs a big database management system to handle with a large amount of the protective device's data. In addition, the electrical transmission systems may be changed the electrical configuration or the electrical transmission systems installed the DG which affects to the protection setting value, so the database information must always be updated. Moreover, 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 these problems. So, the automatic tool should be easy to use, effective and automatically operated.

The case study of RED ELÉCTRICA de ESPAÑA [1] shows the results of developing WAPC in Barcelona, Spain. The statistics for the coordination and miscoordination cases before developing wide area protection and coordination. 16% of the simulations reveal a transmission network coordination...
problem. 12% reveals a distribution or generation coordination problem. To solve the miscoordinations found, 106 transmission protections were readjusted. B. Barman [2] has presented a guideline for the WAPC analysis process and discussed 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 can determine only close-loop structure, it cannot determine wide and large-scale systems.

The development of a wide area system can reduce the miscoordination problem. However, the PEA electrical transmission systems are more complex with larger area. Therefore, the development of a wide area system is very complex, and it can be difficult without effective tools and the management systems. Thus, this paper presents the methodology of development WAPC for PEA electrical transmission systems. The methodology of development WAPC consists of three main parts: the database management system, the evaluated operation of protection relays and the reconfiguration of miscoordinated relays. In this research, DlgsILENT Stationware software is used as a database management software and DlgsILENT PowerFactory is used as an analysis software. The methodology of the WAPC systems are shown in Fig. 1.

![Fig. 1. The methodology of the wide area protection and coordination systems.](image)

2. Database Management by DlgsILENT StationWare

For the part of database management system, a good database management system could be flexible, easy to use and secure. At present, PEA’s staffs use a spread sheet format by Microsoft Excel for storing the protection data and saving it in Google Drive. This storage is difficult and unsafe. In this research, DlgsILENT StationWare [5][6] software is used to create a database. DlgsILENT StationWare has simple user interface, easy to use and secure. The user can log in through a web browser. It can also interface with the relay device directly. The user can directly export the information from relays to StationWare and can display the revision as *.pdf or *.xls files. The DlgsILENT StationWare can also send information directly to DlgsILENT PowerFactory for the power system calculations. The overview illustrating implementation of the protection settings database within the PEA operating is shown in Fig. 2.
Fig. 2 shows DIgSILENT StationWare is a centralization of the WAPC methodology. DIgSILENT StationWare can interface directly to relay devices through the manufacturer’s software. In addition, the relay parameter can be forwarded to the DIgSILENT PowerFactory through the tools which is build-in function in DIgSILENT PowerFactory and StationWare.

![Diagram showing the implementation of protection settings database within the PEA operating.](image)

**Fig. 2.** Overview illustrating implementation of the protection settings database within the PEA operating.

The hierarchy page of DIgSILENT StationWare when accessed via Google Chrome web browser is shown in Fig. 3. This page shows the demarcation of each region of PEA which consists of 12 zones. The users can select the target zone that they want to access relay data. When users click into each region, the window will show the name of PEA substation and when clicking to enter the substation, they will show the name of relay model which installed at that substation. When users click the name of relay, the window will show the relay parameters shown in Fig. 4.

![Hierarchy page of DIgSILENT StationWare.](image)

**Fig. 3.** Hierarchy page of DIgSILENT StationWare.
3. The Evaluating Operation of Protection Relays

For the part of the evaluating operation of protection relays, the Protection Audit Tool [7] in DlgSILENT PowerFactory software is used to monitor the tripping time and coordinate time of the protection device. The structure of this tool can be displayed as shown in Fig. 5.

![Diagram](image)

**Fig. 5. The structure of protection audit tool.**

Firstly, the parameters for auditing are identified following the PEA Protection Setting Criteria [8] to basic options page of Protection Audit Tool shown in Fig 6. Next, the tool calculates short-circuit sweep at all lines of the target path. Finally, the relay tripping times, coordination times and point of miscoordination problems report are shown in the program with table type shown in Fig 7.
4. The Reconfiguration of Miscoordinated Relays Settings

For the part of the reconfiguration of miscoordinated relays settings, the tool for reconfiguration of miscoordinated relays settings was developed by programming DIgSILENT Programming Language (DPL) script [9] in PowerFactory software.

The flowchart of the purposed tool is illustrated in Fig. 8. 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 need to select the path of transmission systems within protection zones to input the protection boundary. Then, the program will check the setting of measurement unit of the relays. If the measurement unit of relays have not been set, the program will calculate new setting parameters. Next step, the program will calculate the impedance for settings in each protection zone. 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 the settings are set to comply with the criteria, the program will export the results for completed settings to the user.

Fig. 8. The flowchart of the purposed tool.

5. Case Study and Results

The case study in this paper is shown in Fig. 9. A transmission system of the PEA southern 1 region is used as case study. The source of this system is from RB2_EGAT substation by Electricity Generating Authority of Thailand (EGAT) that delivers the power through Ratchaburi 2 (RBB) substation to Photharam (PTR) substation, Damnoen Saduak (DNA) substation and Pak Tho (PTH) substation. In this case, a DG is located at Ratchaburi 3 (RBCx) temporary substation, which connected to tap-line between
RBB and PTR substation. Fig. 10 shows the relays data of each substation in DIgSILENT StationWare.

The relay data in DIgSILENT StationWare was imported to DIgSILENT PowerFactory via DPL scripts named “PSMSExport” and “PSMSImport”. The Mapping Table file (MappingTable.xlsx) is responsible for specifying the relay parameters to be imported. The structure of the interface between

Fig. 9. A transmission system of the PEA southern 1 region.

Fig. 10. The relays data of each substation in DIgSILENT StationWare.
PowerFactory and StationWare is shown in Fig. 11.

![Image](image1.png)

Fig. 11. The structure of the interface between PowerFactory and StationWare.

The Protection Audit Tool is used for evaluating operation of protection relays. The parameters for auditing are identified following the PEA Protection Setting Criteria to Protection Audit Tool. Table 1 shows an important parameter using in Protection Audit Tool. Fig. 12 shows the relay coordination results by using Protection Audit Tool.

Table 1. Important parameter using in protection audit tool

| 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) |

![Image](image2.png)

Fig. 12. The relay coordination results by using protection audit tool.

The result in Fig. 12 shows the case of primary relay miscoordination is 8.65% and secondary relay miscoordination is 7.69%. Most miscoordination case are caused by the relay underreach with DG effect. The DG acts to support the network voltage, so it causes the increasing of the impedance to the fault seen by the relay. Then the relay will calculate that the fault is further away, outside the zone of protection and so it will not operate.

The reconfiguration of miscoordinated relays settings tool by DPL scripts is applied to transmission system of the PEA southern 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.13. The relay coordination results after using the reconfiguration of miscoordinated relays settings is shown in Fig. 14.
The result in Fig. 14 shows the relay coordination results after the adjustment of relay settings by developed tool. The case of primary relay miscoordination was decreased to 1.15% and secondary relay miscoordination was decreased to 0.58%. The miscoordination cases are the cases where the miscoordination cannot be solved because of system topology or constraints in the protection technologies installed.

6. Conclusion

The methodology of development WAPC for PEA electrical transmission systems has been presented in this paper. The methodology of development WAPC consists of three main parts: the database management system, the evaluated operation of relays and the reconfiguration of miscoordinated relays. DIgSILENT Stationware software is used as a database management software and DIgSILENT PowerFactory is used as an analysis software. This proposed method could be used to solve miscoordinated relays and to manage data. The results show that can lead the transmission to be more...
reliability by improving selectivity of the protection and therefore limiting the outage area. Even though, there are some cases that cannot be solved regarding the complex 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.

Conflict of Interest

Currently, PEA is responsible for distributing electricity to various areas of Thailand. PEA primary business operations are focused on supplying electrical power and providing electrical power services. PEA is a leading electrical power service provider that has transmission and distribution systems covering of all areas in Thailand. Therefore, the author declares that in this paper no conflict of interest.

Author Contributions

In order to qualify for authorship, all authors have engaged in research and preparation as follows. This study was designed, directed, and coordinated as the principal inspectors, providing conceptual and technical advice for all aspects of this project by Assoc. Prof. Dr. Suttichai Premrudeepreechacharn. performed and supported the experimental data by PEA as Narong Tantichayakorn. Commented by Asst. Prof. Dr. Piyadanai Pachanapan. Finally, summary and wrote the paper by Autthaporn Supannon.

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