Islamic Republic of Pakistan

The Project for Enhancing Grid System Operation and Maintenance Capacities through Strengthening National Transmission and Despatch Company TSG Training Center

Completion Report

December 2023

Japan International Cooperation Agency（JICA）

Asia Engineering Consultant Co., Ltd.

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Abbreviations List

Abbreviation	Name	Remarks
1φT	Single Phase Trip	
2f	Secondary Harmonics	
2φT	Double Phase Trip	
3φT	Three Phase Trip	
AC	Alternative Current	
ARC	Auto-Reclosing	
CB	Circuit Breaker	
CBF	Circuit Breaker Failure	
CT	Current Transformer	
DC	Direct Current	
DMD	Deputy Managing Director	
EAD	Economic Affair Division	
FT	Final Trip	
GM	General Manager	
GSO	Grid Station Operation	
HOC	High-set Overcurrent	For Differential relay of transformer protection
HVDC	High Voltage Direct Current	
JCC	Joint Coordination Committee	
JICA	Japan International Cooperation Agency	
MD	Managing Director	
NPCC	National Power Control Center	
NTDC	National Transmission and Despatch Company	
OC	Overcurrent	
OFR	Over Frequency Relay	
OJT	On the Job Training	
OPGW	Optical fiber in Ground Wire	
P&C	Protection＆Control	
PDM	Project Design Matrix	
PSS	Power System Stabilizer	For Generator control
RTDS	Real Time Digital Simulator	
SCADA	Supervisory Control and Data Acquisition	
SIPS	System Integration Protection Scheme	
SOP	Standard Operating Procedure	
SOTF	Switch Onto Fault	
SP	Solar Power	
TOT	Training of Trainers	
TSG	Technical Service Group	
UFR	Under Frequency Relay	
WG	Working Group	
WP	Wind Power	
Z2	Zone 2	For Distance protection

Pakistan Map (This map has been modified from a United Nations-created map)

Disclaimer:

The notations on this map are for illustrative purposes only, and do not represent JICA's views on the legal status, boundaries and delimitations, as well as geographical names of any country or region.

Chapter 1 Project Overview

background, history and objectives

Chapter 1. Project Overview (background, history and objectives)

1.1. Project Background and Context

Pakistan continued to experience a serious shortage of electricity supply capacity. However, efforts to ensure a stable power supply based on the National Power Policy 2013 have helped to resolve the electricity supply shortage in recent years, and as of 2018, the system had a supply capacity of 27,715 MW, compared to a maximum demand of 26,700 MW. Moreover, the project was designed to ensure sufficient reserve capacity and to develop distribution facilities to meet this reserve capacity from 2019 onwards. The supply capacity with sufficient reserve capacity and the corresponding distribution facilities have been developed.

However, with such an increase in the size and complexity of the electricity system, there is an urgent need to strengthen the basic operational skills of operation and maintenance engineers, especially those involved in the transmission and substation facilities of the distribution system.

Under these circumstances, in order to strengthen the training department of the National Transmission and Despatch Company (NTDC), which is responsible for the transmission and distribution business in Pakistan, the Government of Japan, at the request of the Government of Pakistan, is providing paid account technical assistance under the "The Project for Improvement of Training Capacity on Grid System Operations and Maintenance" (2011-2014) and the grant assistance "The Project for Strengthening Training Center on Grid System Operations and Maintenance" (2016-2018) From this assistance, basic operational capacity has been improved through the effects of simulator training and other training programs.

In the course of this process, on the other hand, a lack of competence in operational work in the event of faults and disturbances in transmission and distribution facilities or power system incidents has been observed. In order to maintain and improve the capacity for more advanced operation and maintenance work, this project provided practical training support for the operation of substation monitoring and control systems and emergency operations in the event of power system faults, as well as support for the improvement of technical skills such as basic analysis of system faults and calculation skills for setting protection relays. In the course of carrying out these tasks, it was conducted a new investigation into the causes of the faults, prevention of recurrence and recommendations for measures and early restoration against the blackout that occurred throughout Pakistan in January 2021. The study revealed that the power system in Pakistan was prone to slight disturbances that immediately spread to widespread power outages, and that the situation was likely to become more serious in the future. For this reason, in making recommendations, it has been tried to convey the importance of the particularly sensitive nature of the power system, as clearly shown by the recent fault, as well as the various measures that need to be taken. However, it is strongly desirable to improve the basic capabilities for stabilizing power systems and ensuring security, since the maintenance and improvement of technology for individual state-of-the-art power facilities and equipment has taken precedence, while analysis and response technology for the dynamic behavior of the entire power system is still in its infancy, and there is a lack of on-the-job training for engineers due to inadequate automatic recording of disturbances to the system.

1.2. Project Objectives

1.2.1. Support for On-Site Technical Support for Power Transmission and Distribution Facilities

Following on from the support for the maintenance and improvement of practical skills in the operation and maintenance of power transmission and distribution facilities up to 2018, the project provided support in response to increasingly sophisticated on-the-job work, with the aim of strengthening the development of grid station operation (GSO) simulator functions, strengthening the training system for their use and implementing training, and strengthening the training function of the system protection relay operation simulator, which enables modelling of the behavior of power systems. Through this support, the project mainly aimed to improve substation staff's know-how on preventing operational errors and their ability to respond and react quickly in the event of system and facility abnormalities, as well as to improve the quality of power system data preparation methods and system understanding among control center staff and basic command operations in the event of a system fault.

1.2.2. Technical Assistance to Prevent Recurrence of Major Blackout Incident

In response to a request to investigate the cause of the 9 January 2021 national blackout incident and to provide recommendations for the prevention of recurrence, the basis was the collection of information on the power system immediately prior to the fault and all fault information, including the operational status of the power plant and transmission and substation equipment involved in the fault and the operation of the grid control system. Although the necessary information was extremely limited compared to the Japanese case, the fault spread over a wide area in seconds was clarified and the cause of the fault spread was determined by using an excessive stability analysis calculation that reproduced the system disturbance after the fault. In addition, the various forms of disturbances that can spread over a wide area, such as those caused by phase faults in the recent operational state of the grid, were clarified and used as the basis for measures to prevent the recurrence of widespread major power outages. The study has shown that the NTDC power system has an inevitable tendency for short duration ground faults to spread to all system disturbances due to the constant northward power flow from the south coast of low-cost coal-fired and nuclear power in Pakistan, and that this tendency will become more pronounced with the increase in demand in the near and medium future term. On the other hand, the main protection relay for long-distance transmission lines, which prevents the spread of system disturbances, has an inadequate fault clearing time of 0.1 s (0.05 s in Japan) for the elimination of faults on transmission lines, and the transmission line fast reclosing function immediately after tripped is also inadequate in the old system. In addition, the system stabilization and protection relay system, which prevents and limits the spread of system disturbances, is limited to a few system separation function systems and is almost functionally inadequate.

In consideration of this situation, it has been proposed to promote an understanding of the grid structure as a factor in the spread of faults, and recommendations have been made on the necessary measures for the preparation of protection relays as numerical type and grid stabilizing relay systems.

In addition, it is extremely important to ensure the proper operation of the under-frequency relay (UFR), which is used for emergency demand suppression in order to recover within a few seconds from a large frequency drop caused by a sudden shortage of supply power in the event of a fault like split the grid. For this UFR operational measure, a frequency analysis method that takes into account the system characteristics and the precise setting of the operating function were also recommended. However, there have been frequent cases where NTDCs and power supply plants of other companies have been disconnected from the UFR during its frequency recovery control to protect power supply equipment, leading to major blackouts with no effect on the UFR control, and the progress of mutual coordination measures between the companies remains difficult.

In order to accurately assess the need for the various grid protection relay measures and grid stabilization measures mentioned above, and to formulate concrete plans and promote their smooth implementation, there is an urgent need to analyze various power system disturbance phenomena and to raise and disseminate power system technology to identify grid protection control measures that can prevent fault spill-over. Therefore, above all, it is considered necessary to promote the acquisition of system analysis technology and to support the development of advanced system protection and control technology by utilizing this technology.

In the event of a blackout, all power plants must be shut down and power distribution facilities must be restored to a state of no-voltage as soon as possible. When restoring all such blackout facilities, an important first step is the smooth initial transmission of power via transmission lines from distant hydroelectric power sources to quickly start up supply power. However, abnormal phenomena often occur at transmission lines energization in this first step. The restoration procedure requires sophisticated power supply command operations to avoid abnormal phenomena, and including securing power supply for thermal power supply start-up as the second step, and restoring each power plant supply capacity and balancing local demand supply as the third step. The blackout in January 2021 took 22 hours to restore, and detailed support was provided for the blackout early restoration operation method and their operation rules, which was based on the Japanese established method including the wide-area blackout early restoration measures established from the perspective of absolute avoidance of long-term blackouts in critical areas including the city centers of Japan's utilities. The support was also provided in detail, including practical improvements such as periodic simulator training. In order to maintain the effectiveness of the support, it will be necessary to strengthen and improve the communication channels between dispatch control centers and between dispatch control centers and gid stations, as well as to support techniques for analyzing abnormal transmission line phenomena during restoration.

Chapter 2　Issues and Management in Project Implementation

Chapter 2. Issues and Management in Project Implementation

2.1. Establishment of the JCC

The project was implemented by holding a kick-off meeting on 11 June 2021 with the participation of relevant stakeholders and selecting the members of the Joint Coordination Committee (JCC) to be held approximately once every six months for decision-making and coordination with relevant organizations. The NTDC agreed to proceed with the participation of the following members.

At the kick-off meeting, the Japanese project team proposed the clarification of the major power outage that occurred across Pakistan in January 2021 and support for countermeasures. After reviewing the proposal, the NTDC agreed to proceed with the technical assistance as part of the project.

Pakistan side	● Joint Secretary NTDC, Ministry of Energy (Power Division) ● Joint Secretary EAD, Ministry of Finance Revenue and Economics Affairs ● Managing Director, NTDC ● General Manager, TSG NTDC (Project Director) ● Chief Engineer, TSG North (Project Manager) ● General Manager, Asset Management/GSO North NTDC ● General Manager, Power System Planning NTDC ● General Manager, HVDC NTDC
Japan side	● JICA Headquarters (Energy and Mining Group, Infrastructure Management Department) ● JICA Pakistan Office ● Project Team (Consultant)

2.1.1. Establishment of Working Groups (WGs) and Roles of WGs

Together with the JCC, the members of the Working Group ('WG'), which is to be established as the implementation structure of the Project, were discussed with the NTDC and selected as shown in Fig. 2.1 below. In order to smoothly implement the Project, three WGs were formed with NTDC and Japanese experts, such as improving the training capacity and training functions of TSGs for operation and maintenance of transmission and substation facilities, proposing a framework (strategy, system, budget, etc.) for human resource development at NTDC, and preparing various manuals on practical operation of GSOs and protective relays. Organized WGs were as follows;

WG1: System Design

WG2: GSO Simulator Training/ Human Resource Development

WG3: Protection Relay Training/ Human Resource Development

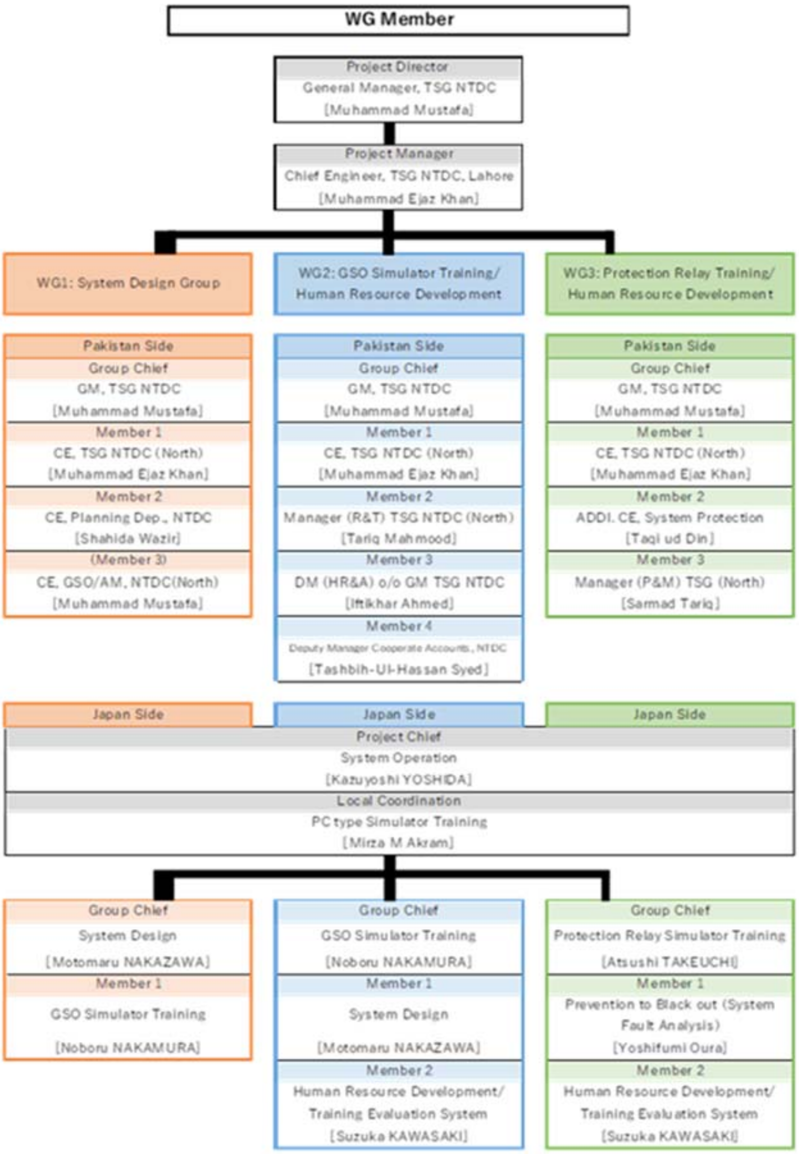


Fig 2.1 Organization of Working Groups

Chapter 3 Activities

Chapter 3. Activities

3.1. Holding of the JCC

In order to facilitate the project, a JCC (Joint Coordination Committee) was held once every six months to report on the activities of each WG and to review the progress of the project. The JCC was held three times during the project period. The contents of each JCC session were as follows.

3.1.1. 1st JCC 8 December 2021

(1) Agenda.

1) About the New System Diagram

It was decided to reflect the ±660 kV HVDC, CASA1000, AC500 kV, AC765 kV, WP, SP system in the new system diagram, and the first draft was presented for discussion. It was decided to continue the study in WG1.

2) Provision of PC Version Simulator

As the GSO simulator installed at the TSG alone limits the number of personnel who can participate in the training, it was decided to provide 22 PC version simulators with the same functions as the GSO simulator installed at the TSG at the main substations. Two of these simulators were to be used by the consultants to prepare simulation cases and procedures, and were to be handed over to the NTDC at the end of the project.

3) Counter Measure for Blackout

It was decided to investigate the causes of the Blackout that occurred in January 2021 and blacked out the entire country of Pakistan, and to study measures to prevent a recurrence. In the course of the study, it was requested the submission of recorded data on relay operation, circuit breaker operation and UFR settings at each power station.

In addition, technical training using the X-TAP software developed by the Central Research Institute of Electric Power Industry in Japan was proposed as a technology for analyzing the excessive stability of power systems, which was accepted.

The need to prepare a procedure document on how to re-energize power from blackout was explained and discussed by the NPCC.

3.1.2. 2nd JCC 16 November 2022

(1) Agenda

1) New system diagram

The results of the WG1 study of the system diagram, which included all ±660 kV HVDC, CASA1000, AC500 kV, AC765 kV, WP, SP requested by the NTDC, were explained and agreed upon.

It was decided to reflect this system diagram in the GSO simulator installed by the TSG and the PC version of the simulator.

2) Human resource development using the GSO simulator

The following items to be introduced in Japan were explained and its introduction at the NTDC was strongly recommended.

- Utilization of the GSO simulator to improve the skills of substation and control centers staffs in normal operation, isolation of fault points and restoration operation at the time of a fault, and to increase their motivation in Japan.
- The outline of the skills certification system implemented by the Japanese Electric Power Company, which has proven effective.

3) Blackout analysis and recommendations on measures to prevent recurrence

The results of the power system analysis of the blackout that occurred in January 2021 were explained and the following nine items were recommended for improvement.

(i) Application of digital current-differential relay as main protection relay for transmission line

(ii) Shortened operating time by digitizing backup protection relays

(iii) Application of voltage phase comparison method as out of step separation relay

(iv) Maintenance of fault-extension-prevention relays

(v) Arrangements with UFR and OFR generators

(vi) Preliminary system analysis at test power transmission and review and maintenance of operation manual at test power transmission

(vii) Maintenance of recording equipment

(viii) Accelerate recovery by developing OPGW and introducing SCADA at local power supply stations

(ix) Maintenance of interlock

The results of this analysis and recommendations for measures to prevent recurrence are to be discussed within the NTDC and with the relevant departments.

3.1.3. 3rd JCC 19 July 2023

(1) Agenda

1) New System Diagram Trainings 200 case scenario prepared

It was reported that 200 case scenarios for operational training with the new system diagram had been organized and prepared for beginners, intermediate and advanced users, which was approved.

2) PC Version Simulator

It was reported that 10 additional PC simulators requested by the NTDC had been handed over.
With this provision, the PCs could be distributed to all 220 kV and 500 kV substations of the NTDC.
MD was instructed to report regularly on the status of training at each substation.

3) Counter measures for Blackout

The following countermeasures to prevent recurrence of blackouts, which should be implemented without incurring too much cost, were proposed.

(i) Installation of recording equipment and preservation of records

(ii) Centralized management of protection relay settings

Setting coordination between hydropower plants, thermal power plants and power system protection relays

(iii) improved protection relay system

Main protection relay; Current Differential Relay system
Back up relay; Review of timer settings to be shortened
Introduction of power system stabilization relay system

(iv) Voltage/reactive power control VQC (Voltage and reactive power Control) System

(v) Clarification of procedures for recovering from blackout

(vi) Black -start over voltage (Prior power system analysis)

4) TOT Japan

It was agreed to organize training in Japan in May and September 2023, including visits to control centers, substations, technical training centers and Japanese electrical equipment manufacturers in order to raise awareness of the human resource development and equipment upgrades that the NTDC should aim for in the future in order to enhance the effectiveness of the project.

5) Next project

The NTDC informed the participants that Pakistan was a large country and that the current TSG alone was not sufficient to provide training for human resource development. Therefore, a request was made to set up another TSG in the premises of the Jamshoro Substation in the southern region, which would be discussed within JICA.

The consultant recommended that there was an urgent need to train personnel who could analyze the power system stability and transient phenomena so that the NTDC could accurately perform power system operations in order to prevent the recurrence of blackouts.

3.2. Activities of each Working Group

3.2.1. [WG1] Grid Diagram Preparation

With regard to the new system diagrams (765 kV/500 kV systems, ±660 kV HVDC systems and renewable energy systems) to be introduced into the GSO operational training simulator and PC version of the simulator, the system configuration was finalized in February 2022 and the transmission line color scheme and substation and transmission line names were finalized in May 2022. Development work on the updated software, including improvements to the analytical calculation convergence of the simulations, was completed.

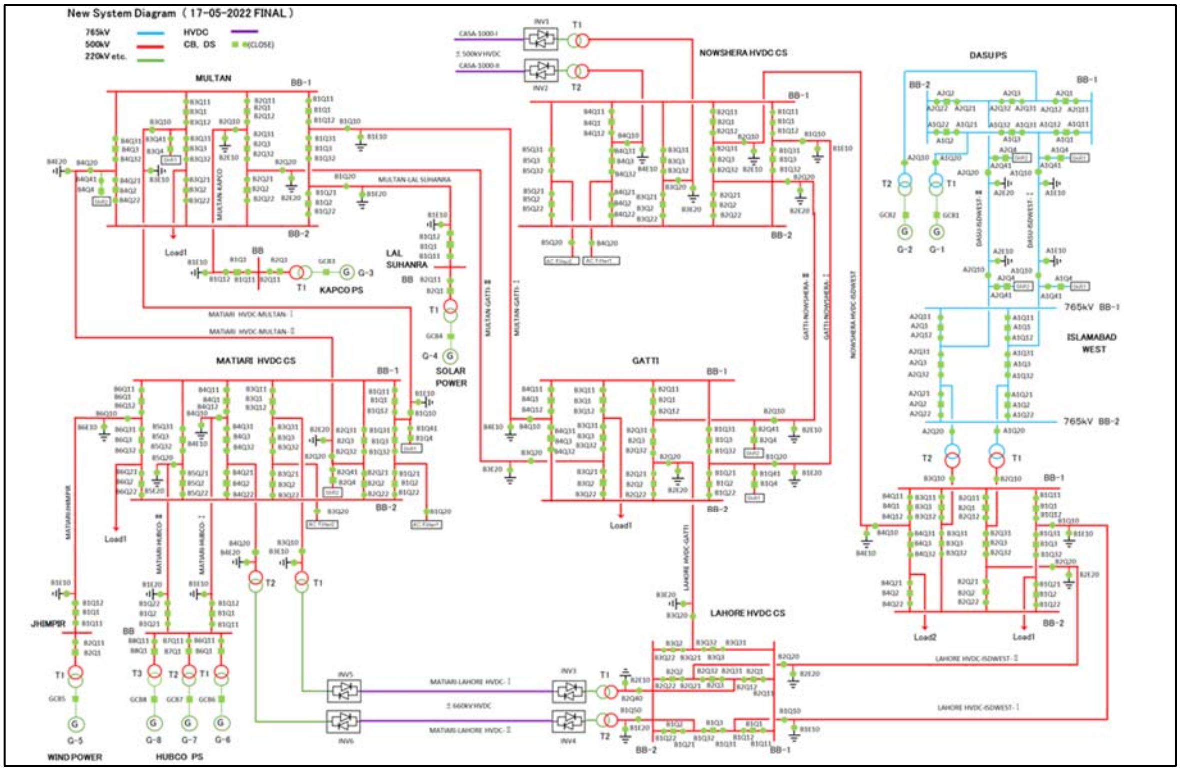


Fig 3.1 Final version of the new grid system diagram (as of May 2022)

In December 2022, the installation of the updated software on the TSG's GSO operational training simulator was carried out, accompanied by an engineer from the development manufacturer, and the software was inspected and confirmed to work with the NTDC/TSG.

After the said installation work, a software transfer ceremony was held, attended by NTDC executives and other relevant personnel from various departments, where the new system diagram was mutually confirmed.

During the seventh visit to NTDC in June 2023, the new system diagram and 200 training scenario cases based on the new system diagram were installed in the GSO simulator and their operation was checked.

In addition, in July 2023, the installation of the new system diagram on the PC version of the simulator was conducted with trainers (including one female trainer) from 20 locations that had already been distributed and 10 newly distributed locations, as well as simulation training on the new system diagram.

Furthermore, the 200-case training scenarios on the new system diagram and the procedure manual on how to implement them were explained and the actual procedure manual was circulated.

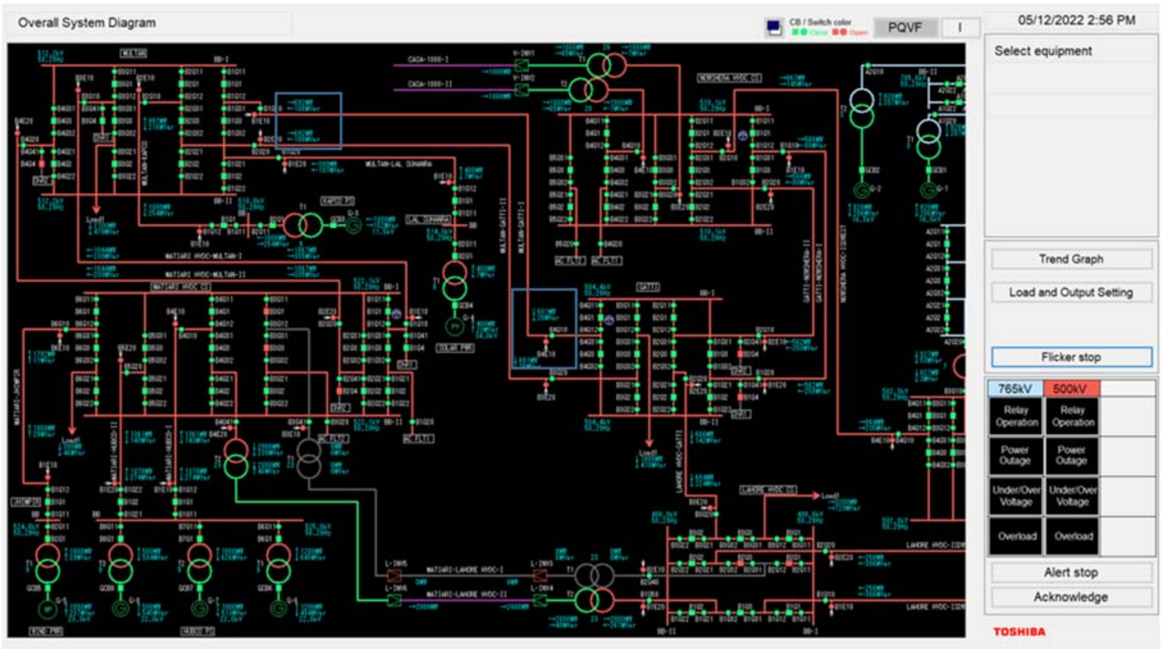


Fig 3.2 The new system diagram on the simulator display

3.2.2. [WG2] GSO Operation Training

(1) GSO simulator training scenario case development

For the GSO simulator, 200 scenario cases were created for each of the new and old system diagrams, so that substation personnel can safely and without error operate the equipment during normal and fault conditions.

The scenarios were compiled into three levels - normal operation, single fault operation and complex fault operation - to enable step-by-step training of beginners, intermediate and advanced operators, in order to encourage NTDCs to introduce the skill certification system implemented by the Japanese utility company.

(2) PC simulator distribution

Pakistan is a large country, and a single TSG training center is not sufficient to provide adequate training. In response to particular requests, PC simulators were distributed to major 220kV and 500kV substations. Thirty-two units were distributed as shown in Table 3.1and Table 3.2 below.

Table 3.1 PC simulators delivered place

No.	Facility	Location name	Delivery date
1	500kV Grid Station	Sheikh Muhammadi Peshawar	17th Jan., 2022
2	500kV Grid Station	Rawat	
3	500kV Grid Station	Gatti Faisalabad	
4	500kV Grid Station	Sheikhupura	
5	500kV Grid Station	Multan	
6	500kV Grid Station	Rahimyar Khan	
7	500kV Grid Station	Guddu	
8	500kV Grid Station	Shikapur	
9	500kV Grid Station	Jamshoro	
10	500kV Grid Station	Dera Ismail Khan	
11	220kV Grid Station	WAPDA Town Lahore	
12	220kV Grid Station	Ludewala Sarghoda	
13	220kV Grid Station	Burhan	
14	220kV Grid Station	Quetta Industrial	
15	220kV Grid Station	TM Khan Rd Hyderabad	
16	220kV Grid Station	Jamali	
17	TSG(North) Training Centre	Lahore	
18	TSG(South) Training Centre	Hyderabad	
19	TSG Training Centre	Tarbela	
20	NPCC Power control Centre	Islamabad	
21	TSG(North) Training Centre	Lahore	27th Oct., 2023
22	NTDC Planning Division	WAPDA House Lahore	

Table 3.2 Additional delivery

No.	Facility	Location name	Delivery date
23	TSG Training Centre	Gatti Faisalabad	20th July, 2023
24	500kV Grid Station	New Lahore	
25	500kV Grid Station	Faisalabad West	
26	500kV Grid Station	Sheikhupura	
27	500kV Grid Station	D.G. Khan	
28	500kV Grid Station	Yousuf Wala	
29	500kV Grid Station	Muzaffargarh	
30	500kV Grid Station	Rahim Yar Khan	
31	500kV Grid Station	Dadu	
32	500kV Grid Station	NKI Karachi	

(3) Training in GSO and PC simulators

1) Group training instruction at TSGs

(i) 1st session 24 January 2022.

Explained and instructed the 20 participants to whom the PC simulators were distributed on the overview of the system, how to operate it and the purpose of the simulator training. Total attendees were 30.

(ii) 2nd session 25 and 26 January 2022.

Training was conducted on two cases of transformer outage for maintenance work and busbar outage by fault using the PC simulator. Approximately 40 participants over the two days

(iii) third session 19 and 20 May 2022.

Explanation of the importance of the Operating Procedures Manual and complementary training on two cases of busbar outage for maintenance work and transmission line outage by fault were conducted. 26 participants

(iv) fourth session 19 December 2022.

New system software was installed on the GSO simulator and its operation was verified in a DC transmission line route faults and a 500 kV busbar fault. 20 participants

(v) 5th session 20 and 21 July 2023.

Two cases of DC transmission line route faults and simulated system instability were conducted. 30 participants

(vi) 6th session 26 and 27 October 2023.

Guidance on training methods was provided to new WG2 members.

2) Training guidance at substations

Visited PC simulator distribution places to conduct training and check the utilization of the PC simulators.

- First 220 kV Grid Station WADA Town, 18 May 2022
- Second 500 kV Grid Station RAWAT, 20 May 2022
- 3rd 220 kV Grid Station Gujrat, 21 Nov 2022
- 4th 220 kV Grid Station OKARA, 25 July 2023
- 5th 500 kV Grid Station New Lahore, 28 Oct 2023

(4) Human resource development using simulators

As the operation of substation equipment is fundamental to the stable supply of electricity, it is very important to improve the skills of on-site technicians and ensure their motivation. For this reason, the Japanese Electric Power Companies have achieved significant results in improving the technical skills and maintaining the motivation of on-site technicians through the use of operational training simulators and a system of step-by-step skills certification.

NTDC conducts examinations and interviews for the appointment of managers and promotes them, but there are no initiatives for on-site engineers. However, there are no initiatives for field technicians.

Using the simulator provided this time, the NTDC will promote the introduction of a skills certification system, which is being implemented in the Japanese electric utilities.

(5) Maintenance of simulators

Through training using the GSO simulator at the TSG, equipment operation and maintenance methods were taught, so it is believed that the simulator can be adequately maintained and managed.

3.2.3. [WG3] Training for Protection Relay Operation, and Analysis of Black-Out and Recommendation for Countermeasures

(1) The manual revision for Protection Relay Operation Simulator

1) Purpose for revision of the manual

(i) The procedure for the user (NTDC) to change value of constant / impedance, which are set by representative value, for transmission line, transformer and busbar, to be explained using figures. Due to this explanation, improvement for effect of training is expected, because following can be implemented.

- ✓ Simulation with values according to the actual system
- ✓ Specific training tailored to the trainee's unique system

(ii) Details explanation about connection of protection relay is added, by using typical relay of ABB, SIEMENS and GE. Therefore, when verification is required, the relay of each manufacturer can be connected to the simulator to facilitate operation check and setting check.

(iii) Description of special test mode

(iv) If a fault caused by close of circuit breaker during close of earthing switch (Switch onto Fault) is occurred, distance protection may not operate, because voltage input to a relay continues "0". And also, there is a possibility not to operate main protection differential relays by distorted current with CT saturation because of large fault current. This special test makes it possible to verify the effectiveness of relay application with suitable settings and countermeasures against Switch-onto-fault, and promotes understandings of the importance of the application method and settings of protection relays.

2) Revision items

(i) Addition of detail explanation about setting change for impedance etc.

An example of the procedure for changing the transmission line impedance is shown below.

<Transmission line impedance>

Below figure shows example for setting of transmission line impedance with fault point.

In this case, fault point is set in center of "Transmission line impedance 1" and "Transmission line impedance 2".

· Transmission line impedance (Total) = Transmission line impedance 1
+ Transmission line impedance 2

Fault point is variable and set by [Fault Selection Ratio]. For example, if [Fault Selection Ratio] is set as 10%, fault is occurred on Transmission line impedance 1: 10%, Transmission line impedance 2: 90%. The [Fault Selection Ratio] is settable when fault point that want to be changed is selected on simulation screen.

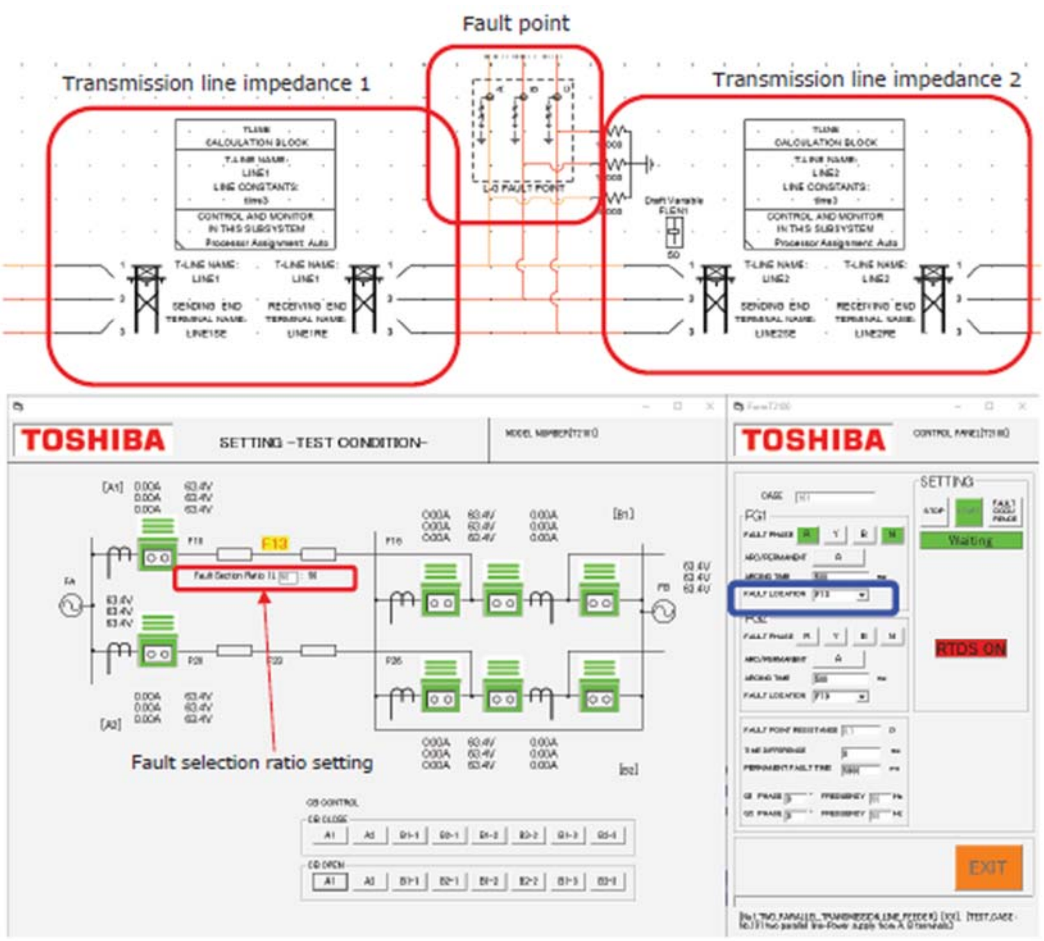


Fig 3.3 Procedure for modification of line impedance

For details, please refer to the following page of Manual (5B2L1127).

P-126 to P-138: RSCAD configuration description - Module connection, setting procedure of power supply, frequency and fault point

P-139 to P-141: Setting change of transmission line impedance.

P-142 to P-143: Setting of fault point for transformer

P-144 to P-150: Detail control procedure of RTDS (RUNTIME)

(ii) Detail explanation of connection with protection relay (ABB, SIEMENS and GE). Detail explanation of connection with example by ABB, SIEMENS and GE relays are added.

P-82 to P-101: Addition of detailed explanatory drawing of connection part between relay and interface box

P-103 : Addition of connection explanation for SIEMENS 7SD5

Connection example of transmission line feeder: 2LA (Line2 - Terminal A)
(in case of SIPROTEC 4 7SD5-SIEMENS)

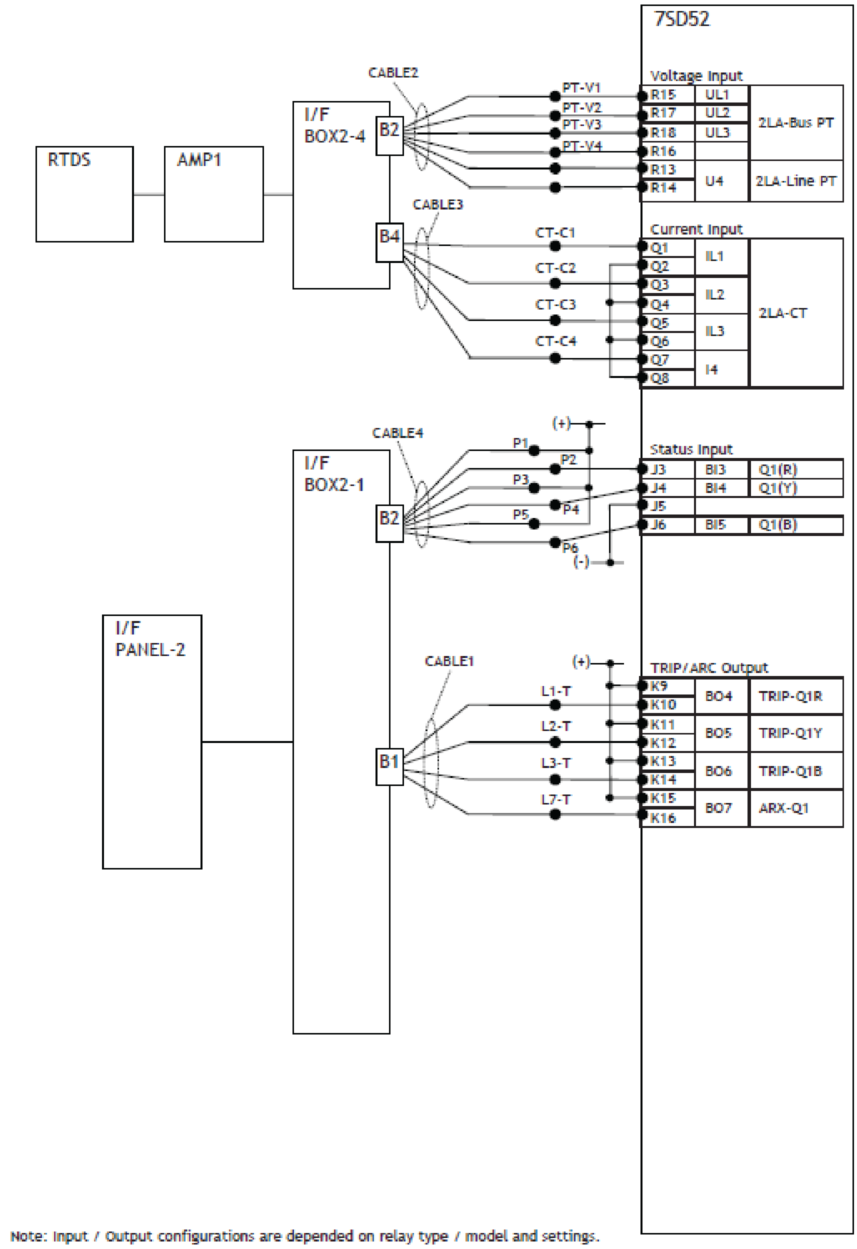


Fig 3.4 Connection between Protection Relay Simulator and relay terminal (7SD5)

P-104: Addition of connection explanation for ABB RET670

P-105: Addition of connection explanation for GE Multilin B30 Please refer to the manual (5B2L1127) for details.

(iii) Description of special test mode

i) Verification that 2f block for inrush countermeasures (inrush judgment with second harmonic generation and differential relay operation blocked) is performed when the current waveform is distorted.
Please refer to P-59 of manual (5B2L1127).

ii) In the case of a three-phase ground fault (SOTF: Switch onto fault) in which a circuit breaker is turned on when the three-phase ground is closed, the voltage remained zero from before the fault to during the fault, therefore distance relay does not operate. A method for confirming and verifying, that SOTF countermeasures (OC-SOTF) using overcurrent relays are effective as countermeasures, is added.
Please refer to P-152 of manual (5B2L1127).

Simulation for fault case of switch onto fault

If circuit breaker is turned on when three phase to ground fault has existed before CB close, line voltage will continue as zero form pre-fault occurrence. (SOTF (Switch onto Fault) situation)

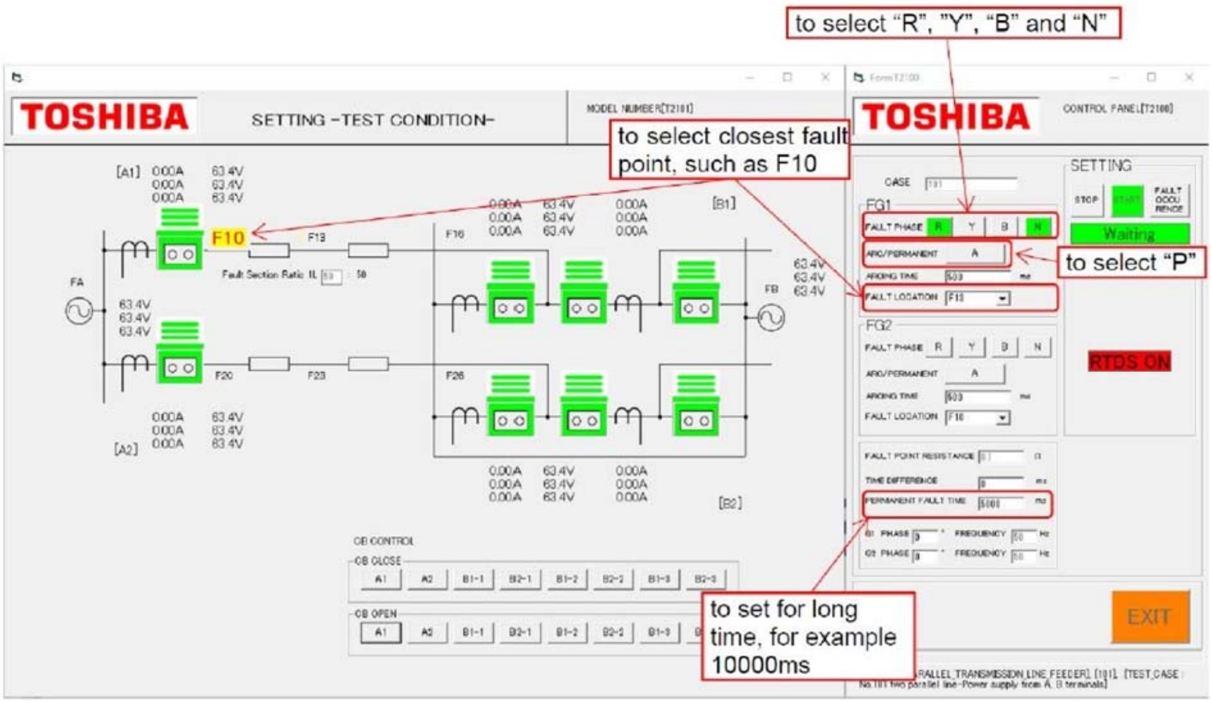
And, there is possibility of distance relay non-operation since input voltage is zero before CB close and after CB close.

Then, this case can be used for check and understandings of SOTF phenomenon and effectiveness of countermeasures like OC-SOTF function.

SOTF situation is simulated by setting the closest fault point as follows.

Step 1) Conditions are set as;

- FAULT PHASE: to select “R”, ”Y”, “B” and “N”
- ARC/PERMANENT: to select “P”
- FAULT LOCATION: to select closest fault point, such as F10
- PERMANENT FAULT TIME: to set for long time, for example 10000ms



Step 2) Both side CBs are opened from interface panel

Step 3) To click the [Fault] red button

Step 4) CB, which is located near of fault point, to be closed from interface panel within duration of PERMANENT FAULT TIME after click the [Fault] button

Fig 3.5 Operation display of Protection Relay Simulator (SOTF case)

(2) Implementation of protection relay technology training

During the third visit (May 2022), training was conducted on the relay methods standardly applied by Japanese electric power companies (power transmission line main protection relay: current differential relay, back-up protection relay: distance relay, Busbar protection relays, transformer protection relays, preventive spreads of fault relay systems).

1) Current differential relay

NTDC has not adopted this method due to issues such as the equipment of high-speed communication channels. Because current differential relay has reliable fault phase selection and high speed fault elimination, the multiphase auto-reclosing method can be applied in many cases, as it enables high-speed reclosing even in transmission line faults that span two parallel circuits. This greatly contributes to improving transient stability. NTDC participants deepened their understanding by explaining the merits of current differential relays and the status of their adoption in Japanese transmission line protection.

I. Current differential relay enables to shorten the fault clearing time of the transmission line, which is based on conventional distance relays, to be shortened from 0.1 seconds to the guaranteed value of 0.07 seconds (actual time: around 0.05 seconds), and this makes it possible to shorten the fault clearing time of the backup protection relay.

II. It becomes possible to adopt a multi-phase auto-reclosing method, which can avoid two-line transmission line disconnection in fault and improve system stability.

Multi-phase auto-reclosing is adopted to a parallel two-circuit transmission line. When a fault occurs across two circuits, the faulted phases are tripped (CB opened) at first. If two or more different phases remain (not faulted poles and CB keeps closing) in total for the two circuits, it can be determined that both ends of the transmission lines are interconnected, and high-speed auto-reclosing can be performed. Table 3.3 shows the effect of increasing the number of cases in which auto-reclosing can be performed using the multi-phase auto-reclosing method. The yellow part represents the case where reclosing (ARC) is not possible with conventional single-phase or three-phase auto-reclosing, resulting in final trip (FT), but reclosing is possible with multi-phase auto-reclosing.

Table 3.3 Effect of increasing cases using the multi-phase auto-reclosing

Case	Fault phase						Tripping and reclosing	
	#1 line			#2 line			#1 line	#2 line
	A	B	C	A	B	C		
1	X			--	--	--	1φT→ARC	--
2	X	X		--	--	--	3φFT	--
3	X	X	X	--	--	--	3φFT	--
4	X						1φT→ARC	
5	X			X			1φT→ARC	1φT→ARC
6	X	X					2φT→ARC	
7	X				X		1φT→ARC	1φT→ARC
8	X	X		X			2φT→ARC	1φT→ARC
9	X	X		X	X		3φFT	3φFT
10	X	X	X				3φT→ARC	
11	X	X				X	2φT→ARC	1φT→ARC
12	X	X			X	X	2φT→ARC	2φT→ARC
13	X	X	X	X			3φT→ARC	1φT→ARC
14	X	X	X	X	X		3φFT	3φFT
15	X	X	X	X	X	X	3φFT	3φFT

Additionally, Table 3.4 shows the track record of avoiding two-line disconnection faults using the multi-phase auto-reclosing method in Japan.

Table 3.4 the track record of multi-phase auto-reclosing compared to single-phase auto-reclosing

Fault phase and fault number of line	Number of faults	Multi-phase auto-reclosing	Single-phase auto-reclosing
2 phases at 2 lines (fault: 2 to 4 conductors)	9	9: Success auto-reclosing	9: 2 lines disconnected
2 phases at 1 line	48	48: Success auto-reclosing	48:1 line disconnected
1 phase at both lines	12	12: Success auto-reclosing	12: Success auto-reclosing
1 phase at 1 line	199	199: Success auto reclosing	199: Success auto reclosing

Note: The record during 24 years

The introduction of digital current differential relays as the main protection relays for NTDC's transmission lines is strongly desired, but the challenge is that it is necessary to prepare the dedicated high-speed communication infrastructure for current differential relays.

2) Distance relay

Distance relays and directional comparison protection methods using distance relays are equivalent to the main protection applied to NTDC's power transmission line protection. It was explained the principle of distance relays, problems and countermeasures arising from the principle, and performance limits. In addition, it was explained in particular the case where the circuit breaker was tripped due to CB closed without disconnecting the earthing switch, which triggered the large-scale power outage (blackout) in January 2021. NTDC understands the effectiveness and necessity of implementing countermeasures for switch-onto-fault (SOTF) which distance relays cannot operate due to non-voltage before fault and during fault. Digital relays have the countermeasure as the method OC-SOTF (overcurrent relay countermeasure scheme).

(i) Switch onto fault countermeasures

Figure 3.6 shows countermeasures against switch-onto-fault which means CB close of the transmission line with fault. For example, forgetting to remove the earth switch, the CB is turn to close. The transmission line is outage and there is no voltage before the CB closed on, and even after the CB is closed on, there will be no voltage because there is a 3-phase ground fault (earthing). For this reason, distance relays cannot operate in principle with no voltage. As a countermeasure, the conditions under which a power transmission line outage is detected are extended by approximately 0.5 seconds after the circuit breaker is closed, and the circuit breaker is tripped by AND conditions under which the overcurrent relay (OC SOTOF) is activated due to the inherent fault.

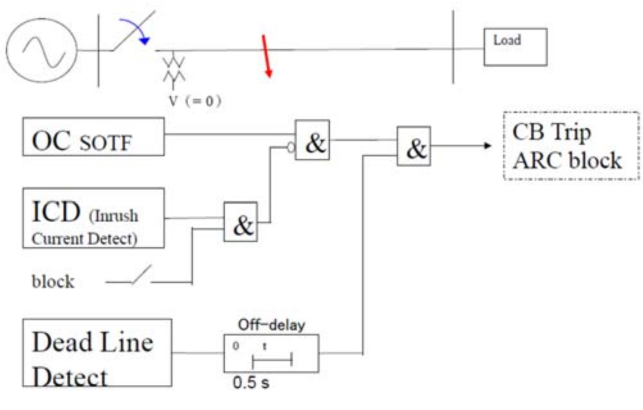


Fig 3.6 Countermeasures against switch-onto-fault

There may be many places where old electromagnetic protection relays are still in use in NTDC, and it is necessary to investigate distance relay to be added this measure.

(ii) Faster backup protection relay in its operating time

The large power outage fault, black-out in January 2021 was triggered by a main protection malfunction, but there were also delays in clearing the fault using backup protection relays (distance relays) in the vicinity, leading to the system collapse. It was recognized the importance of shortening the operation time of backup protection relays with the adoption of digital relays.

Table 3.5 is an example of a trial calculation for shortening operation time of backup protection, but it is necessary to coordinate the operation time of the circuit breaker failure protection relay (CBF) and the operation time of the backup protection zone 2 of distance protection (Z2), and the operation setting of the CBF is required. It is important to review the time.

Table 3.5Calculation example for shortening operation time of backup protection

	Current 500kV line protection	Shortening with digital relays
CBF trip time	250 mS	130 mS
Z2 (zone 2) trip time	300 mS	200 mS

・CBF Trip time ≧ Tmr-fc (70 mS) + Tmr-off (30 mS) + Margin (30 mS) = 130 mS
Tmr-fc: Fault clearing time by main protection (CB arc extinguish time: 40 mS included)
Tmr-off: Main protection relay drop-off time
・Zone 2 Trip time ≧ Tcbf-fc(170 mS) + Margin (30 mS) = 200 mS
Tcbf-fc: Fault clearing time by CBF (CB arc extinguish time: 40 mS included)

Although it is understanded the need for shortening operation time of backup protection, it has adopted a digital current differential relay as the main protection relay to shorten the operation time of the main protection relay, and has also reduced the operating time of the relay for CBF and zone 2 of backup protection. It is necessary to rebuild the entire system, including reviewing settings. This is an important issue that must be considered by the entire NTDC protection system.

3) Busbar protection relay

In NTDC, High-Impedance Differential method is applied, but in Japan, the current differential method (Low-impedance Differential method) is often applied because it has become possible to prevent CT saturation by adopting digital relays. The explanation focused on the principles of CT saturation countermeasures.

CT saturation countermeasures focus on the differential current (Id) waveform, and when CT saturation occurs, there is an interval in one cycle where Id=0 and an interval where Id occurs alternatively. Then, if these are detected, it is determined CT saturation and blocks the operation of the differential relay. This technology was developed by using digital relays, and this makes it possible to apply current differential method for busbar protection relays. High-impedance differential relays have the advantage of being resistant to CT saturation, but they also require a CT with a high saturation voltage dedicated to busbar protection, and in principle, high voltage can be applied to the differential point in the event of an internal fault. It needs to take safety precautions as this could occur. The advantages of the current differential method using digital relays are that they can be used in common with other relays in the CT circuit, and that high voltages are not generated, making it possible to apply entire digital substations. This is an item to be considered for future application, along with the digitization of the entire protection and control system.

4) Transformer protection relay

With the introduction of digital relays, it is focused on how protection specific to transformers, such as voltage ratio, current input matching method corresponding to the Y-Δ of the winding, and countermeasures against excitation inrush, are handled by software. In particular, the major cause of the fault in January 2021 was that the electromagnetic transformer protection relay did not operate, and there was no recorded data such as current and voltage at the time of the fault. There was no clue as to the cause. The busbar three-phase ground fault occurred due to the circuit breaker being closed with the earthing switch closing, and the fault point was within the protection range of the transformer protection relay. It was said that the relay was normal in the relay test after the fault, and although it is only a guess, the following factors can be considered.

I. Due to CT saturation caused by large current, sufficient current was not supplied to the high-set differential OC element (HOC) of the transformer protection relay to operate it.

II. The high-sensitivity biased differential element is based on the principle of harmonic suppression, and could not operate due to waveform distortion caused by CT saturation.

Fig 3.7 shows a simulation of the CT saturation waveform that estimated the state at the time of the fault. It is recommended that the relay will be upgraded to a high reliable digital relay with a recording function.

Primary fault Current

A phase CT secondary current

B phase CT secondary current

C phase CT secondary current

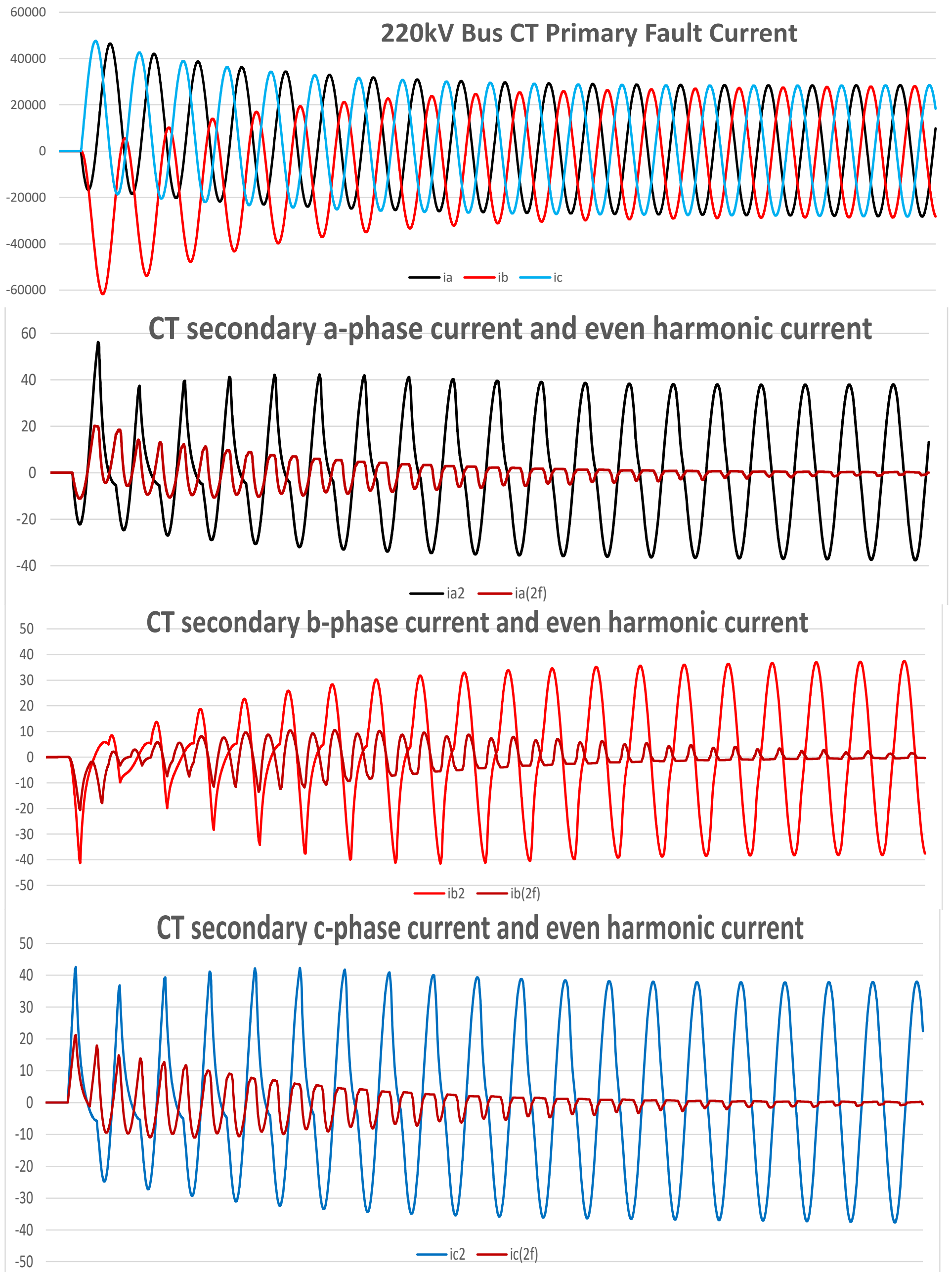


Fig 3.7 Fault current of simulation at 220kVbusbar three phase fault

(3) Training on power system analysis techniques (XTAP CPAT)

In May 2022, a three-day remote XTAP training course was conducted with Mr. Noda and his team, who have been developing the XTAP software at the Central Research Institute of Electric Power Industry (CRIEPI), as lecturers (45 participants).

This time, the training included actual analysis cases and exercises in simulating and analysing DC chopper circuits by running the XTAP software on their own. The circuit configuration took time for all participants and the younger ones were able to finish it, but half of them did not complete it.

As a complementary measure, a DVD of the training content was distributed at a later date.

In Pakistan, the grid planning department uses PSSE, which is used for power system analysis for a dozen or so seconds, but analysis in a very short time domain (instantaneous analysis), such as XTAP, is not conducted, so the participants were very enthusiastic about the course.

CRIEPI has developed software CPAT, which is equivalent to PSSE, is charged for, so we informed them that a simplified version of CPAT is available free of charge.

In order to enhance the learning of XTAP, an exercise on the analysis of overvoltage phenomena occurring in AC systems, a phenomenon familiar to power systems, was conducted remotely with Mr. Noda and his team from CRIEPT as lecturers during the visit to NTDC in July 2022.

3.2.4. [WG2/3] Human resource development plan and Training evaluation system in NTDC/TSG

As a training function of TSGs, it is desirable to develop human resources for operation and maintenance of transmission and substation facilities and GSOs more systematically, using the installed GSO operation training simulators and PC version simulators, from the perspective of future human resource development strategies, while reviewing the current human resource training and development system of the NTDC. The aim was to link training and practice, and training and evaluation, to generate practical benefits.

Furthermore, the need for a hierarchical human resources development system, incentives such as visualisation of performance evaluations, and a system of skills certification through training should also be considered in order to ensure a certain number of trainees in the TSG on an ongoing basis and to increase the motivation of each instructor personnel. Systematic reflection in the subsequent personnel system based on the skill level acquired by trainees in the TSG is also a material for future consideration, and was explained at a later date based on actual examples in Japan.

As a specific discussion, an exchange of views on the above introduction proposal was held with the GM of the NTDC HR department during the fifth visit to NTDC (November 2022) (seeFig 3.8 andTable 3.6).

With reference to the Japanese case studies (seeTable 3.7) and other examples, and while also hearing the current situation and requests of NTDC/TSGs, a model introduction of a skills certification system using GSO operation simulators and PC version simulators were proposed. In particular, when introducing the model, it is envisaged that the 200 cases for the new system diagram would be divided into three training courses according to the skill level of the 200 cases. At the end of each training course, the adequacy of the operational response and recovery procedures for that training case will be evaluated based on indicators. More detailed evaluation criteria will clarify the effectiveness and key points of the training and make it more effective for practical application.

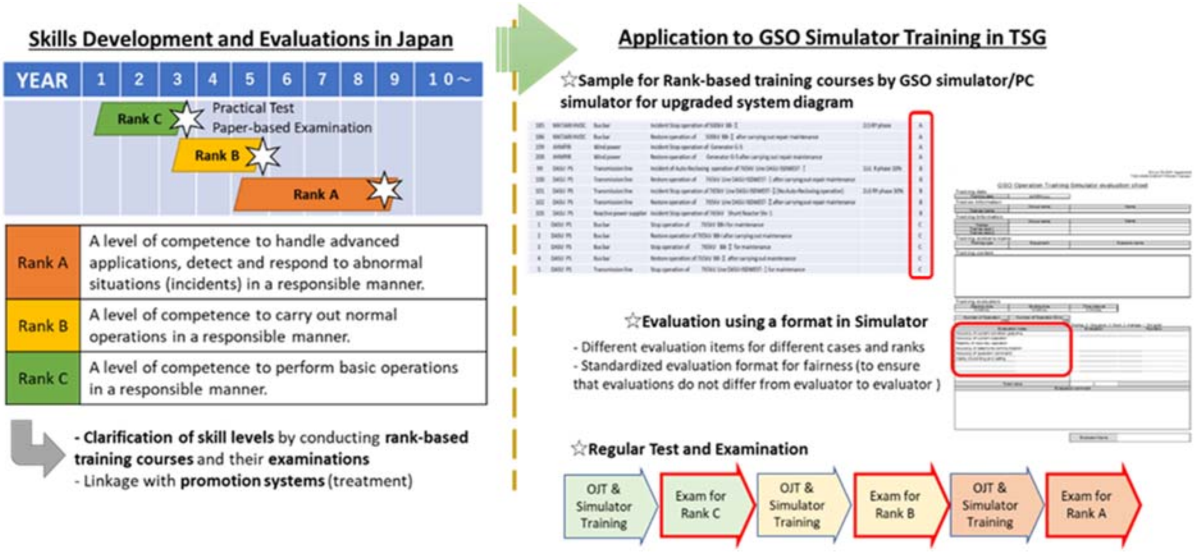


Fig 3.8 The introduction of the skills certification system
(left: Japanese case; right: example of application to Pakistan)

It was explained that the development in the project would be to consider the possibility of a human resource development system focused on the GSO operational sector, but the GM told the NTDC of the need to take into account the personnel systems of a wide variety of sectors. Also, while there is an apparent interest in post-training feedback and performance evaluation at TSGs, there is the lack of a 'failure to certify' custom in training and certification exams as a culture and practice in Pakistan, and the inability of promising instructor personnel to stay with the company for a certain period of time due to frequent personnel changes, are challenges related to the introduction and continuity of the system. (see Table 3.6)

In the future, it is hoped that, with reference to the introduction of actual examples in Japan, the skills certification system and promotion system for human resource development in TSG's GSO simulator training will be enhanced within the NTDC.

Table 3.6 Current status and issues related to the proposed introduction of a skills certification system and human resources development strategy

Current situation and Considerations	・ NTDC/TSG has already conducted a step-by-step training program for new engineers in the NTDC/TSG, which consists of courses at levels A-B-C. Each course consists of a few weeks. ⇒ It was explained that it took about 10 years to reach the final A level, with training and practical experience. ・ In NTDC/TSG, the C level (initial training) includes simulator training at the TSG, training on transmission and substation equipment at a model substation, technical training on transmission lines at the Tarbela Training Centre and online sessions. ⇒The simulator training has been included as a course theme from Class C. This suggests the possibility of introducing a promotion system with more clearly defined skill levels in the future implementation of training in the ranks. ・ NTDC/TSG has been unable to retain promising trainers for a certain period of time due to frequent personnel transfers. It is necessary to consider a system (e.g. allowances and treatment for trainer personnel) to enable them to stay with the organization for at least one year or more. ・ The NTDC/TSG has implemented several initiatives for the recognition and development of trainer personnel (e.g., encouraging the acquisition of international standard qualifications, multi-day lecturer training workshops). The use of other Learning Management Systems is also under consideration. NTDC/TSG engineers have also participated in international online lectures in Canada, Australia and other countries. ⇒ In terms of managing personnel changes, it is somewhat difficult to encourage movement and change, as the decision-making authority is left to the NTDC. On the other hand, there is room to introduce the trainer certification system and examples of treatment and allowances implemented in Japan and discuss what can be referred to in terms of securing lecturer personnel on an ongoing basis. ・ Regarding the score table, it is customary in Pakistan that there is no concept of "pass/fail" in training (everyone is considered to have passed). ⇒The NTDC will continue to discuss a system that is consistent with the cultural background and customs of Pakistan. ・ In NTDC, there is a need to consider HR systems not only for TSG and GSO departments, but also for a wide variety of other departments. ⇒ It was explained that a possible development in the project would be to consider the possibility of a human resources development system focused on the GSO operational divisions.
Introduction and deployment possibilities	・ The NTDC Human Resources Department will also be consulted in the future to deepen discussions on the direction of incorporating the TSG's GSO simulator training skills certification system into the NTDC's promotion system. NTDC/TSG would like to see more skill-level-based evaluations. Currently, the Senior Leadership Course (2 weeks) is linked to promotion.

Table 3.7 Examples of evaluation and skills certification systems for simulator training in Japan

Purpose	・ To improve and standardize technical skills ・ To motivate technicians to improve their practical and technical skills. ・ To promote systematic human resource development plans.
Overview of the skills certification system.	Clarification of skill levels and introduction of rank-based courses according to level Class A: Able to responsibly carry out advanced work processing and handling of unusual situations. Class B: Able to responsibly carry out normal field work. Class C: Able to responsibly carry out elementary field duties.
Training evaluation Methods and criteria	➢ To settle the standard judgement items and acceptance criteria for all training cases (example below). - Confirmation prior to operation: understanding of the purpose of the operation, confirmation of Permission To Work, safety confirmation, status of communication with relevant authorities, etc. - Confirmation during operation: confirmation of voltage, current, etc. at each operation stage, confirmation of operation procedures, etc. - Confirmation after operation: implementation of safety assurance such as grounding, communication to all concerned parties, etc. ➢ To prepare an evaluation table for all training cases (utilize the evaluation table already delivered with the simulator). Based on the above-mentioned judgment items and criteria, describe specifically the evaluation items and their contents in accordance with the contents of each case. As an example, describe the voltage, current, phase angle, tap position, etc. and the specific name of the contact person, etc.
Devices for spread and establish	➢ Conducting regular rank-specific simulator training courses (check technical level) ➢ Conducting training examinations for promotion (maintenance and improvement of technical level)
Challenges to introduction	➢ Selection of pass/fail judges, ensuring technical level ➢ Methods of measuring achievement of standards (e.g. quantitative scoring, qualitative assessment from the leadership side, setting pass borderlines) ➢ Ensuring consistency with NTDC/TSG human resource development plans, consideration of impact on treatment

Based on these and other issues within the NTDC, it was explained a detailed description of the specific human resource development plan and training system for power system engineers in Japan and the evaluation of simulator training at the 2nd TOT in September 2023. Figure 3.12 shows the training system since new recruits to about 10 years in the system operation and facilities planning divisions.

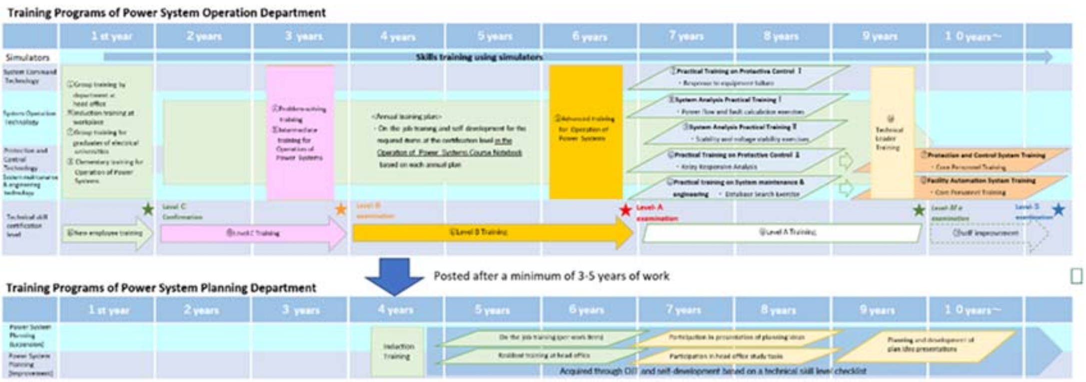
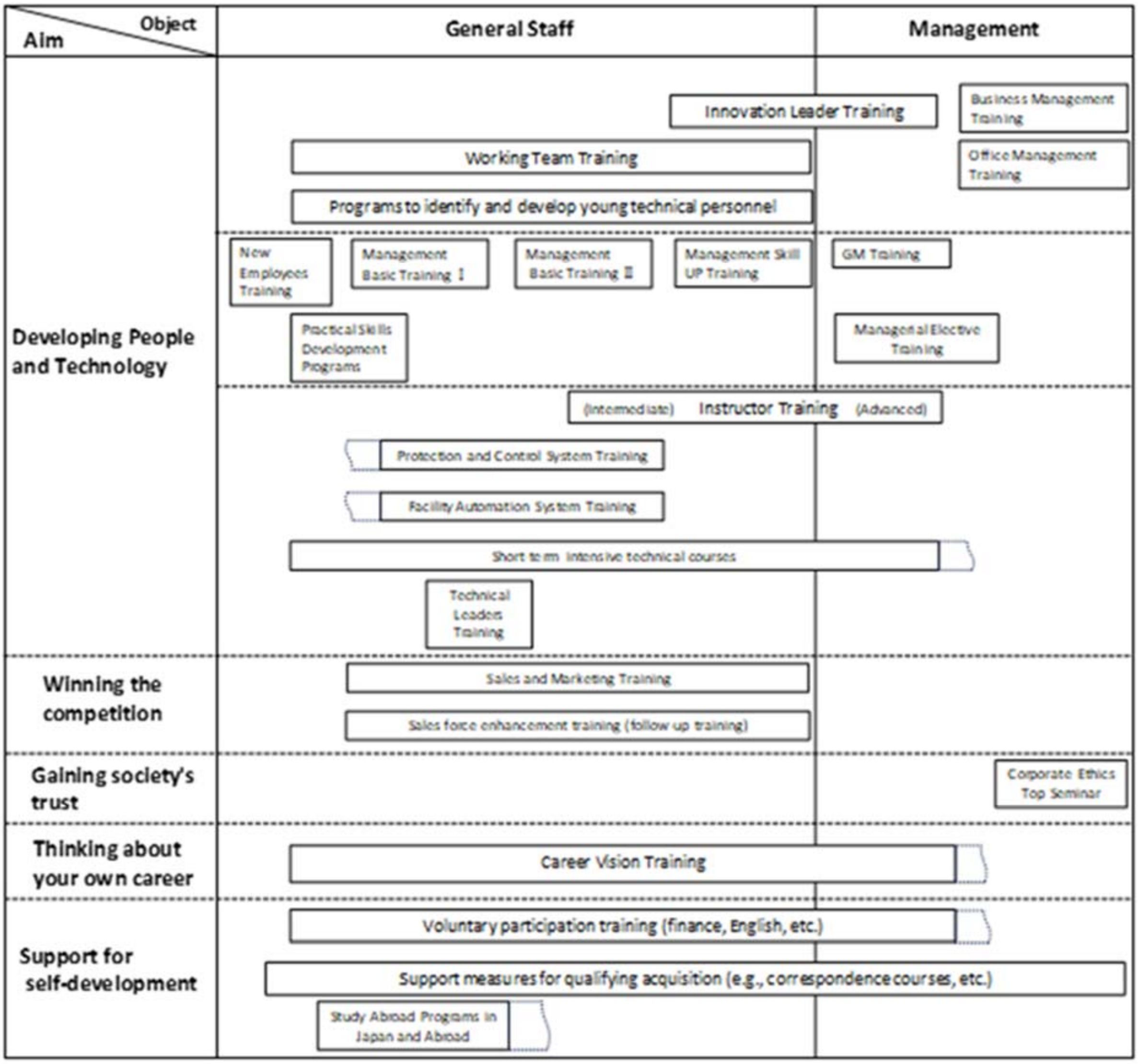


Fig 3.9Training schemes for engineers in Japan (system operation and facility planning divisions).

In particular, the training content for each level was specifically presented and it was understood that the same technology was aimed at acquiring more advanced skills at the advanced level.

In addition, it was introduced that, in order to develop comprehensive competence as well as sector-specific technical training, the company systematically implements competence acquisition training in which the competences to be acquired were clearly defined (Table 3.8).

Table 3.8 Common training structures with clear objectives



Although training scenarios for the simulators were created and introduced this time, the trainer stressed the importance of assessing the level of mastery and back-up through training. To this end, the trainer explained that recovery response and time management in training should be assessed for the entire training team, and that it was important to describe the detail status of individual actions in order to understand the current level and trends of individuals (Table 3.9).

Table 3.9 Example evaluation table for recovery response, time management and personal behavior status

Assessment of response status

	Date of implementation	March 1	March 23
	straightened lumber	A team	B team
Assessing the accident situation	Confirmation of system summary chart	5	5
	Confirmation of outage coverage	4	5
Determination of accident facilities	Accident Facilities - Determination of Aspects	5	5
Establish restoration policy	Emergency Response Procedures	4	3
	Establish restoration policy	5	5
	patrolling (esp. using ships or aircraft) (Equipment to be used, adjacent equipment, time required)	5	5
Perform counter-recovery operations	Conduct meetings (timing and content)	4	4
	Assignment of work within the immediate area	5	5
	Creation of operating procedures chart (timing and assignment)※1	5	5
	Colic vs. colic in the operating procedures table (other than the creator)		
	Approval and execution of operating procedures. Safety checkNote 2	5	5
	Information sharing within the immediate area - Intra-industry linkage	5	3
	Accurate inquiries to electric power stations (including power transmission liaison)	4	5
	Clear policy explanations for local payrolls	5	5
	Grasping and sharing of outage load directly within the company	5	5
Disconnection of	Cut-through accident equipment disconnection	5	5
Implementation of confidence measures	Understanding the transmission load	4	4
	Identification of tidal current bottleneck areas	5	5
	Short - ground fault protection		
Handling of information	Description of serious accident (including time of dispatch)	4	3
	Total	84	82
	Achievement (% of full score (5 points) for the subject item)	93 %	91 %

※1: For telephone directives - make sure you are looking at the screen and making
※2: For telephone commands - confirm that the command is given while looking at t

Response time ○○ line accident, Outage power, Seconds

Teams that conducted		A team	B team
Confirmation of system summary diagram (Accident determination function)		1	1
Confirmation of outage coverage		8	4
Determination of accident facilities		1	1
Execution of emergency measures (system alone, OLR, etc.)		1	1
Completion of emergency procedures			
Confirmation of the electric station where the instantaneous voltage drop occurs		12	1
Implementation of retransmission			
Implementation of re-transmission of electricity			
Understanding Power Outages		8	5
Understanding the amount of power supply dropout			
Completion of treatment at all stops			
Restoration of accidental power outage		10	8
Understand the recovery time of other systems in the secondary system		10	8
electric power station	Shin Tsukuba (GS) Bus CB020 patrol request	19	14
	Shin Sawara Line No. 2 in used	36	28
	Shin Tsukuba Line No.1 combined used	41	36
	Shin Tsukuba (GS) 4B combined used	33	31
	OLR suppression of thermal power output	40	36
systemic parallels			
Disconnection of accident facilities		45	40
Implementation of confidence measures		36	31
First Serious Incident Alert (Phase 1) transmitted (5 minutes)		10	10
First Serious Incident Alert (Phase 2) transmitted (15 minutes)			
Second Serious Incident Alert transmitted (25 minutes)		25	25
Third Serious Incident Alert transmitted			

February 26 (Friday) Training Evaluation Memo - System Load D

	Case 1 ○○○Grid Station A2 B2 Bus bar accident	Ca
[illegible]	[illegible]	[illegible]

3.2.5. Planning and Implementation of Training in Japan

NTDC engineers were invited to Japan for a tour of actual facilities and classroom training, with the aim of acquiring relevant technology and knowledge through visits to Japanese power companies and protection relay manufacturers. The training was originally planned for November 2022 and August 2023, but was postponed due to entry restrictions following the spread of COVID-19 infection, etc. The first training was held from 18 May to 1 June 2023 and the second from 9 to 23 September 2023.

The training focused on the power supply command system, human resources development systems, formation of transmission and substation facilities in overcrowded areas, maintenance and management of power facilities, restoration policies in the event of major faults, clarification of fault causes through system analysis and detailed investigation of fault facilities in Japanese electric power company, and quality management and cyber security measures at Japanese electrical equipment manufacturers. Five trainees each participated in the first and second sessions as trainers from various departments, including practitioners (System Planning, P&C, NPCC), managers (TSG) and TSG instructors. The content of the first and second itineraries was almost the same, but was slightly revised when planning the second itinerary based on the results of the first itinerary and feedback from the participants. The itineraries for each of the Japanese training courses are shown in the table below.

Table 3.10 Training schedule in Japan

First training（May 2023）		Second training（September 2023）	
1st day	Explanation of outline of Tokyo Electric Power Company Visit to Tokyo Dispatch Centre	**1st day**	Explanation of outline of Tokyo Electric Power Company Visit to Tokyo Dispatch Centre
2nd day	Visit to Central Load Dispatch Centre Lecture of outage plan for equipment maintenance	**2nd day**	Visit to Central Load Dispatch Centre Lecture of Training system for power system engineers in Japan and evaluation system
3rd day	Visit to Shin-Shinano Frequency Convertor Station	**3rd day**	Visit to Training Centre of Dispatch technology Visit to Shin-Toyosu Substation
4th day	Visi to Tokyo Densetsu Services Co.	**4th day**	Visit to Shin-Shinano Frequency Convertor Station
5th day	Lecture of power system analysis Introduction of supervisory equipment and recording equipment for power system	**5th day**	Visi to Tokyo Densetsu Services Co.
6th day	Visit to Training Centre of Dispatch technology	**6th day**	Lecture of power system analysis /Fault analysis
7th day	Visit to Toshiba Fuchu works.	**7th day**	Visit to Toshiba Fuchu works.
8th day	Visit to Toshiba Fuchu works Training of Cyber Security	**8th day**	Visit to Toshiba Fuchu works Training of Cyber Security
9th day	Wrap-up	**9th day**	Wrap-up

* Underline shows different itinerary between first training and second training (except holiday)

In the participants' questionnaire after the training in Japan, many responded that they were very satisfied and that the training content and materials were beneficial. In particular, many commented that the visit to the Shin-Shinano Frequency Convertor Station was very useful, as although similar facilities exist in Pakistan, they were constructed and operated by China behind closed doors and the NTDC was not even allowed to observe the facilities. During the wrap-up on the final day, there were also presentations on reflections on the training and future action plans, with comments on knowledge sharing and promotion at NTDC, particularly in relation to knowledge on system analysis and fault analysis, and training and evaluation systems. Overall, the training was highly satisfactory for the participants, and there were high expectations for the effectiveness of the training at the NTDC for each of the participants after their return.

3.2.6. Cooperation with Domestic Subcontractors

(1) Preparation of operating procedures based on training scenario cases

The preparation of detailed operating procedures based on training scenarios for a total of 400 cases, 200 cases for each of the old and new system diagrams, was subcontracted to Yachiyo Engineering Co., Ltd. and completed as planned.

(2) PC simulator

A PC version of the simulator was commissioned to Toshiba and a total of 32 sets were provided to NTDC so that the same functions of the simulator installed at TSG as GSO simulator could be used at substations.

(3) Setting up new system diagrams on GSO simulators

A new system diagram including ±660 kV HVDC, 765 kV AC system, solar power generation and wind power generation requested by the NTDC was installed in the simulator installed at the GSO, commissioned by Toshiba, to enable operational training on the NTDC's main transmission system.

(4) Revised relay simulator manuals.

The relay simulator manual was revised to allow easy connection to other manufacturers' relays such as GE, SIEMENS and ABB, under contract to Toshiba.

Chapter 4 Achievement of project objectives

Chapter 4. Achievement of Project Objectives

Project objective	To strengthen the capacity to operate and maintain transmission and distribution facilities (substation and protection relays) to improve the quality of power supply.

The following is a summary of the progress made by the WGs as they work towards achieving the above project objectives.

[WG1]

Include all ±660kV HVDC, CASA1000, 500kV AC, 765kV AC and renewable energy (Wind Power, Solar Power), which were strongly requested by NTDC, in the new grid diagram preparation. As it is not possible to include all 765kV, 500kV substations, HVDC stations and power stations using the simulator installed in the TSG, priority was given to simulating double busbar and one-half busbar as the busbar configuration with power plants and transmission lines were condensed to achieve a system diagram that does not interfere with operational training.

[WG2]

Training scenarios with the new system diagram were discussed in WG2 and 200 cases were created.

Detailed operation procedures based on these scenarios were prepared, and group training at TSGs and training at grid stations using PC simulators were conducted, which helped to establish the operation procedures and prevented operational errors.

The simulation of faults also improved technical skills in determining the relay operation during faults and the fault point from the voltage and current waveforms.

Group training at TSGs and training using PC simulators at each grid station has been conducted for approximately 1,500 persons as of December 2023.

[WG3]

For relay simulators, GE, SIEMENS and ABB protection relay specifications have been investigated and the manual was revised that they could be connected to and tested on the relay operation simulator.

This has made it easier to test the protective relays currently held by the NTDC, and thus easier to test the protective relays and check the setting values using the relay operation simulator.

Training using the relay operation simulator has been provided to a total of 200 people.

Chapter 5　Achievement of High-level Objectives

Chapter 5. Achievement of High-level Objectives

High-level objectives	By the end of the project, the SOPs for grid station operation prepared by the TSG will be properly operated in the grid stations, thereby improving reliability in the entire power system.

The following indicators and target values for the above high-level objectives were identified and generally achieved.

Table 5.1 Project indicators

High-level objectives	Indicators (draft values) *Each item is based on the provisional PDM	Indicator achieved
The reliability of the grid as a whole is improved through the proper operation of grid stations in accordance with the SOPs for grid station operation prepared by the TSG.	・ Annual outages in the NTDC network due to miss-operation are reduced by 672,000 MWh* (*outages at maximum power (31.5 GW) are assumed to last 21 hours as in January 2021). ・ 100% reduction in frequency and duration of power system faults due to miss-operation. ・ Fault recovery time is improved to within 24 hours.	・ The use of GSO simulators and PC simulators has resulted in zero miss-operation. In addition, the creation of a procedure chart was established. ・ Black Out was avoided during a transmission line fault in the southern region due to a review of UFR setting values. ・ The power outage in the southern region caused by the transmission line fault in October 2022 was restored in about two hours.

Appendices

Appendices

Appendix 1 GSO Simulator Training Scenarios

Appendix 1. GSO Simulator Training Scenarios

GSO simulator training scenarios are submitted on CD-ROM.

Appendix 2 Protection Relay Training Handouts

Appendix 2. Protection Relay Training Handouts

2.1. WG3_Current_Diff_Protection (Transmission Line)

Theory of Current differential protection

Project for Enhancing Grid System Operation and Maintenance Capacities through Strengthening National Transmission and Despatch Company TSG Training Center

【WG3: Protection Relay Simulator Training 】

- Transmission line protection -

May, 2022

Asia Engineering Consultant Co. Ltd 1

Contents

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1. Theory and characteristics

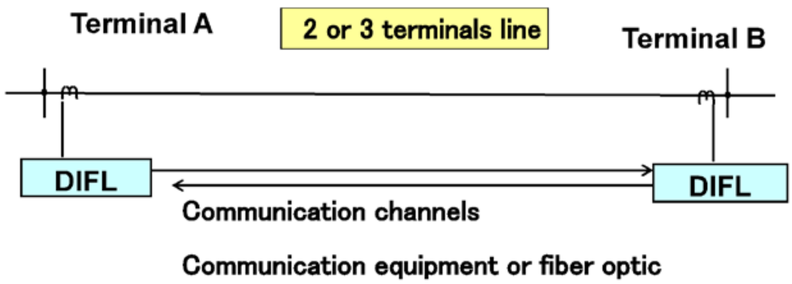
Current Differential Protection

Theory and Characteristics

1. Theory and characteristics

Applications

<System configuration>



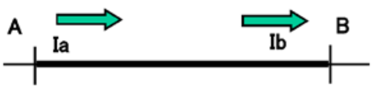
This system converts instantaneous values of current, measured at each terminal into digital values which are then transmitted to the remote terminal; the differential current is calculated from the instantaneous values of current from each terminal through digital computation.

1. Theory and characteristics

Basic theory of Current Differential Protection

<Principle>

[Normal state]



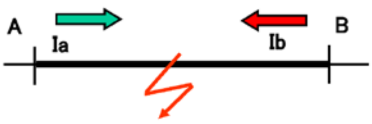
Ia + Ib = 0

(Kirchhoff' s low)

Bold lines: Zone of protection

Ia, Ib : Inflow, outflow current

[Internal fault]



Id = Ia + Ib ≠ 0

Id: Fault current

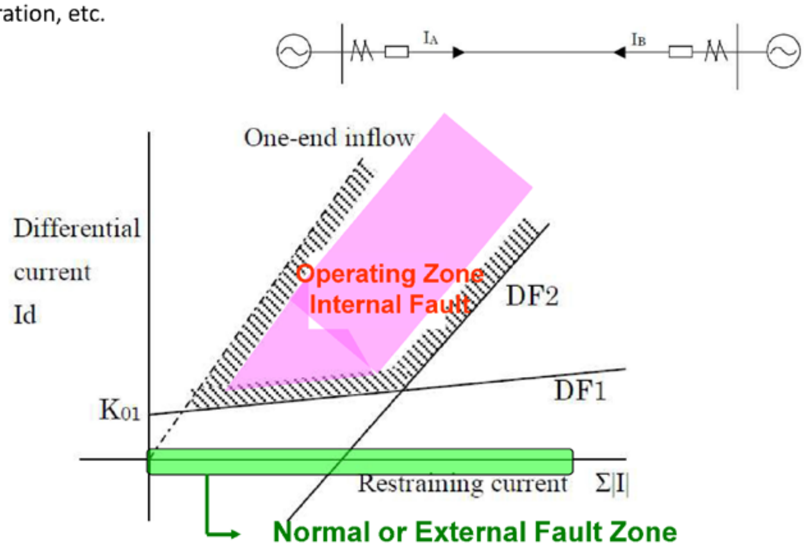
Theory equation of operation: $Id \geqq k1 \cdot Ir + k0$

Operating current: Id = | Ia + Ib |, vector sum

Restraint current: Ir = |Ia| + |Ib|, k1, k0: constants

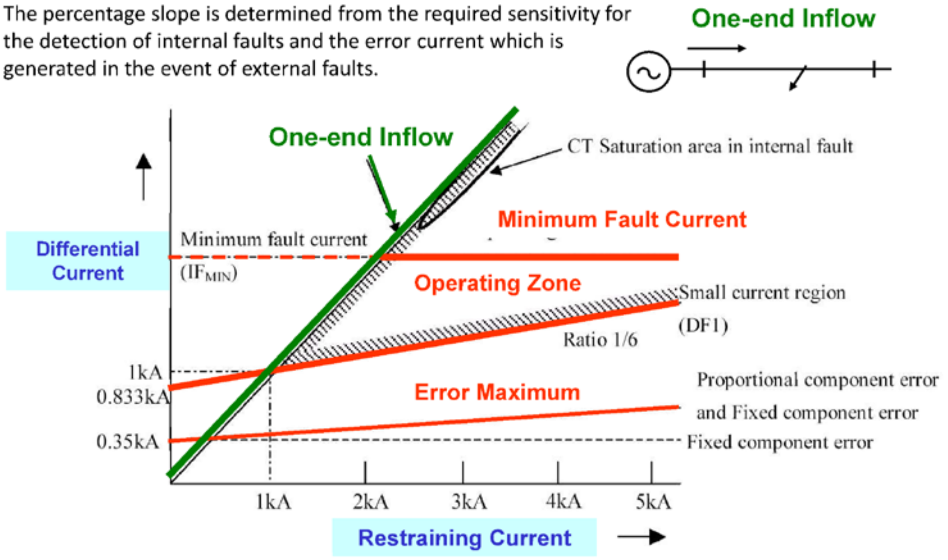
1. Theory and characteristics (Characteristics of DIFL)

The characteristic for the large current region (DF2) is provided to restrain in this region of operation because the proportional component error increases owing to CT saturation, etc.



1. Theory and characteristics (DIFL small current zone)

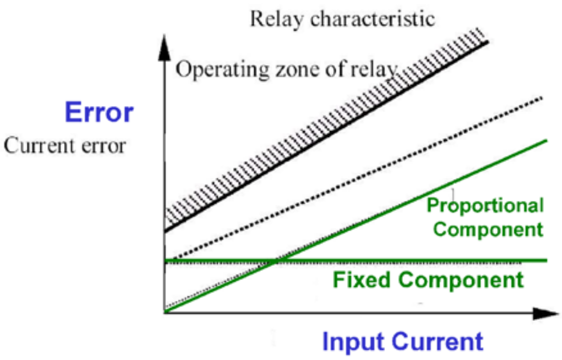
The percentage slope is determined from the required sensitivity for the detection of internal faults and the error current which is generated in the event of external faults.



Example: characteristic of small current region
Settings: DIFL-I = 1kA, k1= 17% (1/6)

1. Theory and characteristics (DIFL small current zone)

Error Component Analysis



Errors relating to differential protection

Error:

Fixed Component
- Input Transformer
- Drift of Analogue Filter
- Quantizing Error

Proportional Component
- CT Error
- Input Transformer
- Gain Error of Analogue Filter
- Data Transmission Delay
- Sampling Timing

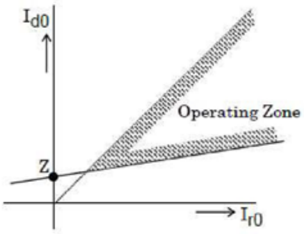
1. Theory and characteristics (DIFGL)

Zero-sequence Current Differential (DIFGL)

DIFGL (87G)

Zero Sequence Diff. Characteristic

- High sensitivity by use of residual current
- Sensitivity not affected by load current



Theory equation of operation: $Id_0 \geqq k_0 \cdot Ir_0 + kn$

Operating current: $Id_0 = | Ia_0 + Ib_0 |$, vector sum

Restraint current: $Ir_0 = |Ia_0| + |Ib_0|$, scalar sum, k_0, kn: constants

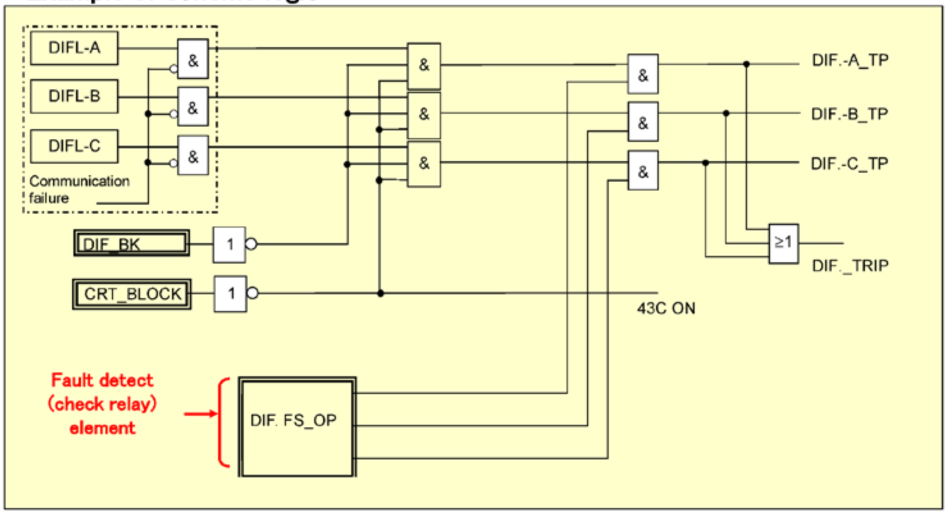
2. Scheme Logics of Current Differential Protection

Scheme Logics of Current Differential Protection

2. Scheme Logics of Current Differential Protection

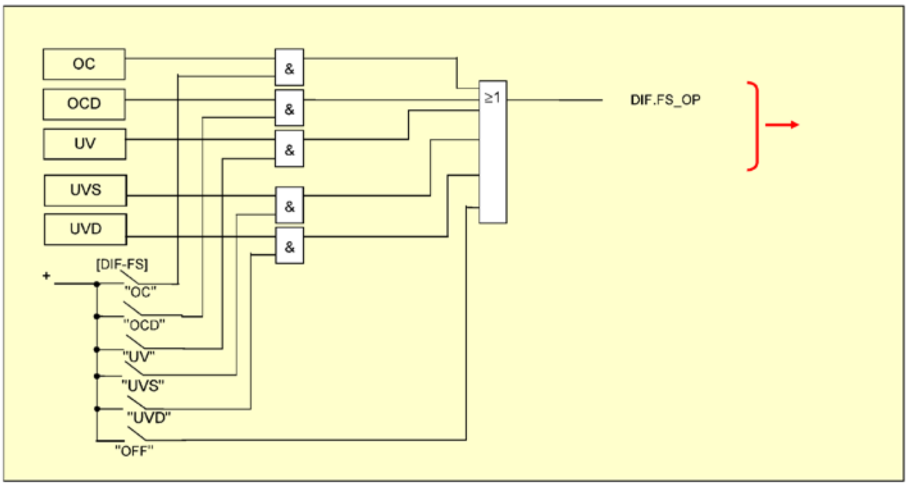
< Segregated-phase current differential protection (DIFL) >

Example of scheme logic



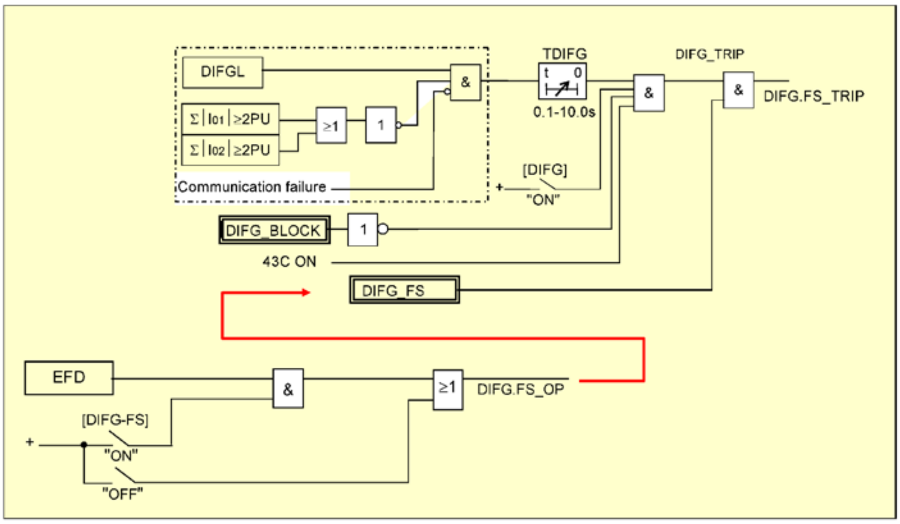
2. Scheme Logics of Current Differential Protection

< fault detect (check relay) function for current differential protection >



2. Scheme Logics of Current Differential Protection

Zero-phase current differential protection scheme logic

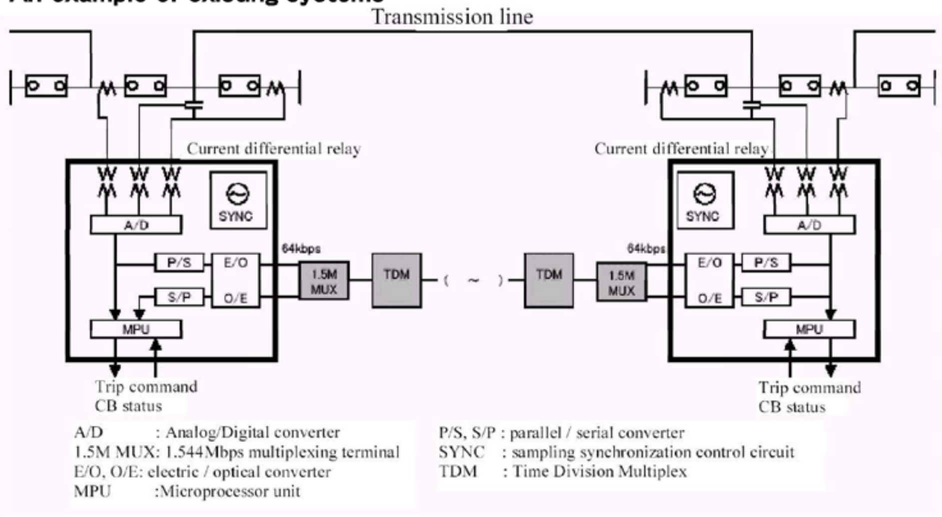


3. Communication Systems

Communication Systems for Current Differential Protection

3. Communication Systems

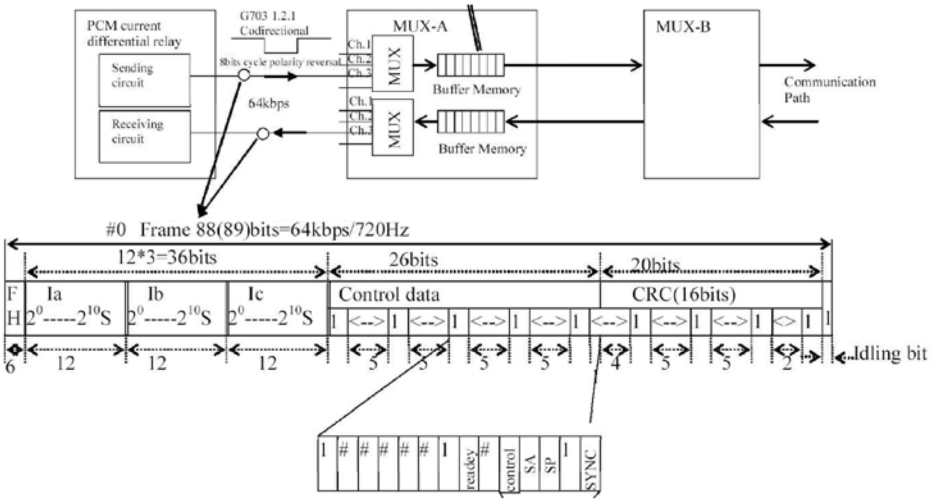
An example of existing systems



Configuration of the digital-type current differential relaying system

3. Communication Systems

Transmission data format (example for 60Hz systems)

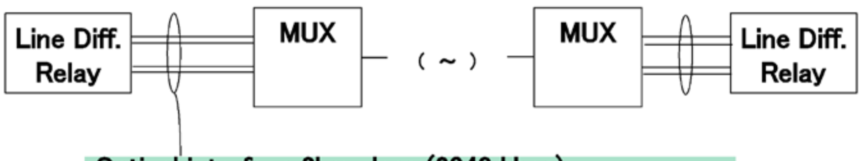


・fundamental wave 60Hz、Sampling frequency 720Hz

3. Communication Systems

Recent standard of IEEE C37.94

Securing clock recovery, jitter tolerance, physical connection, and spuriousness are specified by the international standard.

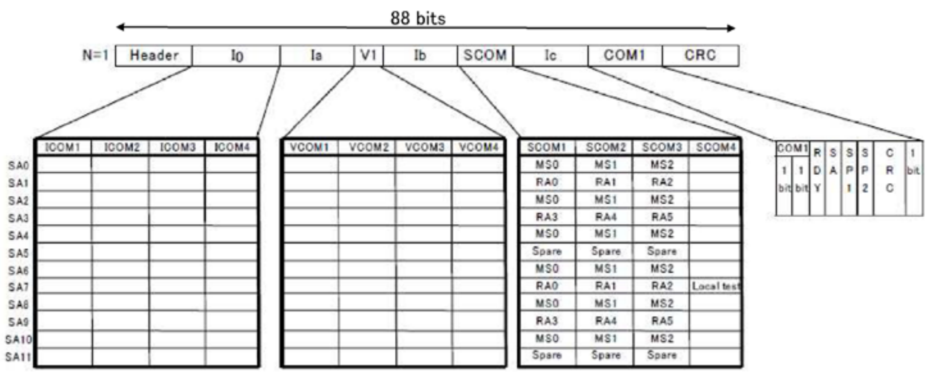


Optical interface 2km class (2048 kbps)
Graded-Index 50/125 or 60/125 micro m
Connector: ST type
Wave length: 820 nm

3. Communication Systems

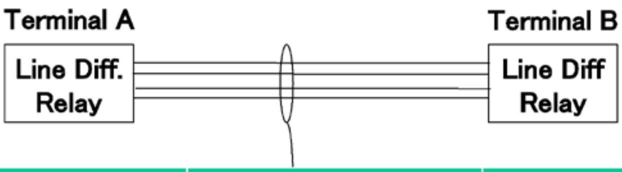
Transmission data format (example 2)

IEEE C37.94 frame format



3. Communication Systems

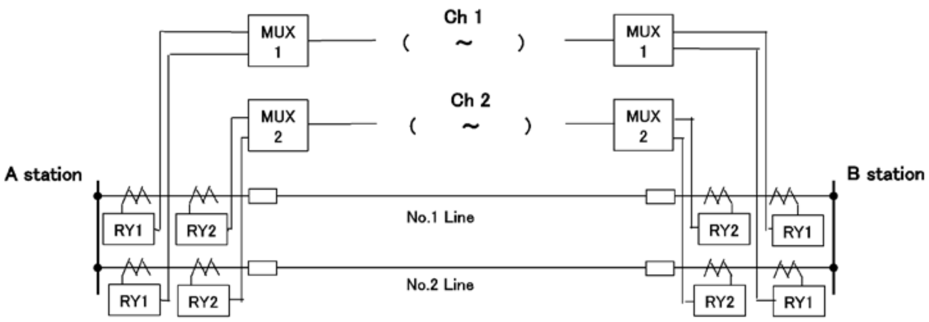
Direct fibre communication



Length	30km class	80km class
Type of fibre	Single mode 10/125 µm	DSF 8/125µm
Connector type	Duplex LC	Duplex LC
Wave length	1310nm	1550nm

3. Communication Systems (redundant configuration (1))

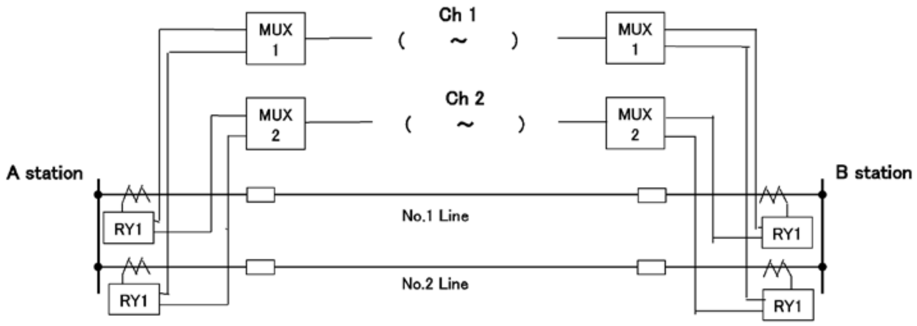
Dual Relay systems and
Dual Data Transmission system



Relay 1 and Relay 2 have the separate communication route.

3. Communication Systems (redundant configuration (2))

Single Relay system and
Dual Data Transmission system



Relay 1 has two communication control parts.

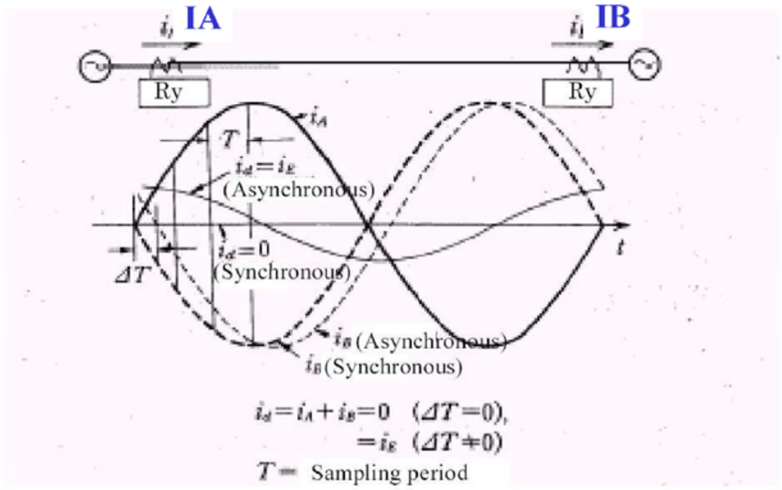
These communication routes are separate paths.

4. Synchronized Sampling

Synchronized Sampling of
Current Differential Protection

4. Synchronized Sampling

Data Sampling Synchronism between the both terminals



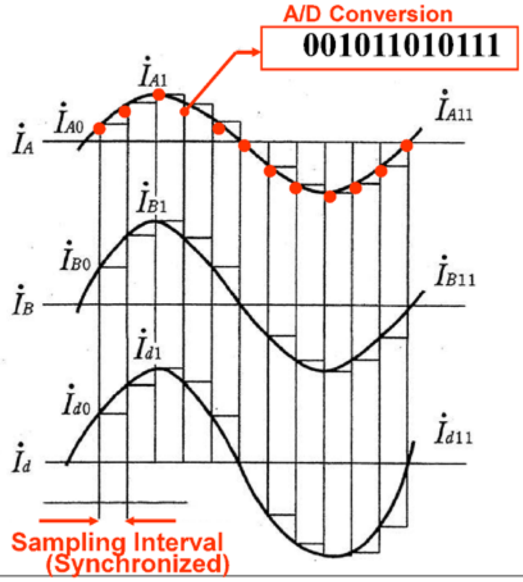
Sampling synchronization is necessary.

An error current i_E will be generated if there is a lag (ΔT) in the sampling timing.

4. Synchronized Sampling

The instantaneous values of current from each terminal need to be obtained at the same time, and synchronization control is required to match the acquisition timing (sampling timing).

Data Sampling



$$\dot{I}_{d0} = \dot{I}_{A0} + \dot{I}_{B0}$$

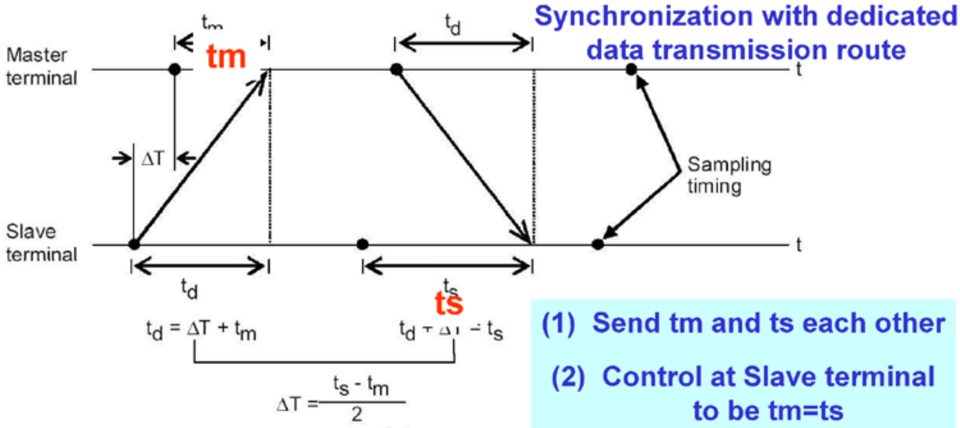
$$\dot{I}_{d1} = \dot{I}_{A1} + \dot{I}_{B1}$$

$$\vdots$$

$$\dot{I}_{d11} = \dot{I}_{A11} + \dot{I}_{B11}$$

4. Synchronized Sampling (Control theory)

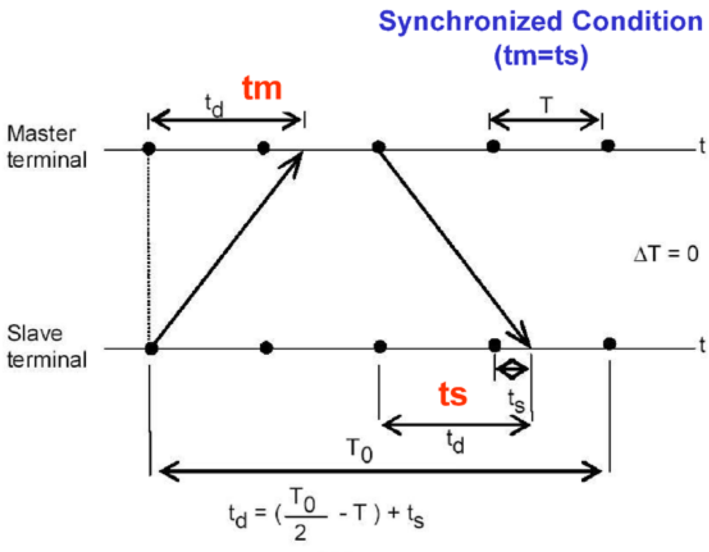
Synchronization control is performed on the assumption that the upstream and downstream (transmit and receive) transmission paths are identical



(a)

At both master and slave stations control is exercised such that the time differences tm and ts between the time at which the sampling synchronization flag was received from the remote station and the timing of the sample taken at the local station are transmitted alternately to bring about the state ΔT=0 at the slave station side.

4. Synchronized Sampling (Control theory)

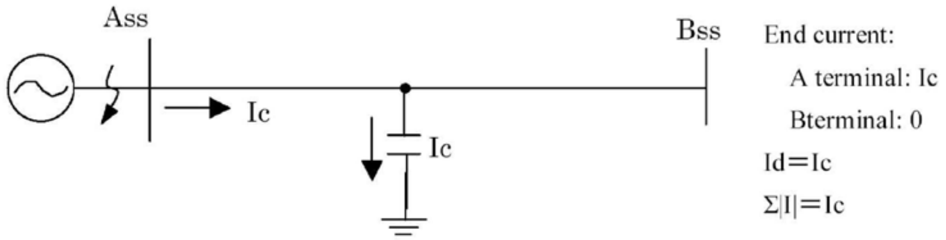


(b)

Charging Current Compensation of Current Differential Protection

Line Charging Current

Line charging current "Ic" appears differential current "Id".



Charging current will flow in the protected section of long-distance overhead transmission lines and underground cables and can lead to the incorrect operation of the protection if the value exceeds the detection sensitivity level.

5. Charging Current Compensation

$$\begin{bmatrix} i_{ca} \\ i_{cb} \\ i_{cc} \end{bmatrix} = \begin{bmatrix} C_{aa} & -C_{ab} & -C_{ac} \\ -C_{ba} & C_{bb} & -C_{ba} \\ -C_{ca} & -C_{cb} & C_{cc} \end{bmatrix} \cdot \frac{d}{dt} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad \cdots \quad (5.6)$$

C_{ae}, C_{be}, C_{ce} : Earth capacity

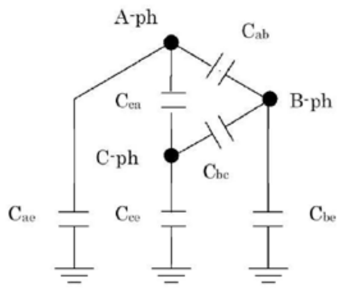
C_{ab}, C_{bc}, C_{ca} : Line capacity

i_{ca}, i_{cb}, i_{cc} : Charge current (each phase)

$C_{aa} = C_{ae} + C_{ab} + C_{ac}$

$C_{bb} = C_{be} + C_{bc} + C_{ba}$

$C_{cc} = C_{ce} + C_{ca} + C_{cb}$



Example

Phase-earth (μF/km)	Phase-phase (μF/km)
0.01222	-0.00147

(275kV transmission line measurement capacity)

Charging capacitance of transmission line

It is normally adequate for practical applications to regard the diagonal element as being the same for each phase, with the off-diagonal element set to zero, as long as the line is 200 km or shorter in length.

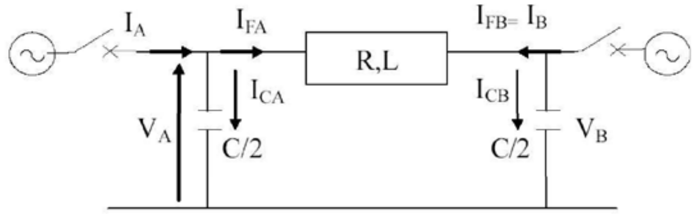
5. Charging Current Compensation (Divisional Compensation)

Compensation of the charging currents of all sections are equally divided at each terminal,

Transmission Data

terminal A: $I_A - \frac{C}{2}\frac{dV_A}{dt}$

Terminal B: $I_B - \frac{C}{2}\frac{dV_B}{dt}$



RL : Line impedance (whole length)

C : Line charging capacity (whole length)

Relationship between charging current and current of each terminal:

Equivalent compensation for all terminals

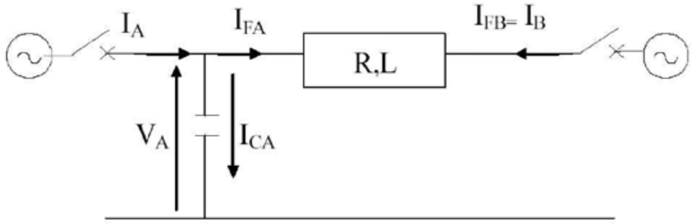
5. Charging Current Compensation (Lump-sum Compensation)

100% compensation is implemented at the local terminal

Compensation at one-terminal

Terminal A: $\left|I_{FA} + I_{FB}\right| = \left|I_A - C\frac{dV_A}{dt} + I_B\right|$

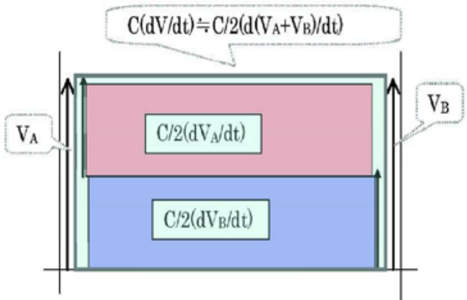
Terminal B: $\left|I_{FA} + I_{FB}\right| = \left|I_A + I_B - C\frac{dV_B}{dt}\right|$



Relationship between charging current and current of each terminal:
Compensation for all sections in local terminal

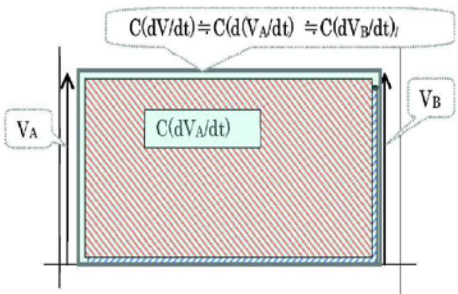
5. Charging Current Compensation (normal condition)

Divisional Compensation



(a) Compensation quantity of the terminals

Lump-sum Compensation



(b) Each compensation for charging current of the terminals

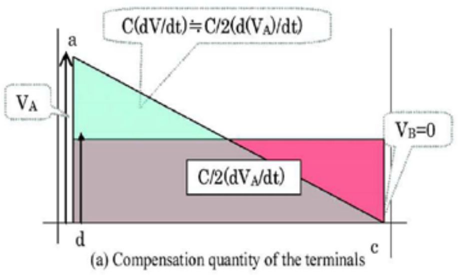
Charging current and compensation current under normal condition

There is little compensation error in both methods under normal conditions.

5. Charging Current Compensation (close-up fault at B)

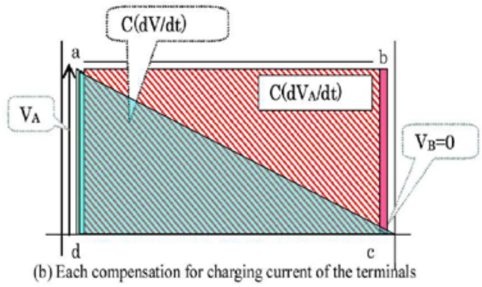
A close-up fault has occurred external to terminal B, and hence VB is zero. The area of triangle 'a-c-d' is equivalent to the total charging current.

Divisional Compensation



(a) Compensation quantity of the terminals

Lump-sum Compensation



(b) Each compensation for charging current of the terminals

Charging current and compensation current under external fault in B terminal

(a) Divisional: the compensation quantity (rectangle) based on the voltage VA/2 at terminal A is equivalent to the approximate area of the triangle, and little compensation error.

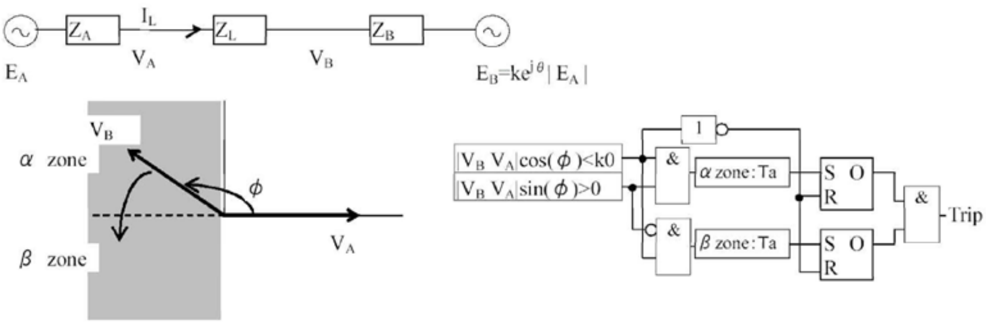
(b) Lump-sum: under compensation at B terminal, overcompensation at A terminal

6. Out-of-Step Protection (Voltage phase comparison)

Out-of-Step Protection with voltage phase comparison

6. Out-of-Step Protection (Voltage phase comparison)

Out-of-step Detection: voltage phase comparison

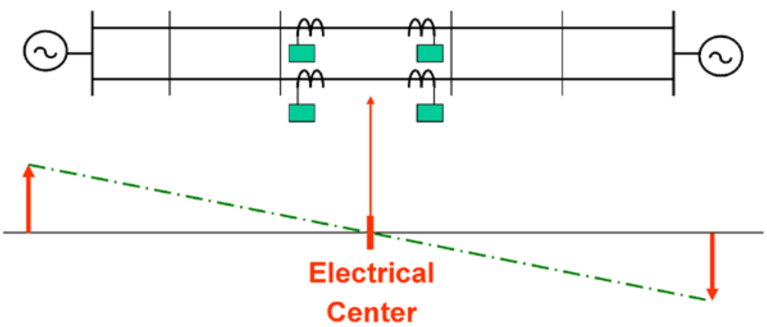


Out-of-step detection relay using positive-phase

The out-of-step protection function is realized by comparing the phase angle of the positive-sequence voltage received from the remote terminal with that of the local voltage, confirming that the phase angle difference passes through 180 degrees.

6. Out-of-Step Protection (Voltage phase comparison)

to separate the power system at the Electrical Center for a Out-of-step



The best separation point is the "electrical center" of the out-of-step. Voltage phase comparison will operate only when the "electrical center" is located in the protected area of line differential relay.

7. Auto-reclosing function

Current Differential Protection

Auto-Reclosing Function

7. Auto-reclosing function (outline)

Outline of Auto-reclosing

<TRANSIENT FAULT>

Majority of faults on overhead line ➡ Lightning(Transient Fault)

Permit re-energization after short time interruption

This processes are performed automatically

➡ *Auto-reclosing*

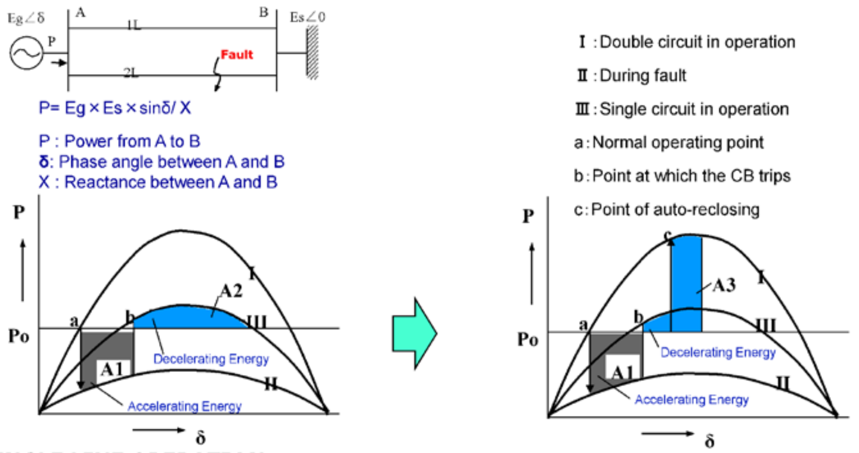
<PERMANENT FAULT>

Faults on cable circuits ➡ Insulation Failure (Permanent Fault)

Auto-reclosing is not performed on cable circuits, and also transformers, generators and busbars to prevent from the extension of system damage.

7. Auto-reclosing function (purpose)

(1) Improvement in Transient Stability



SINGLE LINE OPERATION	PARALLEL LINE OPERATION(After reclosed)
Accelerating Energy(A1) > Decelerating Energy(A2)	Accelerating Energy(A1) = Decelerating Energy(A3)
➡ **UNSTABLE**	➡ **STABLE**

7. Auto-reclosing function

(2) Reduction in power outage period

- Fast auto-reclosing enables re-transmission of power within 0.5 to 1 sec or so
- Transient stability is improved

➡ **Failure of the entire system can be prevented.**

(3) System restoration time and operator workload

- Complicated operations and checks are required for system restoration. It will take a long time to restore the system.
- The workload for operators will increase.

➡ **Execute quickly, Reduce workload, minimize human errors**

7. Auto-reclosing function (classification)

Classification for dead time

Classification	Dead time	Description
High-speed Auto-reclosing	0.35s to 1s	To auto-reclose with consideration given to de-ionization time in the case of interconnection
Medium-speed Auto-reclosing	A few seconds to 25s	To auto-reclose with consideration given to turbine generator axis torsion; attenuation of conductor vibration due to damage induced by wind and snow; to maintain an interconnection in the event of an unsuccessful high-speed auto-reclosing operation to perform automatic recovery
Low-speed auto-reclosing	A few second to 70s	To auto-reclose in order to achieve recovery of a power network automatically and quickly

Example of High-speed Autoreclosing Dead time (in Japan):

- **500kV system : approx. 1.0s**
- **187 – 275kV system : approx. 0.5 – 0.8s**

7. Auto-reclosing function (classification)

Number of disconnected phases

Classification		Auto-reclosing	Description
Single phase Auto-reclosing		High-speed	To auto-reclose only the faulted phase (single phase) for the case of a single phase trip for a single phase-earth fault
Three phase auto-reclosing	Interconnection to an adjacent line	High-speed Medium-speed Low-speed	To auto-reclose three phase for the case when a three phase trip is issued for every fault, used for the condition when interconnected to an adjacent line
	Synchronism check		To auto-reclose three phase when a three phase trip is issued for every fault, used for the condition of synchronism check depending on the leading and following terminal i.e. dead line charge and check sync
Multi-phase Auto-reclosing		High-speed	To auto-reclose on the condition that a total of at least two different phases or three phases are healthy in two lines of a parallel line
Preference trip/reclosing on double circuit lines (not multi-phase auto-reclosing)		High-speed	When two differing fault types occur simultaneously in a double circuit line configuration e.g. a single phase-to-earth fault on one line and a phase-to-phase fault on the second line preference will be given to the phase-to-phase fault because it is more severe in terms of network stability. A three phase trip is issued separately for each fault the most severe fault taking priority.

7. Auto-reclosing function (1-phase ARC)

(1) Single-phase auto-reclosing

Performance

-Reclosing is preformed, if single-phase fault occurs

-Final trip is performed, if multi-phase fault occurs

Case	Fault phase						Tripping and relosing	
	#1 line			#2 line			#1 line	#2 line
	A	B	C	A	B	C		
1	X						1φT→ARC	
2	X	X					3φFT	
3	X	X	X				3φFT	

7. Auto-reclosing function (3-phase ARC)

(2) Three-phase auto-reclosing

Performance

-Reclosing is always preformed, if any fault occurs

Case	Fault phase						Tripping and relosing	
	#1 line			#2 line			#1 line	#2 line
	A	B	C	A	B	C		
1	X						3φT→ARC	
2	X	X					3φT→ARC	
3	X	X	X				3φT→ARC	

7. Auto-reclosing function (1-phase and 3-phase ARC)

(1)&(2) Combination of Single-phase and Three-phase auto-reclosing

Performance

-Reclosing is preformed, if any fault occurs

- Single-phase AR is performed, if single-phase fault occurs
- Three-phase AR is performed, if multi-phase fault occurs

Case	Fault phase						Tripping and relosing	
	#1 line			#2 line			#1 line	#2 line
	A	B	C	A	B	C		
1	X						1φT→ARC	
2	X	X					3φT→ARC	
3	X	X	X				3φT→ARC	

7. Auto-reclosing function (Multi-phase ARC)

(3) Multiple-phase auto-reclosing (MPAR)

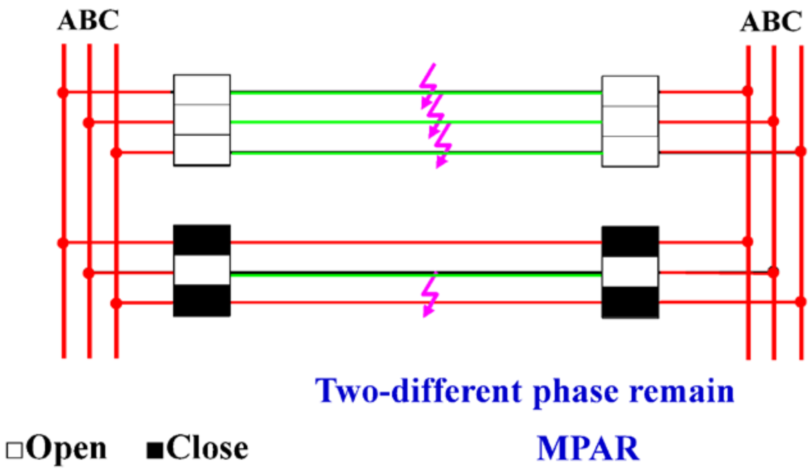
Performance

-Reclosing is preformed according to the fault condition in double-circuit line

- MPAR is to be performed, if two or more healthy phase remain in double-circuit line
- Final trip is to be performed, if above condition is not satisfied.

7. Auto-reclosing function (Multi-phase ARC)

(3) Multiple-phase auto-reclosing



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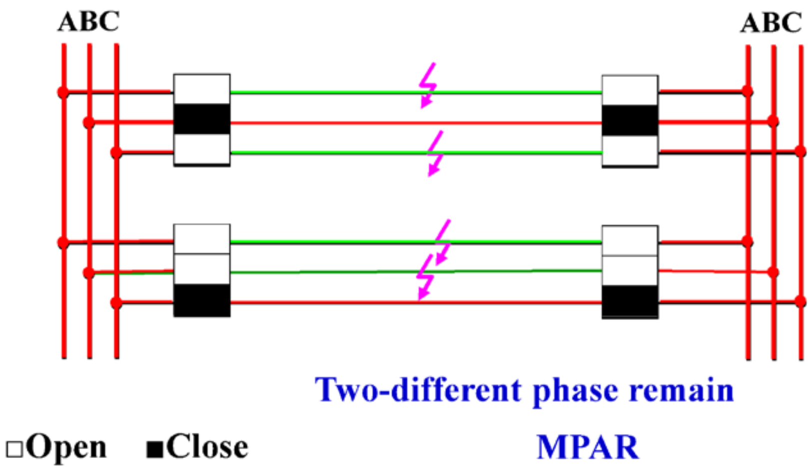
7. Auto-reclosing function (Multi-phase ARC)

(3) Multiple-phase auto-reclosing



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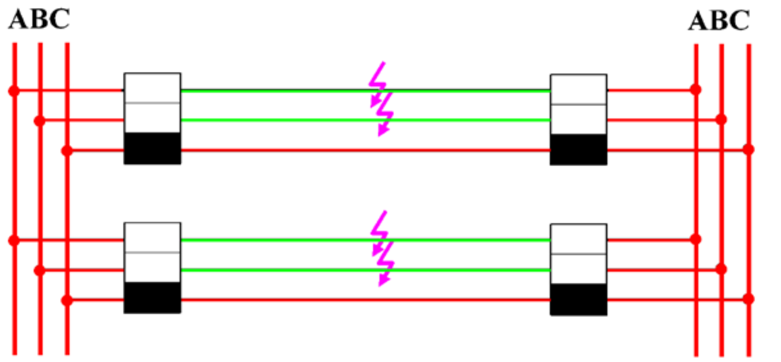
7. Auto-reclosing function (Multi-phase ARC)

(3) Multiple-phase auto-reclosing



Two-different phase don’t remain

□Open ■Close FT(Final Trip)

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7. Auto-reclosing function (Multi-phase ARC)

(3) Multiple-phase auto-reclosing

Case	Fault phase						Tripping and reclosing	
	#1 line			#2 line			#1 line	#2 line
	A	B	C	A	B	C		
1	X			--	--	--	1φT→ARC	--
2	X	X		--	--	--	3φFT	--
3	X	X	X	--	--	--	3φFT	--
4	X						1φT→ARC	
5	X			X			1φT→ARC	1φT→ARC
6	X	X					2φT→ARC	
7	X				X		1φT→ARC	1φT→ARC
8	X	X		X			2φT→ARC	1φT→ARC
9	X	X		X	X		3φFT	3φFT
10	X	X	X				3φT→ARC	
11	X	X				X	2φT→ARC	1φT→ARC
12	X	X			X	X	2φT→ARC	2φT→ARC
13	X	X	X	X			3φT→ARC	1φT→ARC
14	X	X	X	X	X		3φFT	3φFT
15	X	X	X	X	X	X	3φFT	3φFT

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7. Auto-reclosing function (High-speed ARC)

Classification according to dead time

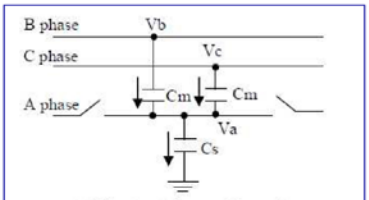
(1) High-speed auto-reclosing

- The dead time is mainly determined by **the de-ionization time**

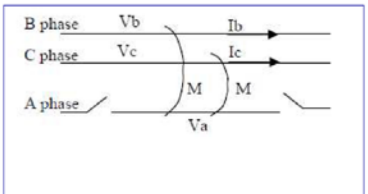
  ↓

  The time taken for the secondary arc to disappear

- **Secondary arc current**



(a) Electrostatic coupling voltage
(a-phase disconnection)



(b) Electromagnetic coupling voltage
(a-phase disconnection)

The dielectric recovery time and de-ionization time

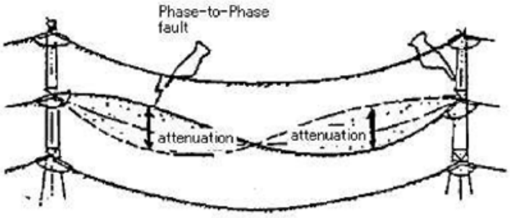
➡ **Longer as fault current increases, In proportion to system voltage**

7. Auto-reclosing function (Medium-speed ARC)

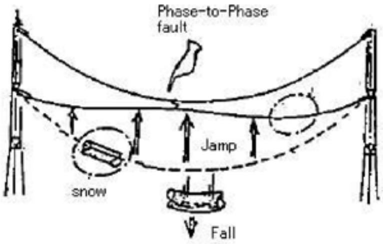
Classification according to dead time

(2) Medium-speed auto-reclosing

- The dead time is considered by:
  - Attenuation of turbine generator shaft vibration,
  - Attenuation of conductor vibration ("Galloping" and "Sleet jump") etc.



"Galloping"



"Sleet jump"

7. Auto-reclosing function (Low-speed ARC)

Classification according to dead time

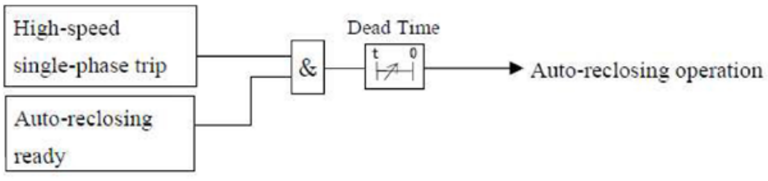
(3) Low-speed auto-reclosing

- The dead time is considered to be more like an automatic recovery method
  - In the event of unsuccessful high-speed auto-reclosing

7. Auto-reclosing function (Requirement)

(1) Single-phase auto-reclosing

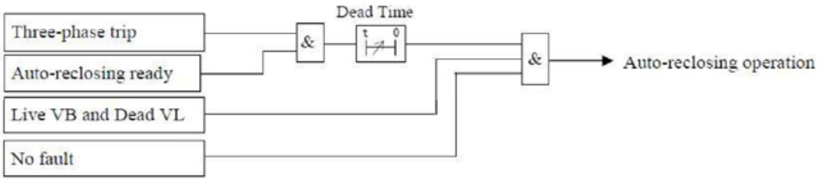
- **Only one out of three phases is opened**
- **Other two phases maintain the interconnection between both terminals**
- **No special interconnection checks are required**



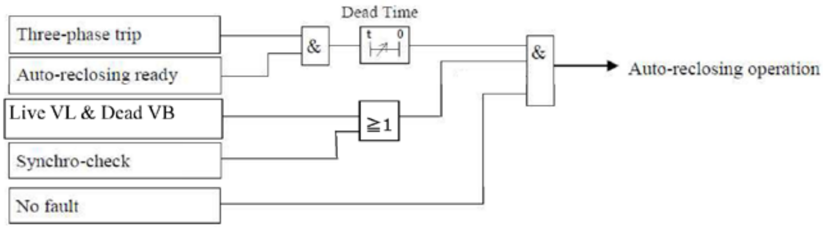
7. Auto-reclosing function (Requirement)

(2) Three-phase auto-reclosing

- **Synchronism-check**



Auto-reclosing condition for leading terminal

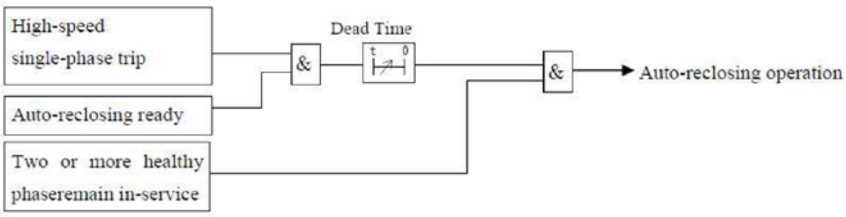


Auto-reclosing condition for follower terminal

7. Auto-reclosing function (Requirement)

(3) Multiple-phase auto-reclosing

- **High speed auto-reclosing after first confirming of different phases in double circuit line**
- **Interconnection of the form of two phases or three phases**



8. Application examples of Japan to long distance line

Line name	Line length	Voltage	In service from	User name	Remarks
Nishi-Gumma-kansen	137.7 km	500kV	1992 ～	TEPCO	1000kV design
Minami-Niigata-kansen	110.8 km	500kV	1993 ～	ditto	ditto
Higashi-Gumma-kansen	44.4 km	500kV	1999 ～	ditto	ditto
Minami-Iwaki-kansen	195.4 km	500kV	1999 ～	ditto	ditto
Dai Kurobe-kansen	245.16 km	275 kV	1988～2011(*1) 2011～ (*2)	KEPCO	1:FM (Analog) 2: Numerical

Note: TEPCO : Tokyo Electric Power Company /TEPCO–Power Grid Inc.

KEPCO: Kansai Electric Power Company /Kansai Transmission and Distribution Inc.

FM: Current differential relay based on Frequency modulation, static type relay

END

2.2. WG3_Distance_Protection (Transmission Line)

Theory of Distance protection

Project for Enhancing Grid System Operation and Maintenance Capacities through Strengthening National Transmission and Despatch Company TSG Training Center

【WG3: Protection Relay Simulator Training 】

- Transmission line protection -

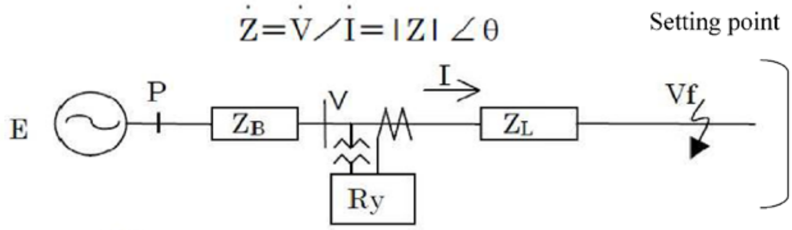
May, 2022

Contents

1. BASICS
2. RELAY CHARACTERISTICS & SCHEME LOGIC
3. ANALYSIS OF TRANSMISSIONLINE FAULT
4. PRINCIPLE OF RELAY OPERATION
5. CONSIDERATIONS OF SETTING
6. MEASURING ERROR COMPONENT
7. APPLICATION PROBLEMS

1. BASICS: *Duty of Distance Relay*

The distance relay measures the impedance from a relay installation part to the fault point, and distinguishes whether it is the fault of protection within the setting.



where

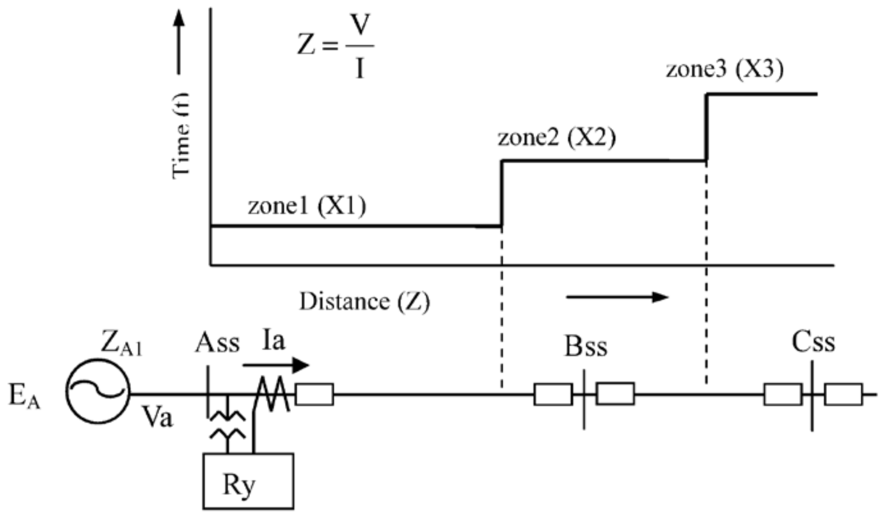
E : Source voltage, V : Measured voltage at terminal

I : Measured current

V_L : Line dropped voltage, V_f : Voltage at the fault,

Z_L : Line impedance, Z_B : Source impedance

1. BASICS: *Distance Protection Scheme*

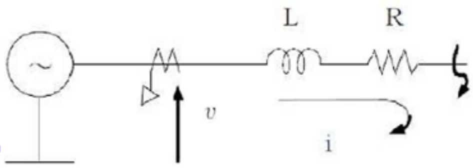


The distance relay is used for main protection and backup protection for transmission lines.
Generally, Zone 1 is for main protection, transmission line between Ass and Bss, Zone 2 and Zone 3 are for backup protection.

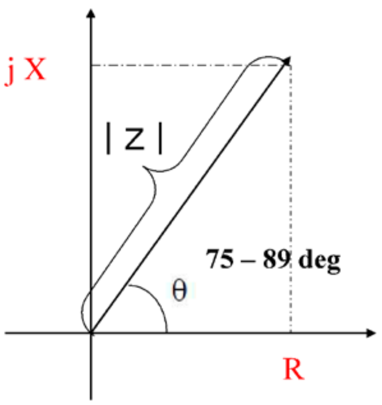
1. BASICS: *R-X plane vs V-I plane*

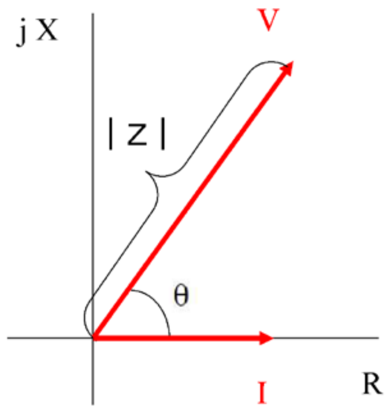
The impedance from the point installing relay to the fault point is almost equivalent to measuring the impedance of a transmission line.

The relation between resistance and reactance in the R-X plane is the same as the voltage V introduced into a relay and Current I.



$$\dot{Z}=\dot{V}/\dot{I}=|Z|\angle\theta=R+jX$$



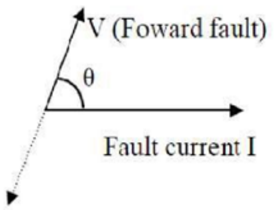


1. BASICS: *Voltage and Current*

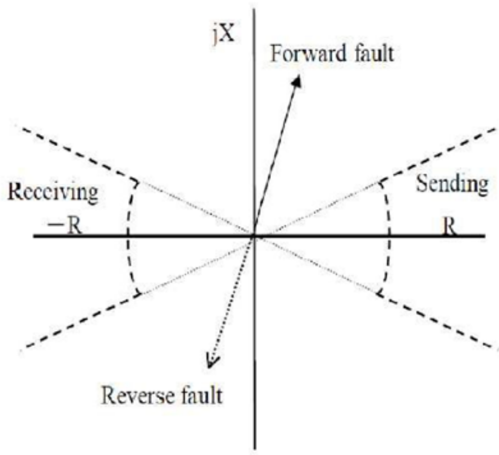
Load impedance during power transmission is almost in +R or -R axis direction.
the impedance exists almost near +X axis in the first quadrant in the event of a forward fault, and exists near –X axis in the third quadrant in the event of a reverse fault.

Voltage and Current at Normal Condition

Voltage and Current during a Fault



(I : Reference, θ : Line angle)



2. RELAY CHARACTERISTICS & SCHEME LOGIC

2. RELAY CHARACTERISTICS & SCHEME LOGIC: (1)

Characteristics of distance relay

Basic requirements
[1]It should be rendered inoperative with load impedance.
[2]It should be able to measure a distance to the fault point accurately.
[3]It should be rendered inoperative in the event of fault which is out of the range of the protection and normal service conditions.

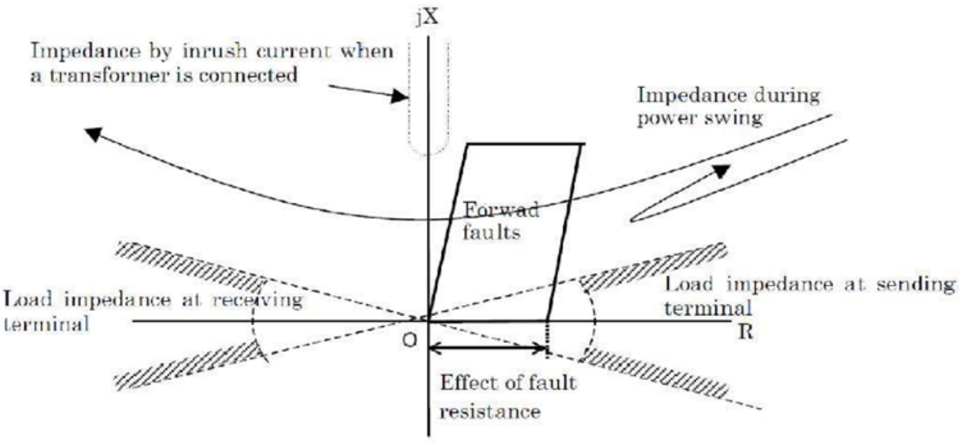
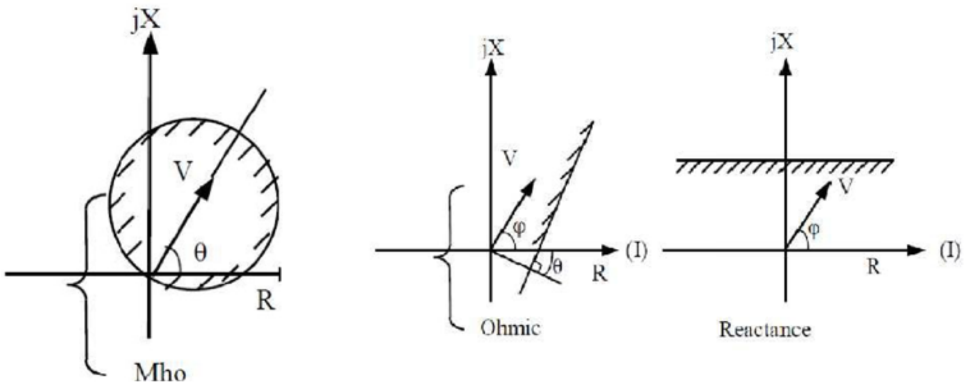


Fig.1.2 Impedance during various events

2. RELAY CHARACTERISTICS & SCHEME LOGIC: (1)

Relay Characteristics

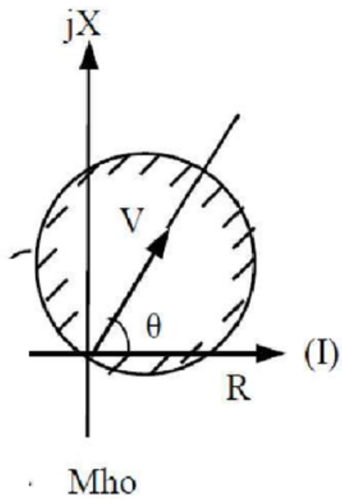


Mho type | Ohm Type | Reactance Type

The basic characteristics of the distance relay should be of mho type and of the ohm type, and also as a reactance type.

2. RELAY CHARACTERISTICS & SCHEME LOGIC: (1)

Relay Characteristics

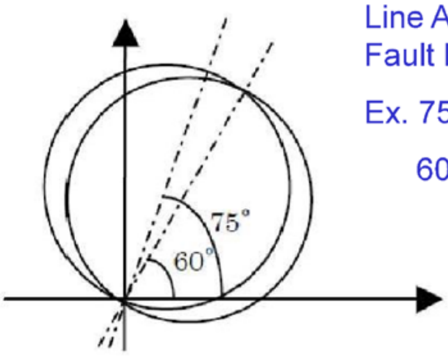


The mho-type distance relay passes through the point of origin and has its operational area on the side of the first quadrant.

2. RELAY CHARACTERISTICS & SCHEME LOGIC : (1)

Relay Characteristics

Characteristic Angle



Line Angle
Fault Resistance with Load

Ex. 75° for phase fault

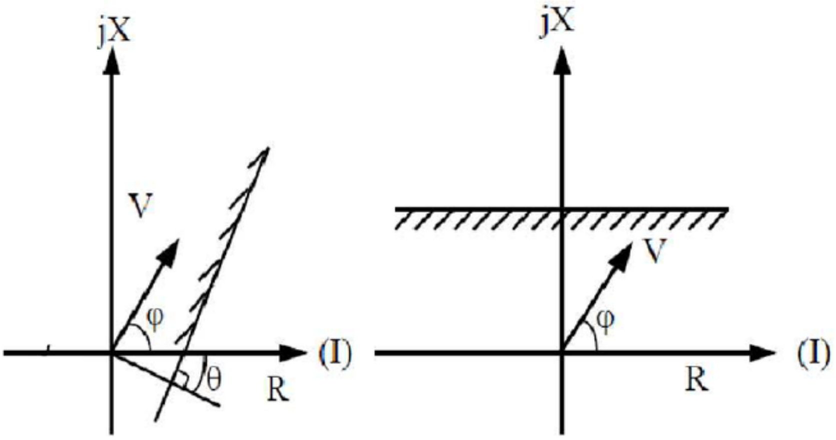
60° for earth fault

The maximum sensitivity angle of a mho-type distance relay is in the direction of the Mho diameter directional angle.

Accordingly, the setting for the maximum sensitivity angle is usually suited to the characteristics of the transmission line and resistance of a fault point.

2. RELAY CHARACTERISTICS & SCHEME LOGIC: (1)

Relay Characteristics



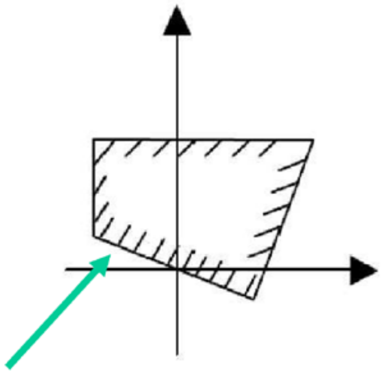
Ohm Type **Reactance Type**

The ohm-type distance relay is used as a blinder element. The reactance-type operates only in response to the reactive component. it has to be used in combination with a mho-type directional element, or quadrilateral directional element.

2. RELAY CHARACTERISTICS & SCHEME LOGIC : (1)

Relay Characteristics

Quadrilateral *-- by Numerical Relay*



Directional element
In combination with the reactance type and ohm type, this element is used when creating quadrilateral characteristics.

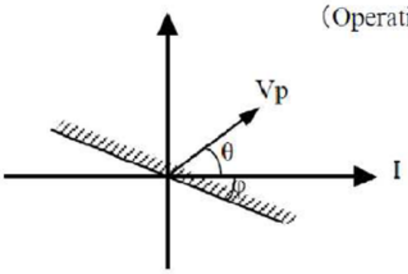
2. RELAY CHARACTERISTICS & SCHEME LOGIC : (1)

Relay Characteristics

The directional element distinguishes the direction of an fault using the phase relation between voltage and current.

(Operating zone is shown as)

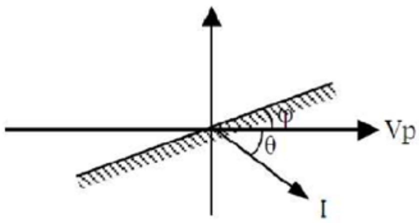
Current base



Directional characteristic with reference to current

=

Voltage base



Directional characteristic with reference to voltage

2. RELAY CHARACTERISTICS & SCHEME LOGIC

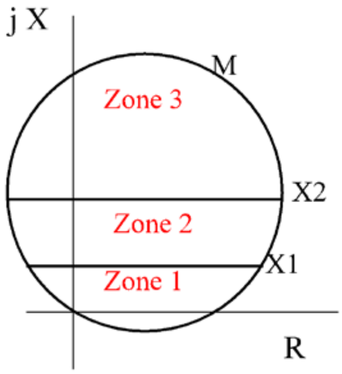
2. RELAY CHARACTERISTICS & SCHEME LOGIC
(1) Relay characteristics
(2) Protection scheme
Time- stepped distance protection

2. RELAY CHARACTERISTICS & SCHEME LOGIC: (2)

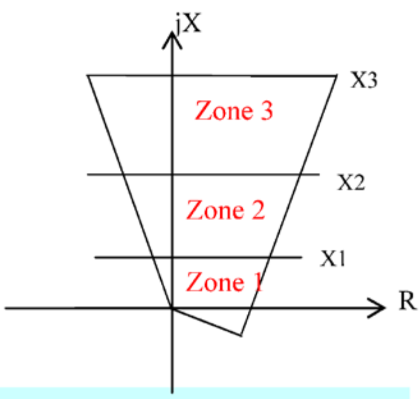
Relay Characteristics

Distance and Directional Element

Examples of characteristics of distance relay



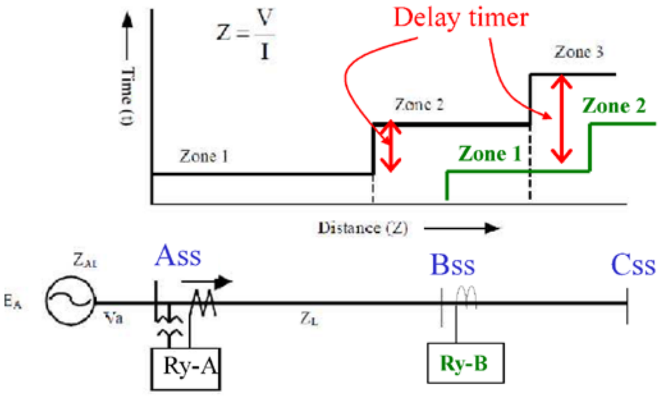
Mho Characteristics



Quadrilateral Characteristics

2. RELAY CHARACTERISTICS & SCHEME LOGIC

Distance Protection Scheme



Zone 1:
typically 80% of the line

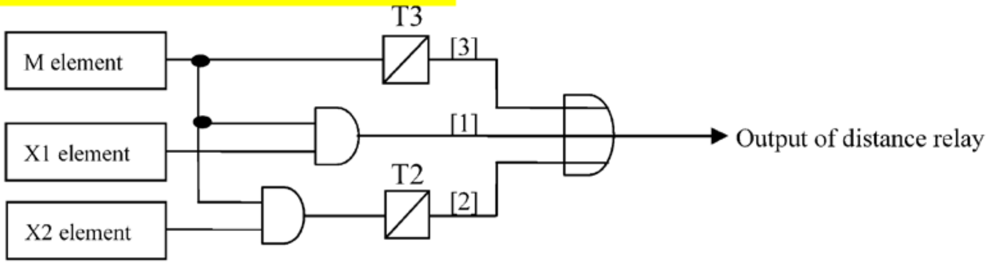
Zone 2:
typically 120% of the line including the next SS busbar

Zone 3:
typically 300% - 500% of the line

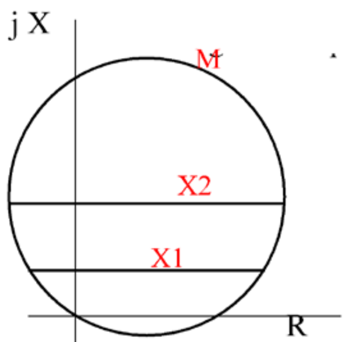
The operating time of zone1 is set to operate instantaneously.
The operating time of the zone2 is set to about 0.2- to 0.5-second. The operating time of the zone3 is set to about 0.8- to 2-second.

2. RELAY CHARACTERISTICS & SCHEME LOGIC

Distance Protection Scheme



[1]: zone1 output, [2]: zone2 output, and [3]: zone3 output



An example of logic of time-Stepped distance protection.
The output of distance relay is produced in accordance with the AND condition of the directional element (mho element) and the distance element (reactance element).

3. Analysis of Transmission line fault

1. BASICS
2. RELAY CHARACTERISTICS & SCHEME LOGIC
3. ANALYSIS OF TRANSMISSIONLINE FAULT
4. PRINCIPLE OF RELAY OPERATION
5. CONSIDERATIONS OF SETTING
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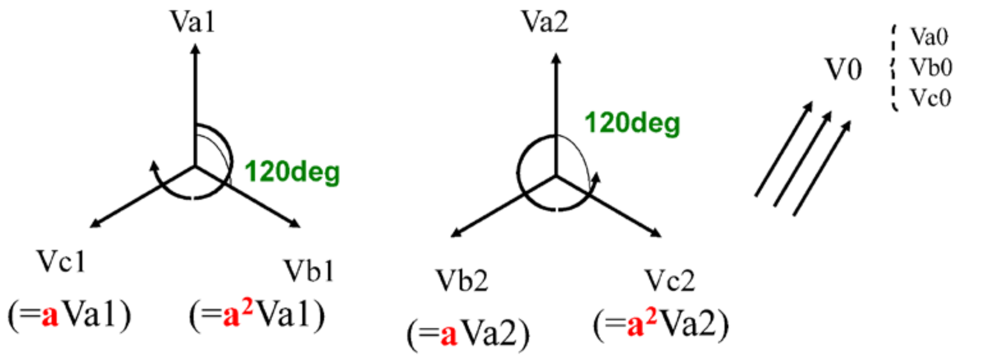
7. APPLICATION PROBLEMS

3. Analysis of Transmission line fault

Symmetrical Component Analysis

A symmetrical component analysis is invented as the analysis technique of the unbalanced fault about 100 years ago.

Positive- sequence Component	Negative- sequence Component	Zero- sequence Component

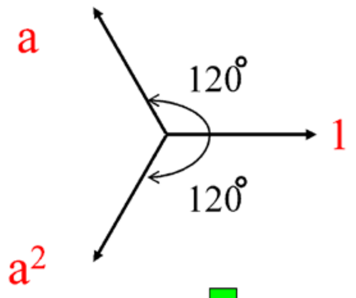


This method considers that each phase component which is consists of positive sequence component, negative sequence component, and zero sequence component.

3. Analysis of Transmission line fault

Vector operator **a**

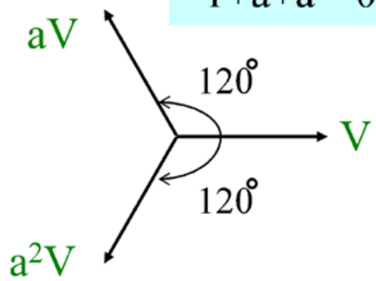
[a] is called vector operator.
[a] means that a phase is 120 degrees advanced without changing a size.
[a^2] means that 120 degrees is advanced twice.



$$\mathbf{a} = -1/2 + j\sqrt{3}/2$$

$$\mathbf{a}^2 = -1/2 - j\sqrt{3}/2$$

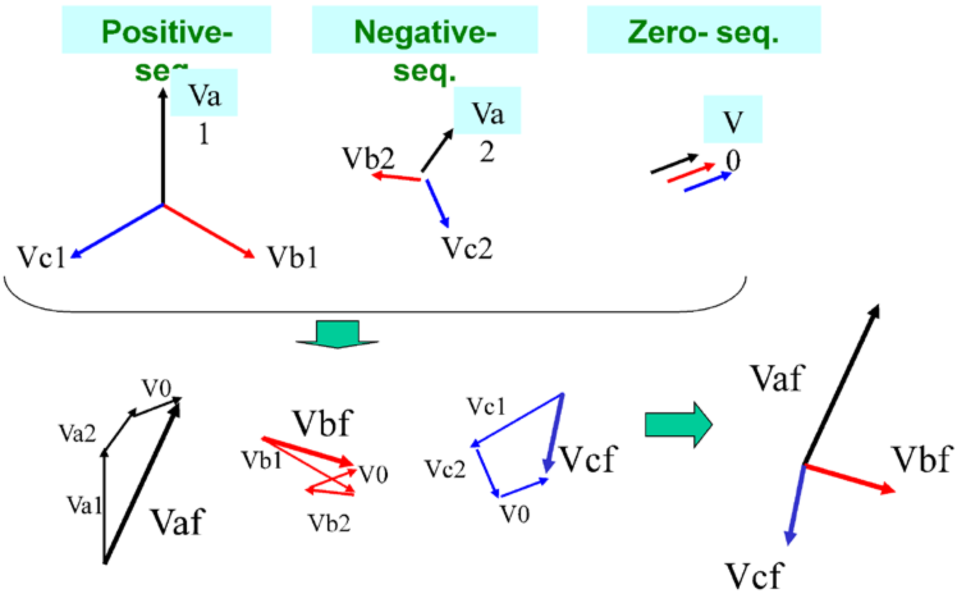
$$1 + a + a^2 = 0$$



3. Analysis of Transmission line fault

Fault Voltage and Symmetrical Component

The relation between the voltage in case of a fault, and a symmetrical component.



3. Analysis of Transmission line fault

Symmetrical to Phase Component

Each phase component is expressed by symmetrical components.

$Va = V0 + Va1 + Va2$

$Vb = V0 + Vb1 + Vb2 = V0 + \mathbf{a^2} Va1 + \mathbf{a} Va2$

$Vc = V0 + Vc1 + Vc2 = V0 + \mathbf{a} Va1 + \mathbf{a^2} Va2$

$$\begin{pmatrix} Va \\ Vb \\ Vc \end{pmatrix} = \begin{pmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{pmatrix} \begin{pmatrix} V0 \\ V1 \\ V2 \end{pmatrix}$$

Symmetrical Component based on A- phase

3. Analysis of Transmission line fault

Phase to Symmetrical Component

On the contrary, symmetrical components is expressed by each phase electrical quantity.

Zero phase: $V0 = 1/3\ (Va + Vb + Vc)$

Positive phase: $V1 = 1/3\ (Va + \mathbf{a} Vb + \mathbf{a^2} Vc)$

Negative phase: $V2 = 1/3\ (Va + \mathbf{a^2} Vb + \mathbf{a} Vc)$

$$\begin{pmatrix} V0 \\ V1 \\ V2 \end{pmatrix} = 1/3 \begin{pmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{pmatrix} \begin{pmatrix} Va \\ Vb \\ Vc \end{pmatrix}$$

Symmetrical Component based on A- phase

3. Analysis of Transmission line fault

Phase to Symmetrical Conversion

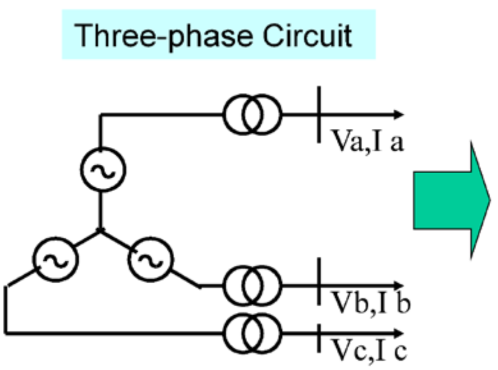
$$\begin{pmatrix} V0 \\ V1 \\ V2 \end{pmatrix} = 1/3 \begin{pmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{pmatrix} \begin{pmatrix} Va \\ Vb \\ Vc \end{pmatrix}$$

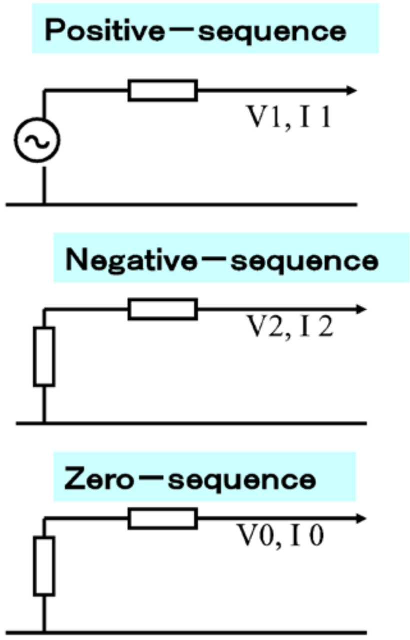
Symmetrical to Phase Conversion

$$\begin{pmatrix} Va \\ Vb \\ Vc \end{pmatrix} = \begin{pmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{pmatrix} \begin{pmatrix} V0 \\ V1 \\ V2 \end{pmatrix}$$

3. Analysis of Transmission line fault

In order to perform fault analysis of an electric power system, the equivalent circuit by the symmetrical components method is used.





3. Analysis of Transmission line fault

Line Impedances

The impedance of a single-circuit type transmission line includes the self impedance and the mutual impedance of the line.

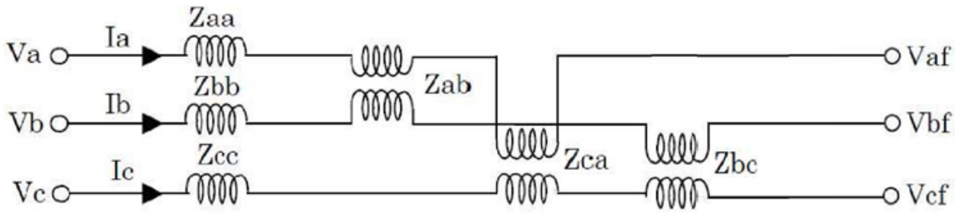


Fig. 2.2 Single line impedance model

$$\left.\begin{aligned} Va &= Zaa \cdot Ia + Zab \cdot Ib + Zca \cdot Ic + Vaf \\ Vb &= Zba \cdot Ia + Zbb \cdot Ib + Zbc \cdot Ic + Vbf \\ Vc &= Zca \cdot Ia + Zbc \cdot Ib + Zcc \cdot Ic + Vcf \end{aligned}\right\} \cdots \quad \text{Equation 2.1}$$

3. Analysis of Transmission line fault

Line Impedances

$$\left.\begin{aligned} Va &= Zaa \cdot Ia + Zab \cdot Ib + Zca \cdot Ic + Vaf \\ Vb &= Zba \cdot Ia + Zbb \cdot Ib + Zbc \cdot Ic + Vbf \\ Vc &= Zca \cdot Ia + Zbc \cdot Ib + Zcc \cdot Ic + Vcf \end{aligned}\right\} \cdots \quad \text{Equation 2.1}$$

considering the symmetry of the line.

$$Zaa = Zbb = Zcc = Zs$$

$$Zab = Zbc = Zca = Zm$$

Then,

$$\left.\begin{aligned} Va &= Zs \cdot Ia + Zm \cdot Ib + Zm \cdot Ic + Vaf \\ Vb &= Zm \cdot Ia + Zs \cdot Ib + Zm \cdot Ic + Vbf \\ Vc &= Zm \cdot Ia + Zm \cdot Ib + Zs \cdot Ic + Vcf \end{aligned}\right\} \cdots \quad \text{Equation 2.2}$$

For example, A-phase voltage is related to b and c phase current in addition to a phase current. It turns out that analysis is complicated and it is difficult in case of the unbalanced fault such as earth fault.

3. Analysis of Transmission line fault

Impedance in Phase Circuit

$$\begin{pmatrix} Va \\ Vb \\ Vc \end{pmatrix} = \begin{pmatrix} Zs & Zm & Zm \\ Zm & Zs & Zs \\ Zm & Zm & Zs \end{pmatrix} \begin{pmatrix} I\,a \\ I\,b \\ I\,c \end{pmatrix}$$

Impedance in Symmetrical Circuit

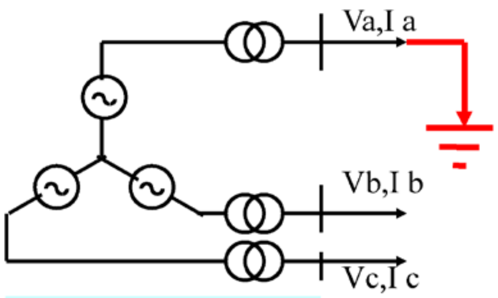
$$\begin{pmatrix} V0 \\ V1 \\ V2 \end{pmatrix} = \begin{pmatrix} Zs+2Zm & 0 & 0 \\ 0 & Zs-Zm & 0 \\ 0 & 0 & Zs-Zm \end{pmatrix} \begin{pmatrix} I\,0 \\ I\,1 \\ I\,2 \end{pmatrix}$$

Since positive sequence, negative sequence and zero sequence component can constitute independently, **analysis becomes easy** also in the unbalance fault.

3. Analysis of Transmission line fault (1LG)

one-phase earth fault (1LG)

In case of the A-phase fault, the current of b and c phase is 0 and the terminal voltage Va is 0.
From this, a symmetrical component is shown like this formula.



Three-phase Circuit

Fault Condition

$Va=0$
$I\,b = I\,c = 0$

Symmetrical Component

$V0 + V1 + V2 = 0$
$I\,0 = I\,1 = I\,2$

3. Analysis of Transmission line fault (1LG)

Conversion

Fault Condition

$V_a=0$
$I_b = I_c = 0$

Symmetrical Component

$V_0 + V_1 + V_2 = 0$
$I_0 = I_1 = I_2$

Conversion to the symmetrical component

$V_a=0$

then $V_0+V_1+V_2 = 0$ -- (1)

$I_b=I_c=0$

then $I_0 + a^2 I_1 + a I_2 =$

$I_0 + a I_1 + a^2 I_2 = 0$ ---(2)

From (2)

$(a - a^2)(I_1 - I_2) = 0$

i.e. $I_1 = I_2$ ---(3)

From (2) and (3),

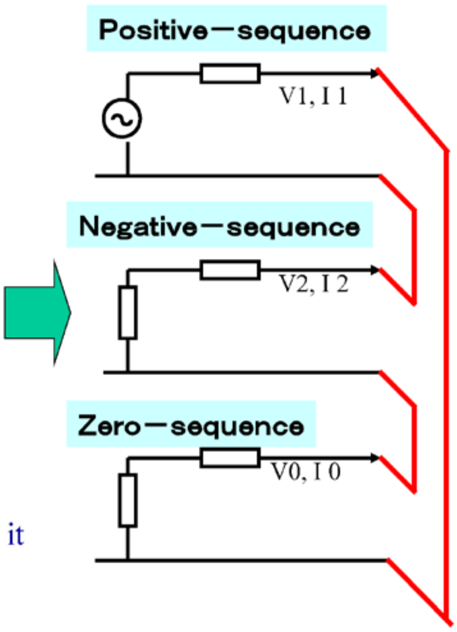
$I_0 = I_1 = I_2$ ---(4)

3. Analysis of Transmission line fault (1LG)

one-phase to earth fault (1LG)

Fault Condition in Symmetrical Component

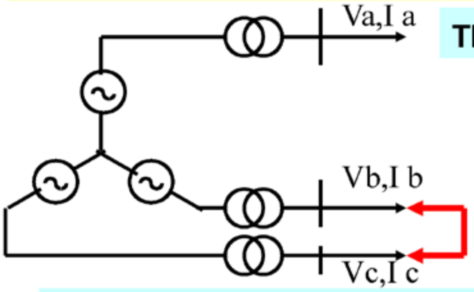
$V_0 + V_1 + V_2 = 0$
$I_0 = I_1 = I_2$



Since positive sequence current, negative sequence current, and zero phase sequence current are the same, it serves as connection as shown in red line.

3. Analysis of Transmission line fault (2LS)

Phase-to-phase fault (2LS)



Three-phase Circuit

Fault Condition

Vb=Vc
I a=0
I b+ I c=0

Symmetrical Component

V1 = V2
I 1 + I 2 =0
I 0 = 0,V0=0

Conversion to the symmetrical component

Ia=0, Ib + Ic=0 i.e. Ia+Ib+Ic=0

then I0+I1+I2 =3I0=0 -- (1)

From (1),

I0=0 , I1+I2=0 ---(2)

Vb=Vc

then $V0 + a^2 V1 + a V2 =$

$V0 + a V1 + a^2 V2 = 0$ ---(3)

From (3)

$(a^2 - a)(V1 - V2) = 0$

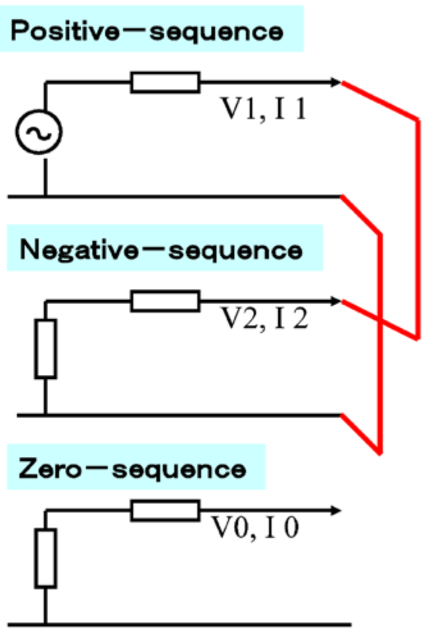
i.e. V1 = V2, V0=0 ---(4)

3. Analysis of Transmission line fault (2LS)

Phase-to-phase fault (2LS)

Fault Condition in Symmetrical Component

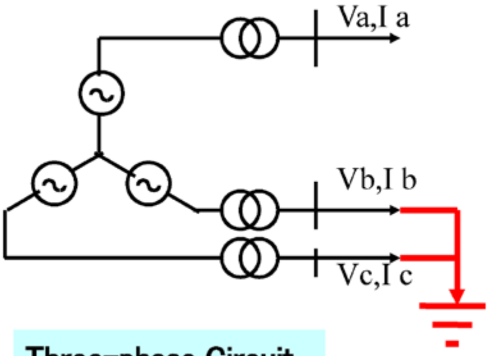
V1 = V2
I 1 + I 2 =0
I 0 = 0、V0=0



Since these formula shows that positive sequence current and negative sequence current have the same magnitude, and it is a reverse phase, an equivalent circuit becomes such.

3. Analysis of Transmission line fault (2LG)

Two-Phase Earth Fault (2LG)



Three-phase Circuit

Fault Condition

Vb=Vc=0
I a=0

Symmetrical Component

V1 = V2 = V0
I 1 + I 2 + I 0 =0

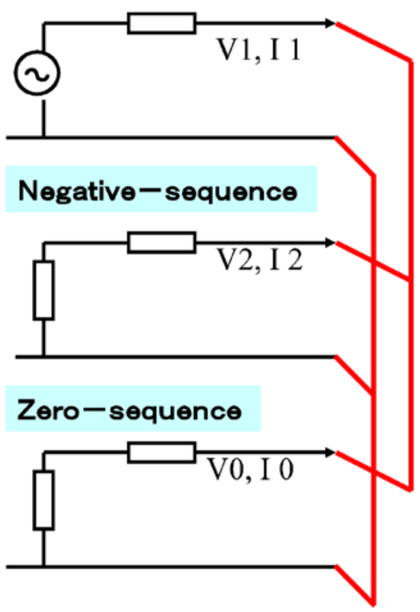
3. Analysis of Transmission line fault (2LG)

Two-Phase Earth Fault (2LG)

Fault Condition in Symmetrical Component

V1 = V2 = V0
I 1 + I 2 + I 0 =0

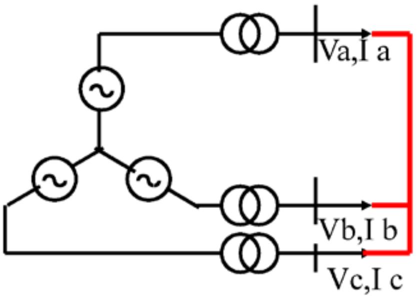
Positive sequence voltage, negative sequence voltage, and zero sequence voltage are the same, and an equivalent circuit is obtained from the relation of this amount of symmetrical components.

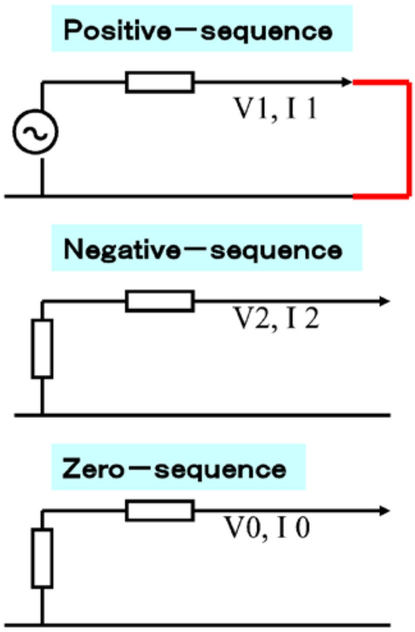


3. Analysis of Transmission line fault (3LS)

Three-phase Fault

Three-phase Circuit



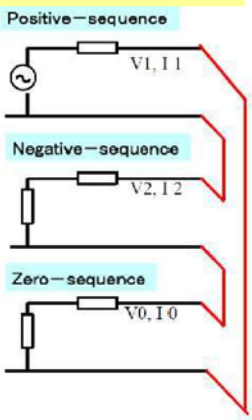


Only positive sequence circuit exists.

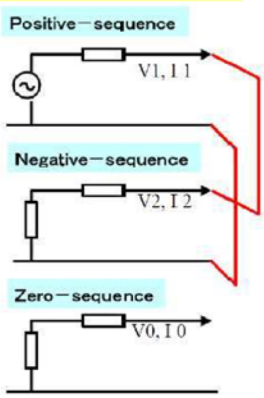
3. Analysis of Transmission line fault

Equivalent Fault Circuit

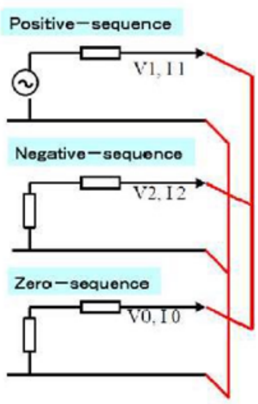
One-phase Earth fault



Phase-to-phase fault

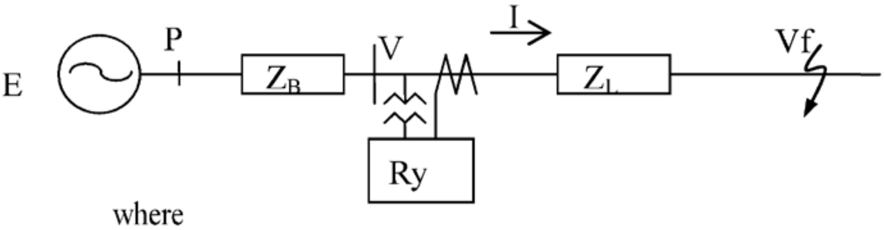


Two-phase Earth fault



3. Analysis of Transmission line fault

(Impedance seen by relay)



where

E: Source voltage, V: Measured voltage at terminal

I: Measured current

V_L: Line dropped voltage, V_f: Voltage at the fault,

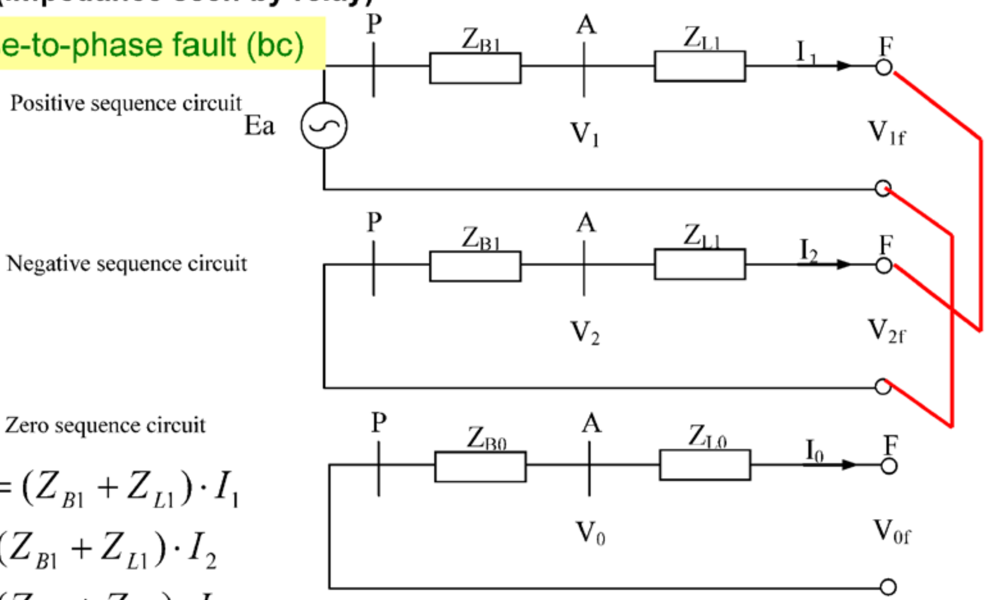
Z_L : Line impedance, Z_B: Back impedance

In order to examine the impedance seen by the distance relay, a virtual distance relay should be installed inside point P of the generator impedance.

3. Analysis of Transmission line fault

(Impedance seen by relay)

Phase-to-phase fault (bc)



$$Ea = (Z_{B1} + Z_{L1}) \cdot I_1$$

$$0 = (Z_{B1} + Z_{L1}) \cdot I_2$$

$$0 = (Z_{B0} + Z_{L0}) \cdot I_0$$

the line impedance and transformer impedance have a relationship such that positive phase impedance is almost equal to negative phase.

3. Analysis of Transmission line fault (Impedance seen by relay)

$$\begin{pmatrix} Ea \\ Eb \\ Ec \end{pmatrix} = \begin{pmatrix} Z_{B1}+Z_{L1} & Z_{B1}+Z_{L1} & Z_{B0}+Z_{L0} \\ a^2(Z_{B1}+Z_{L1}) & a(Z_{B1}+Z_{L1}) & Z_{B0}+Z_{L0} \\ a(Z_{B1}+Z_{L1}) & a^2(Z_{B1}+Z_{L1}) & Z_{B0}+Z_{L0} \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \\ I_0 \end{pmatrix}$$

$$_P Zab = \frac{Eab}{Ia-Ib} = 2(Zb_1 + Z_{L1})\exp(-j60°)$$

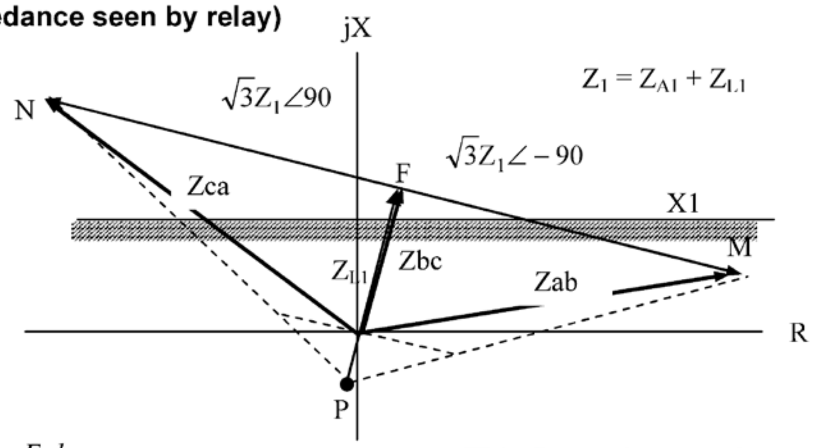
$$_P Zbc = \frac{Ebc}{Ib-Ic} = (Zb_1 + Z_{L1})$$

$$_P Zca = \frac{Eca}{Ic-Ia} = 2(Zb_1 + Z_{L1})\exp(+j60°)$$

Zbc (BC phase relay) measures the line impedance up to the fault point (Zb1 + ZL1).
Zab measures the line impedance lag 60 degrees.
Zca measures the line impedance lead 60 degrees.

3. Analysis of Transmission line fault

(Impedance seen by relay)



$$_P Zab = \frac{Eab}{Ia-Ib} = 2(Zb_1 + Z_{L1})\exp(-j60°)$$

$$_P Zbc = \frac{Ebc}{Ib-Ic} = (Zb_1 + Z_{L1})$$

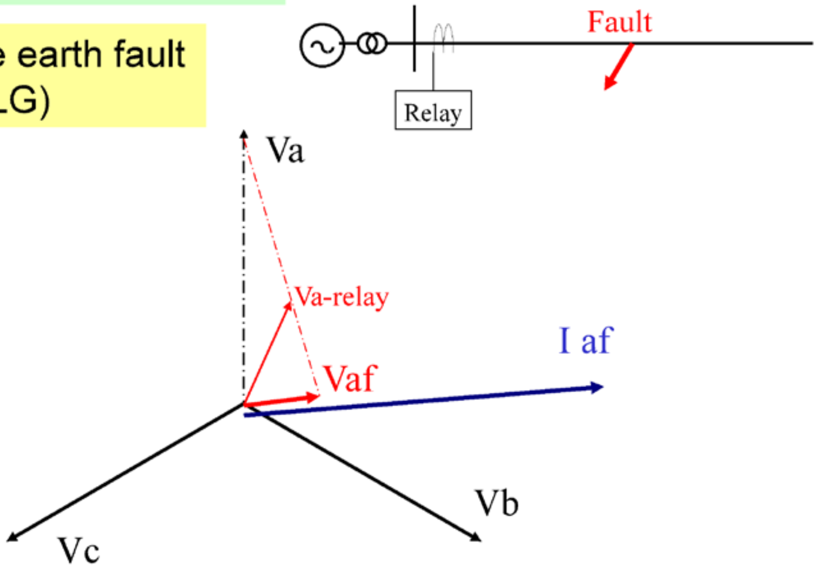
$$_P Zca = \frac{Eca}{Ic-Ia} = 2(Zb_1 + Z_{L1})\exp(+j60°)$$

This figure shows an instance in which the 'ab' phase of the leading phase to the faulted phase goes into the operating zone of the reactance measurement (X1).

3. Analysis of Transmission line fault

Fault Voltage and Current

One-phase earth fault (1LG)

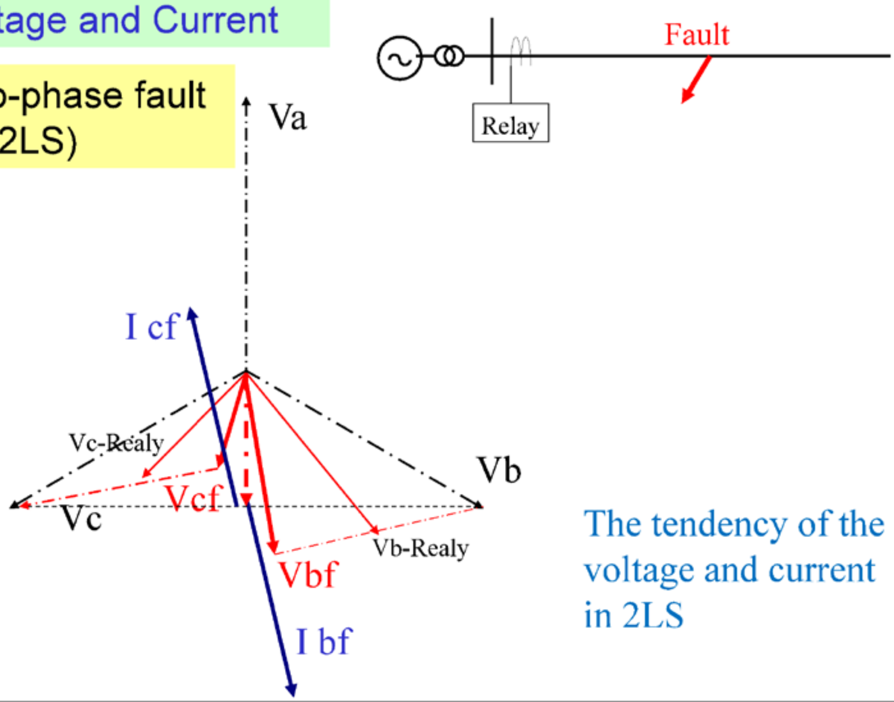


The tendency of the voltage and current in 1LG.

3. Analysis of Transmission line fault

Fault Voltage and Current

Phase-to-phase fault (2LS)

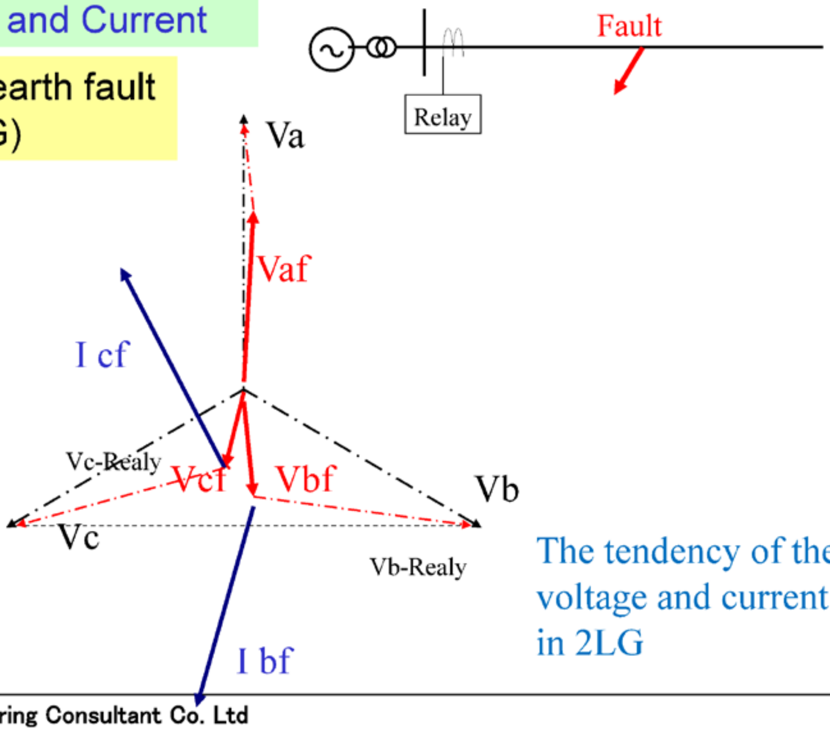


The tendency of the voltage and current in 2LS

3. Analysis of Transmission line fault

Fault Voltage and Current

Two-phase earth fault (2LG)



The tendency of the voltage and current in 2LG

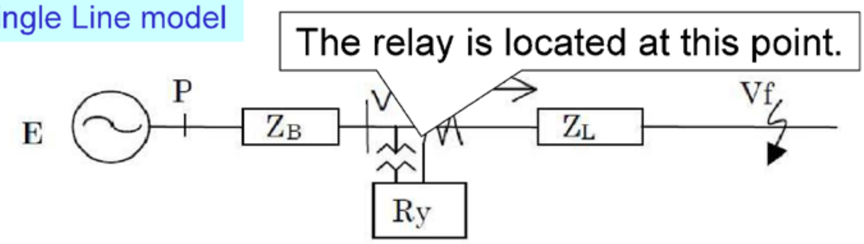
4. Principle of Relay operation

1. BASICS
2. RELAY CHARACTERISTICS & SCHEME LOGIC
3. ANALYSIS OF TRANSMISSIONLINE FAULT
4. PRINCIPLE OF RELAY OPERATION
5. CONSIDERATIONS OF SETTING
6. MEASURING ERROR COMPONENT
7. APPLICATION PROBLEMS

4. PRINCIPLE OF RELAY OPERATION
(1) The principle of the distance measurement
(2) The principle of the directional element
(3) The relay characteristic and the principle of operation

(1) The principle of the distance measurement

Single Line model



where

E : Source voltage, V : Measured voltage at terminal

I : Measured current

V_L : Line dropped voltage, V_f : Voltage at the fault,

Z_L : Line impedance, Z_B : Source impedance

The distance relay measures positive-phase-sequence impedance (Z1) from the voltage and current.

4. Principle of Relay operation

(1) The principle of the distance measurement

Line Impedances

The impedance of a single-circuit type transmission line includes the self

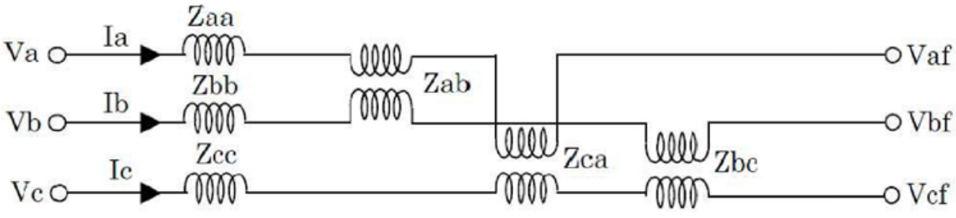


Fig. 2.2 Single line impedance model

$$\left.\begin{aligned} Va &= Zaa \cdot Ia + Zab \cdot Ib + Zca \cdot Ic + Vaf \\ Vb &= Zba \cdot Ia + Zbb \cdot Ib + Zbc \cdot Ic + Vbf \\ Vc &= Zca \cdot Ia + Zbc \cdot Ib + Zcc \cdot Ic + Vcf \end{aligned}\right\} \cdots \quad \text{Equation 2.1}$$

4. Principle of Relay operation

(1) The principle of the distance measurement

Phase voltage

$$\left.\begin{aligned} Va &= Zaa \cdot Ia + Zab \cdot Ib + Zca \cdot Ic + Vaf \\ Vb &= Zba \cdot Ia + Zbb \cdot Ib + Zbc \cdot Ic + Vbf \\ Vc &= Zca \cdot Ia + Zbc \cdot Ib + Zcc \cdot Ic + Vcf \end{aligned}\right\} \cdots \quad \text{Equation 2.1}$$

considering the symmetry of the line,

$$Zaa = Zbb = Zcc = Zs$$

$$Zab = Zbc = Zca = Zm$$

Then,

$$\left.\begin{aligned} Va &= Zs \cdot Ia + Zm \cdot Ib + Zm \cdot Ic + Vaf \\ Vb &= Zm \cdot Ia + Zs \cdot Ib + Zm \cdot Ic + Vbf \\ Vc &= Zm \cdot Ia + Zm \cdot Ib + Zs \cdot Ic + Vcf \end{aligned}\right\} \cdots \quad \text{Equation 2.2}$$

4. Principle of Relay operation

(1) The principle of the distance measurement

Phase voltage

$$\left.\begin{aligned} Va &= Zs \cdot Ia + Zm \cdot Ib + Zm \cdot Ic + Vaf \\ Vb &= Zm \cdot Ia + Zs \cdot Ib + Zm \cdot Ic + Vbf \\ Vc &= Zm \cdot Ia + Zm \cdot Ib + Zs \cdot Ic + Vcf \end{aligned}\right\} \cdots \text{Equation 2.2}$$

voltage drop across the line impedance is VL

$$\left.\begin{aligned} Va &= VaL + Vaf \\ Vb &= VbL + Vbf \\ Vc &= VcL + Vcf \end{aligned}\right\} \cdots \text{Equation 2.3}$$

$$\begin{pmatrix} VaL \\ VbL \\ VcL \end{pmatrix} = \begin{pmatrix} Zs & Zm & Zm \\ Zm & Zs & Zm \\ Zm & Zm & Zs \end{pmatrix} \bullet \begin{pmatrix} Ia \\ Ib \\ Ic \end{pmatrix} \cdots \text{Equation 2.4}$$

4. Principle of Relay operation

(1) The principle of the distance measurement

Impedance in Symmetrical Component

$$\begin{pmatrix} VaL \\ VbL \\ VcL \end{pmatrix} = \begin{pmatrix} Zs & Zm & Zm \\ Zm & Zs & Zm \\ Zm & Zm & Zs \end{pmatrix} \bullet \begin{pmatrix} Ia \\ Ib \\ Ic \end{pmatrix} \cdots \text{Equation 2.4}$$

$$\begin{pmatrix} V0 \\ V1 \\ V2 \end{pmatrix} = \begin{pmatrix} Zs + 2\,Zm & 0 & 0 \\ 0 & Zs - Zm & 0 \\ 0 & 0 & Zs - Zm \end{pmatrix} \begin{pmatrix} I0 \\ I1 \\ I2 \end{pmatrix}$$

The positive-phase-sequence impedance, negative-phase-sequence impedance and zero-phase-sequence impedance are Z1, Z2 and Z0

$$Z1 = Zs - Zm,\ Z2 = Zs - Zm,\ Z0 = Zs + 2Zm$$

4. Principle of Relay operation

(1) The principle of the distance measurement

Impedance seen by the Relays

Phase-to-phase Fault Relay

$$Z = (Vb - Vc) / (Ib - Ic)$$

Δ, (delta) impedance can be found by dividing phase voltage by phase current.

Earth Fault Relay

$$Z = Va / (Ia + k1\ I0 + k2\ I0')$$

Y impedance can be found by dividing voltage by current.

4. Principle of Relay operation

(1) The principle of the distance measurement

Phase-to-phase Fault Relay

$$\left.\begin{aligned} Zab &= Vab / (Ia - Ib) \\ Zbc &= Vbc / (Ib - Ic) \\ Zca &= Vca / (Ic - Ia) \end{aligned}\right\} \quad \cdots \quad \text{Equation 2.5}$$

$$Vbc = (Zs - Zm)(Ib - Ic) + Vbf - Vcf \quad \cdots \quad \text{Equation 2.6}$$

$$Zbc = Z_1 \qquad (\because Z_1 = Zs - Zm) \quad \cdots \quad \text{Equation 2.7}$$

(Zs – Zm) (Ib – Ic) of equation 2.6 is the voltage drop across the line impedance. VL, and Vbf – Vcf will give the voltage at the fault point. Impedance can be found by dividing voltage by current.

4. Principle of Relay operation

(1) The principle of the distance measurement

Earth Fault Relay

$$\left.\begin{aligned} Za &= Va/(Ia + kIo) \\ Zb &= Vb/(Ib + kIo) \\ Zc &= Vc/(Ic + kIo) \end{aligned}\right\} \quad \cdots \quad \text{Equation 2.8}$$

$$\begin{aligned} Va &= ZsIa + ZmIb + ZmIc + Vaf \\ &= (Zs - Zm)Ia + Zm(Ia + Ib + Ic) + Vaf \\ &= (Zs - Zm)Ia + Zm \cdot 3Io + Vaf \\ &= (Zs - Zm)\left\{Ia + \frac{3Zm}{Zs - Zm} Io\right\} + Vaf \quad \cdots \quad \text{Equation 2.9} \end{aligned}$$

based on $Zs - Zm = Z_1, \quad Zs + 2Zm = Zo$:

$$Va = Z_1\left\{Ia + \frac{Z_0 - Z_1}{Z_1} Io\right\} + Vaf \quad \cdots \quad \text{Equation 2.10}$$

4. Principle of Relay operation

(1) The principle of the distance measurement

Earth Fault Relay

$$Va = Z_1\left\{Ia + \frac{Z_0 - Z_1}{Z_1} Io\right\} + Vaf \quad \cdots \quad \text{Equation 2.10}$$

$$\underline{Za = Z_1} + \frac{Vaf}{Ia + kIo} \quad \cdots \quad \text{Equation 2.11}$$

$$\text{Where, } k = \frac{Z_0 - Z_1}{Z_1}$$

Z1 of the first term in the right-hand side of equation 2.11 is the impedance up to the fault point and the second term is impedance at fault point.
At equation 2.11, when the residual voltage at the fault point (Vaf) is 0, the following equation holds:
Za = Z1
The distance measurement principle in parallel line is explained later.

4. Principle of Relay operation

(2)Directional Element

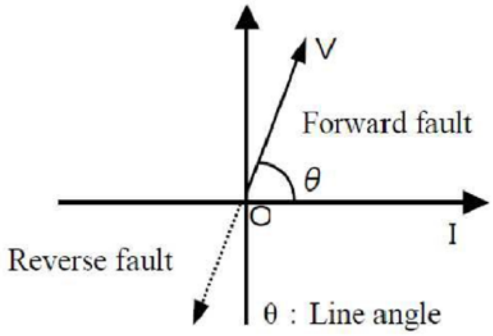


Fig.3.1 Angular relationship between voltage and current during faults

The following are the required performance criteria for a directional element.
(i) It must always be operative in the event of a forward fault.
(ii) It must be always be rendered inoperative in the event of a reverse fault.

4. Principle of Relay operation

(2)Directional Element

Polarizing - - Voltage in close-up fault

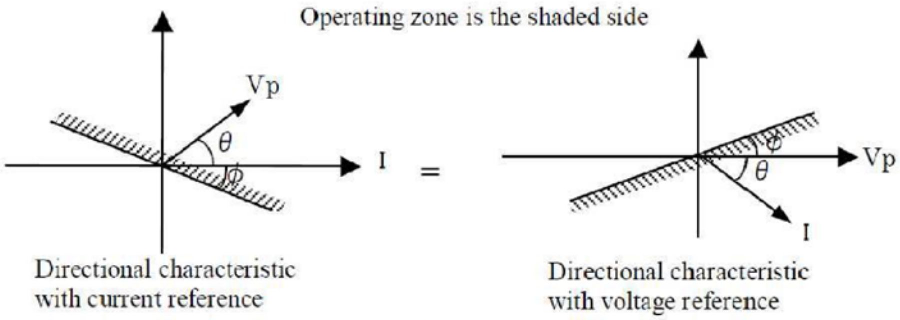


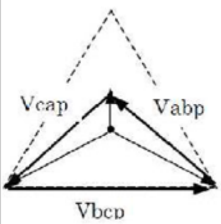
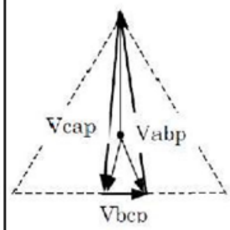
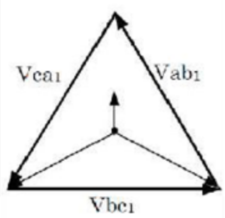
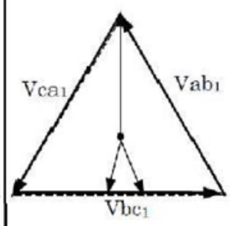
Fig.3.2 Directional element and Relationship between voltage and current (Forward faults)

$$I \cdot Vp \cdot \sin(\theta + \Phi) > 0 \quad \cdots \quad (3.1)$$
$$Zs \cdot I \cdot Vp \cdot \cos(\phi - \theta) \geq V \cdot Vp \quad \cdots \quad (3.2)$$

The phase relationship between the polarising voltage Vp and the current I is determined as shown in equation 3.1, or for a relay with mho characteristics it is used for determining the direction as a directional element as shown in equation 3.2.

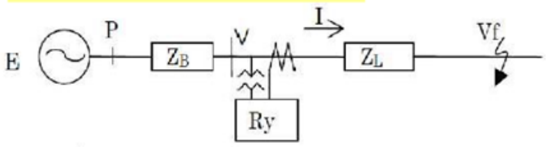
4. Principle of Relay operation

Table 3.1(a) Polarising voltage for phase-to-phase distance

Polarising voltage	"a" phase to earth fault	"b" to "c" phase fault	Features
(1) With memory (phase-to-phase polarizing voltage) Vp=Vbc+Vbcm/k Vbcm : Memorised Voltage k : Constant			Large angle shift of the polarizing voltage involving faulted phase for single phase to earth faults. No angle shift of polarizing voltage of the faulted phase for two-phase to earth faults. Large angle shift of the polarizing voltage involving healthy phase for two-phase to earth faults.
(2) Positive sequence voltage $Vbc_1 = \sqrt{3}(Va - V_0)\angle -90° - Vbc$			No shift of the angle of the polarising voltage either for one phase-to-earth faults or two phase-to-earth faults.

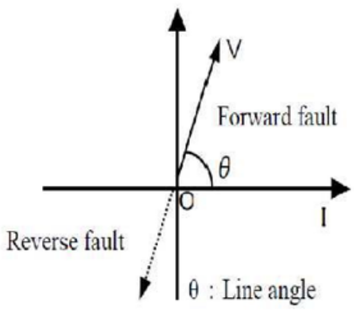
4. Principle of Relay operation

Memory Functions



where
E : Source voltage, V : Measured voltage at terminal
I : Measured current
V_L : Line dropped voltage, V_f : Voltage at the fault,
Z_L : Line impedance, Z_B : Source impedance

Fig. 2.1 Single line model



The occurrence of a close-up fault,

(1) Measures against loss of polarising voltage
The conventional methods that are used frequently include the following methods:
(i)Method by which polarising voltage is made available using memory voltage for short-circuit distance relay
(ii)Method by which polarising voltage is made available shifting a sound phase voltage for earth-fault distance relay
(iii)Method by which positive-phase-sequence voltage functions as the polarising voltage

4. Principle of Relay operation

Memory Functions

(i) Polarising voltage is made available using memory voltage

Vp = Vm+kVm-n · · · (3.3)

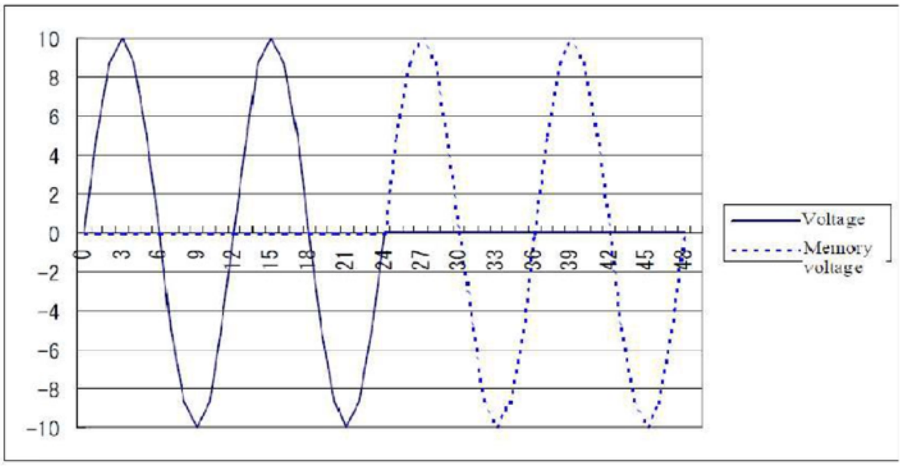


Fig. 3.3 Explanation of the principle of memory voltage

4. Principle of Relay operation

Memory Functions

(ii) Shifting a sound phase by 90° to the leading phase,

$Vp = Va + k \cdot Vbc \angle 90°$

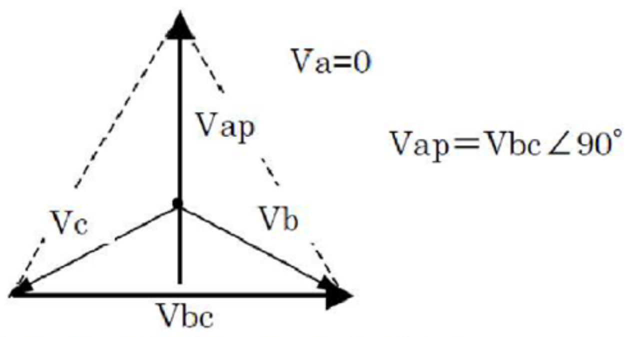


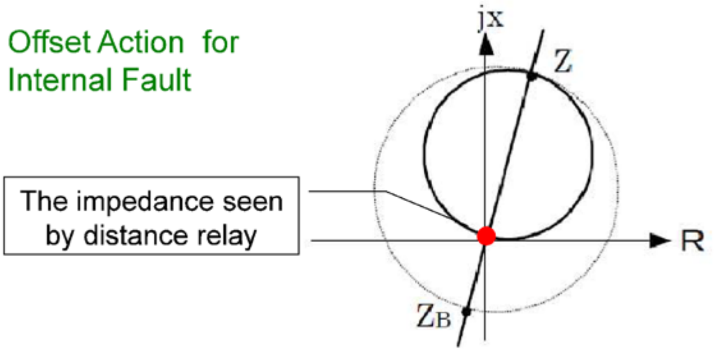
Fig. 3.4 Principle of polarized voltage

4. Principle of Relay operation

On-delay measures at close-up fault

When the first stage of a distance relay is used as a backup protection with time delay, it is highly likely that memory voltage as a polarising voltage will already have disappeared.

Offset Action for Internal Fault



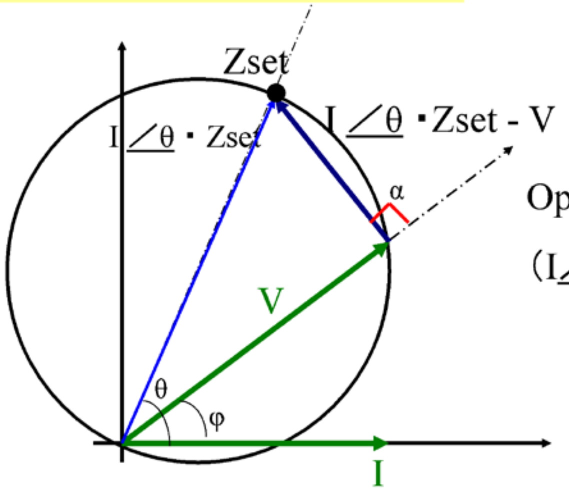
In order to continue operation when the first stage element of the distance relay operates, a measure is taken such that directional element (mho element) of the first stage relay has a reverse offset so as to include the origin.

4. Principle of Relay operation

4. PRINCIPLE OF RELAY OPERATION
(1) The principle of the distance measurement
(2) The principle of the directional element
(3) The relay characteristic and the principle of operation

4. Principle of Relay operation

Mho-type Characteristics



I・cos (φ−θ) / V = k

(I∠θ :I shifted angle θ)

Operating formula

(I∠θ・Zset−V)・Vcosα≧0

<Official formula>

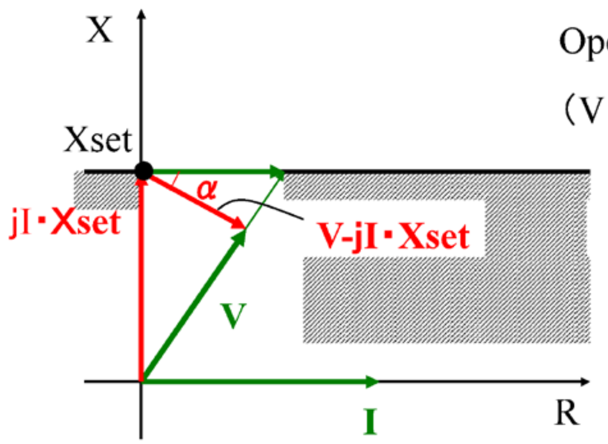
The angle which the diameter of a circle makes is 90 degrees.

α＞90° (cosα＜0) → outside of zone : No-operate

α≦90° (cosα≧0) → inside of zone : Operate

4. Principle of Relay operation

Reactance-type Characteristics



Operating formula

(V−jI・Xset)・Isinα≦0

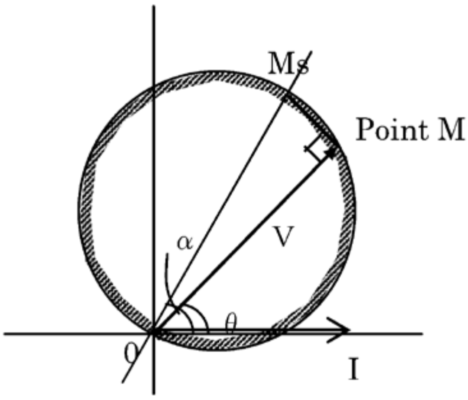
α＞0° (sinα＞0) → outside of zone : No-operate

α≦0° (sinα≦0) → inside of zone : Operate

4. Principle of Relay operation

The theoretical operating voltage value

Mho element



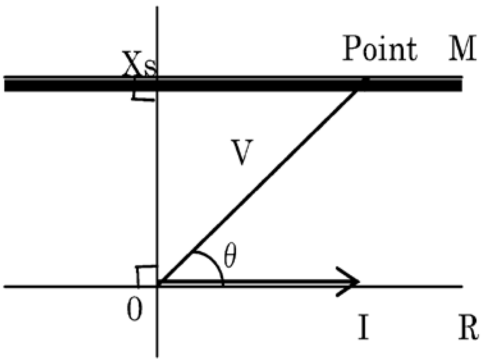
$$Ms \cdot I \cdot \cos(\alpha - \theta) = V$$

$$V = Ms \cdot I \cdot \cos(\alpha - \theta)$$

4. Principle of Relay operation

The theoretical operating voltage value

Reactance element



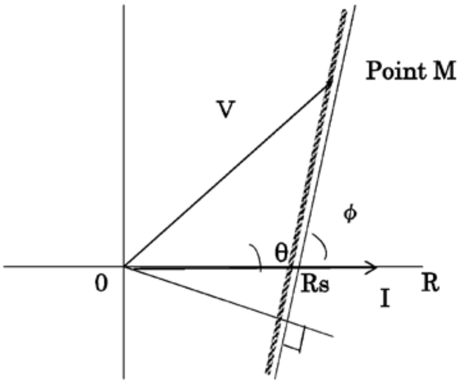
$$V\cos(90^\circ - \theta) = Xs \cdot I$$

$$V = Xs \cdot I / \cos(90^\circ - \theta)$$

4. Principle of Relay operation

The theoretical operating voltage value

Blinder element



$$V\cos(\theta+90^\circ-\varphi)$$
$$=Rs\cdot I\cos(90^\circ-\varphi)$$

$$V=Rs\cdot I\cdot(90^\circ-\theta)/\cos(\theta+90^\circ-\varphi)$$

5. Considerations of setting

1. BASICS
2. RELAY CHARACTERISTICS & SCHEME LOGIC
3. ANALYSIS OF TRANSMISSIONLINE FAULT
4. PRINCIPLE OF RELAY OPERATION
5. CONSIDERATIONS OF SETTING
6. MEASURING ERROR COMPONENT
7. APPLICATION PROBLEMS

5. Considerations of setting

5. CONSIDERATIONS OF SETTING
(1) Setting of reactance element
(2) Setting of blinder element
(3) Setting of directional element

5. Considerations of setting

(1) Setting of Reactance element

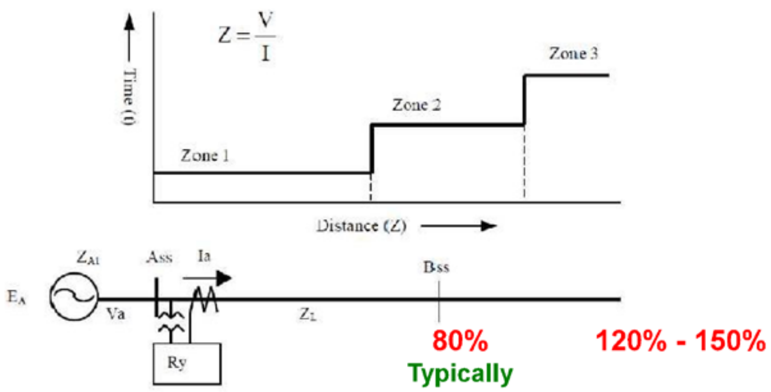
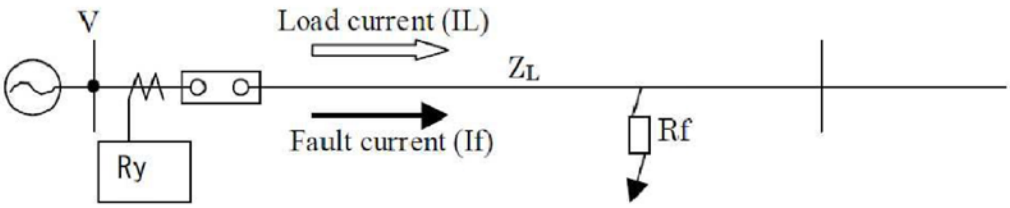


Figure 2.4 Distance protection

For the distance setting of the zone1, 80% or so of the impedance up to the remote terminal so as to avoid overreach.
The zone2, about 120% to 150% of the impedance of the local section.
The zone3, about 300% to 500% of the impedance of the local section.

5. Considerations of setting

Fault Resistance with Power Flow



System model

If there is resistance at the fault point, a distance relay will have a tendency to overreach because of the load current.

5. Considerations of setting

Fault resistance with Power Current

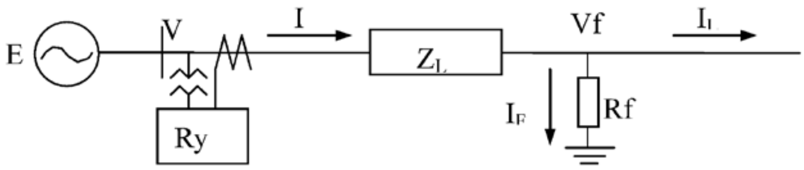


Fig. 4.12 Model of resistance at fault point (single-end power source)

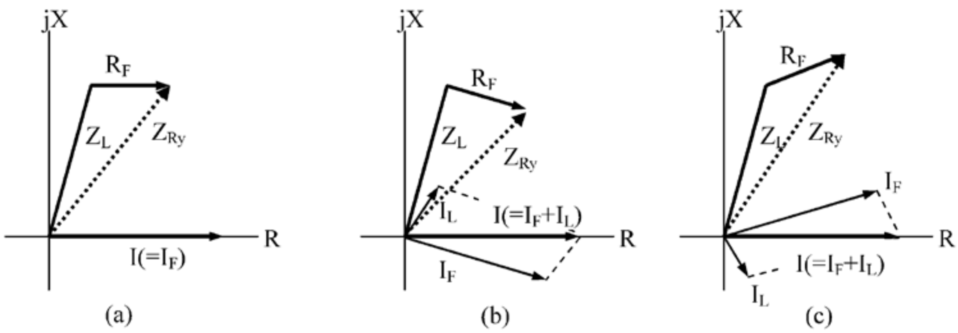


Fig. 4.13 Effect of resistance at the point of fault

Fault Resistance with Power Flow

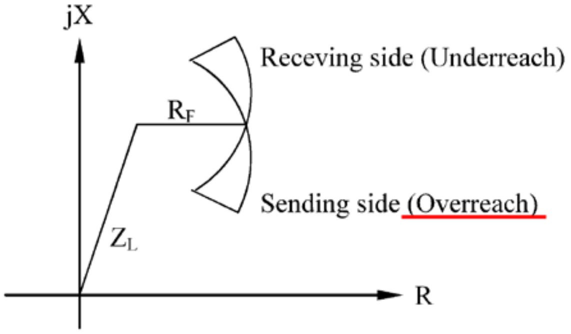


Fig. 4.11 Effect of load current

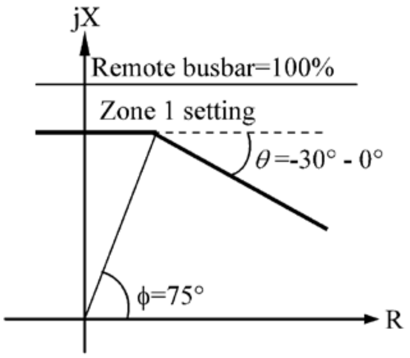
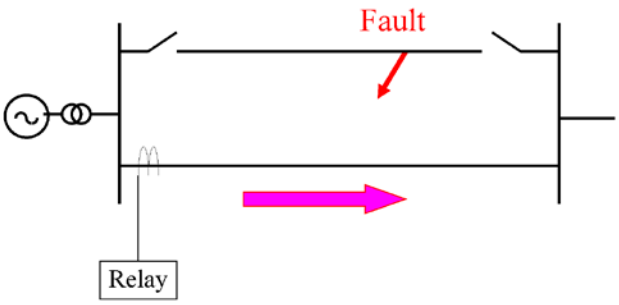


Fig. 4.12 Adaptive reactance element

In particular, the power transmission side shows a tendency to overreach. Overreach is the phenomenon which measures impedance small.

(2) Setting of Blinder element



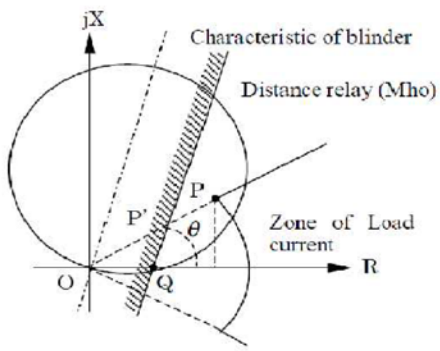


Fig. 7.14 Application of blinder

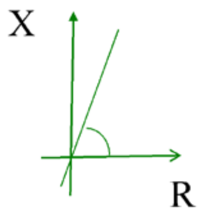
In the setting of a distance relay, it is necessary to guard against operation for maximum load under normal service conditions. In the case that the M-element setting needs to be large in order to accommodate the length of an adjacent section, then it is important that the relay characteristic is not affected by load, for example through application of a blinder element, etc.
To be considered the total load current from both lines is concentrated on one line for a parallel-line system.

5. Considerations of setting

(3) Setting of directional element

Voltage / Current for Directional Detection

For distinguish forward fault or reverse fault with angle relationship between V and I



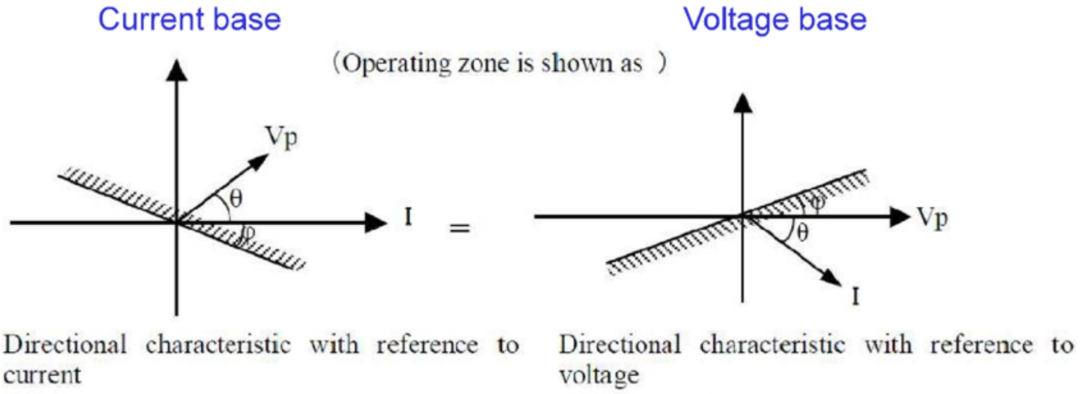


Fig.1.3 Characteristics of distance relays

5. Considerations of setting

(3) Setting of directional element

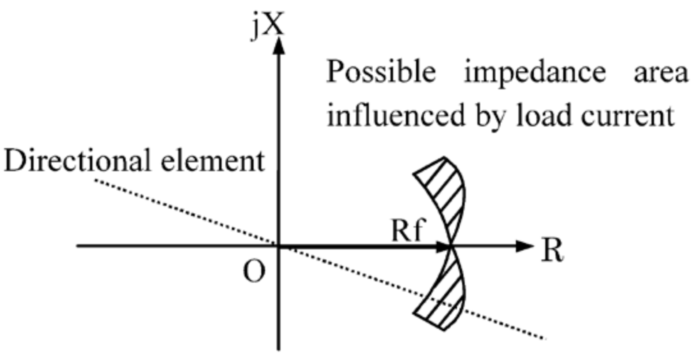


Fig.2.1 Influence of load current on fault resistance

The tendency is for the impedance in the event of fault existing on the + R axis in the R-X plane when resistance at the fault point exists in the event of a forward close-up fault, whereas impedance tends to be deflected if there is load current,

5. Considerations of setting

Since the directional element needs to recognize the direction of an fault certainly in a front fault, it is made into the characteristic of operating also with a sending current.
And in a back fault, it considers as the characteristic of not operating so that an fault may not be detected.

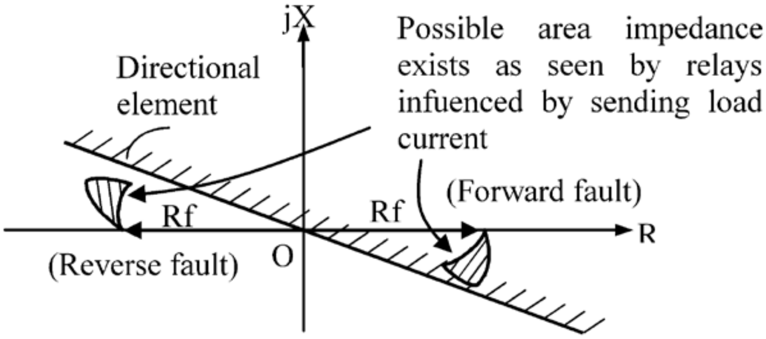


Fig.2.2 Influence of load current on fault resistance-2

5. Considerations of setting

Here, suppose the ratio of load current to fault current is equal to 1:2 as the condition under examination. Even under this condition, the sensitivity of the directional element sensitivity angle needs to be -30° in order to ensure inside and outside area determination.

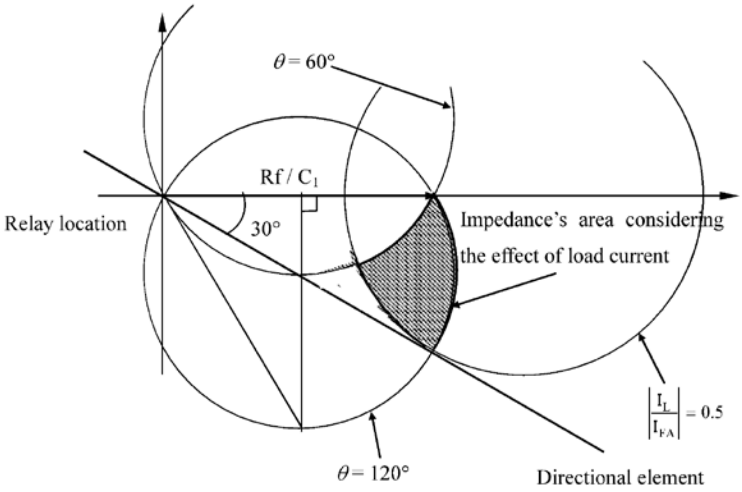


Fig.2.3 Characteristic of directional element

5. Considerations of setting

(3) Setting of directional element (Phase to phase fault distance relay)

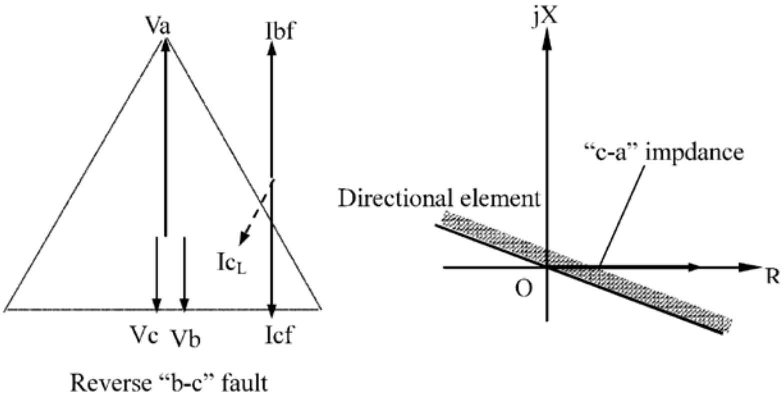


Fig. 2.4 Lagging phase impedance for phase to phase faults

The lagging phase ('ca' phase) relay sees impedance on +R axis in the R-X plane in the reverse 'bc' phase fault. When there is load current, it operates depending on the magnitude of the power flow and phase. The operating range needs to be narrowed by selecting the faulted phase correctly or by adopting a positive-phase-sequence voltage polarizing quantity.

5. Considerations of setting

(3) Setting of directional element (Phase to phase fault distance relay)

The phase of the positive-phase-sequence voltage remains unchanged before and after a fault occurs.
It is better to make a directional element into about -15 degrees in consideration of load current.

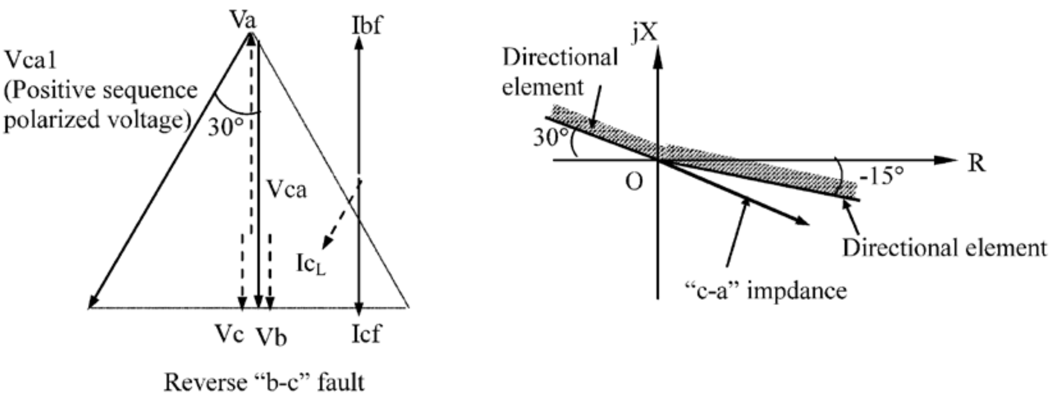


Fig.2.5 Characteristic of phase-to-phase positive sequence polarizing voltage

6. Measuring Error Component

6. Measuring Error Component

(1) Line Constants & VT/CT error

(2) Fault Resistance with Power Flow

(3) Transient DC

(4)Leading-phase Fault

(5)Zero-phase Coupling in Parallel line

6. Measuring Error Component

(1) LINE CONSTANTS ERROR

Examples of transmission line constants are expressed in terms of 500kV overhead line reactance (Ω/km) as follows:

	a	b	c	a'	b'	c'
a	0.437	0.1718	0.1156	0.1054	0.1408	0.1623
b		0.419	0.1478	0.1195	0.1474	0.1408
c			0.3874	0.1212	0.1195	0.1054

When Z_1, Z_0 and Z_m are calculated from the above example, they will be respective values as shown in Table 5.2 below.

Table 5.2 Impedance of each phase Ω／km

	Z_1	Z_0	Z_m	Z_1'
Phase a	0. 2934	0. 7245	0. 4085	−0. 0462
Phase b	0. 2592	0. 7386	0. 4077	0. 0173
Phase c	0. 2557	0. 6508	0. 3461	−0. 0152
Average	0. 2694	0. 7046	0. 3874	−0. 0146

Errors in distance measurement which result from imbalance of the phase impedance of the transmission line range from about -10% to +4% in of the case of a 500kV transmission line.

6. Measuring Error Component

(1) LINE CONSTANTS ERROR

Table 5.3 Compensation factor of each phase

	$k = \frac{Z_0 - Z_1}{Z_1}$	$k' = \frac{Z_m}{Z_1}$
Phase a	1. 469	1. 392
Phase b	1. 850	1. 573
Phase c	1. 545	1. 353
Average	1. 615	1. 438

About 10% error

For zero-phase sequence compensation where impedance is treated as an average value and three-phase operation is performed, the reach setting must be calculated with consideration given to 10% or so of overreach.

6. Measuring Error Component

(1) Line Constants & VT/CT error

(2) Fault Resistance with Power Flow

(3) Transient DC

(4)Leading-phase Fault

(5)Zero-phase Coupling in Parallel line

CT and VT errors cause errors in distance measurement. CT errors tend to occur on the negative side and result in underreach, especially if a high current flows. VT errors, on the other hand, may be either positive or negative, and both overreach and underreach could occur.

6. Measuring Error Component

(1) Line Constants & VT/CT error

(2) Fault Resistance with Power Flow

(3) Transient DC

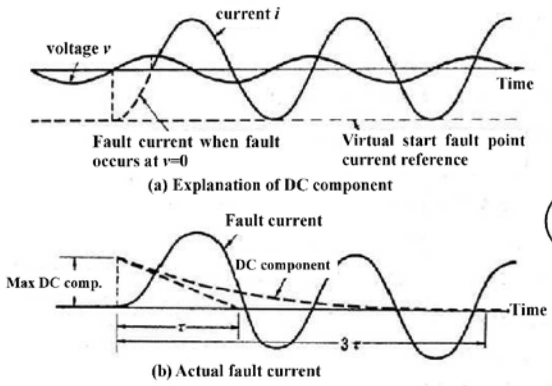
(4)Leading-phase Fault

(5)Zero-phase Coupling in Parallel line

As already explained in sec. 5 "consideration of setting", an error is produced in distance measurement by fault point resistance and load current.

6. Measuring Error Component

(3) Transient DC



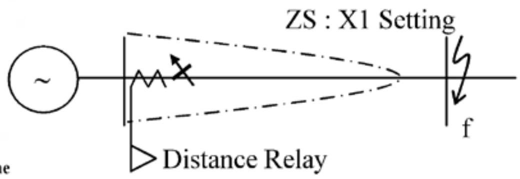
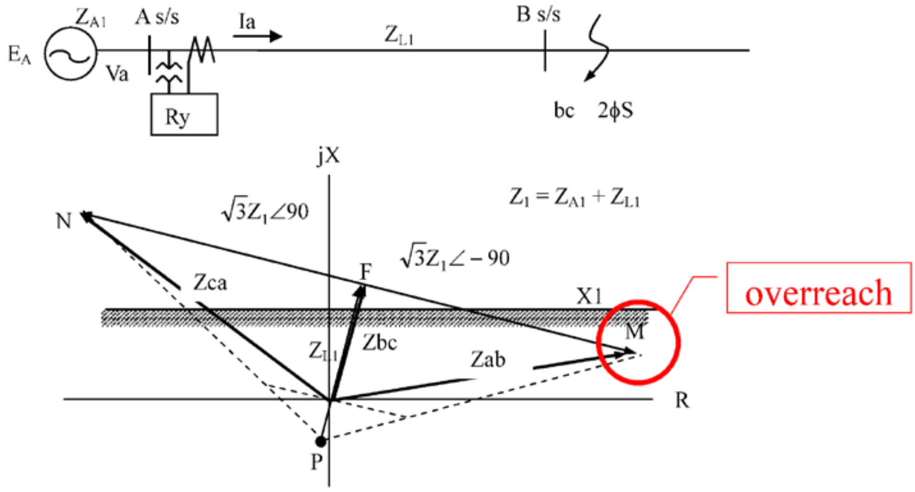


Fig. 4.15 Fault current when fault occurs at v=0

The current value including DC component is large seemingly and the impedance seen by distance relay becomes small. Consequently, transient operation (overreach) may occur. For transient overreach, an improvement is made by means of the overall frequency characteristics of the analog or digital filter as well as the relay arithmetic algorithm.

6. Measuring Error Component

(4) Leading-phase Fault



In a distance relay, if the leading phase relay of a short-circuit relay shows a tendency to overreach, there is a concern that the leading or lagging phase of a earth fault relay will overreach because of a reverse power source condition in the event of double-line ground fault.

6. Measuring Error Component

(4) Leading-phase Fault

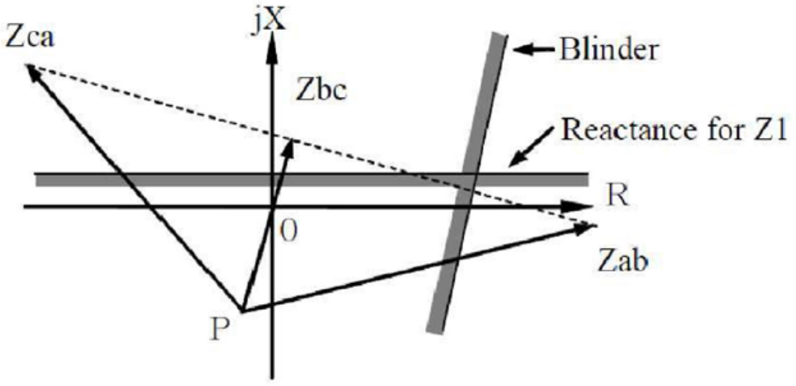


Fig. 5.2 A solution using blinder

Measures taken to avoid overreach of the leading phase of a short-circuit distance relay are;

[1] Blinder element

Operation of the leading phase relay is prevented, by considering the setting of the blinder element.

6. Measuring Error Component

(4) Leading-phase Fault

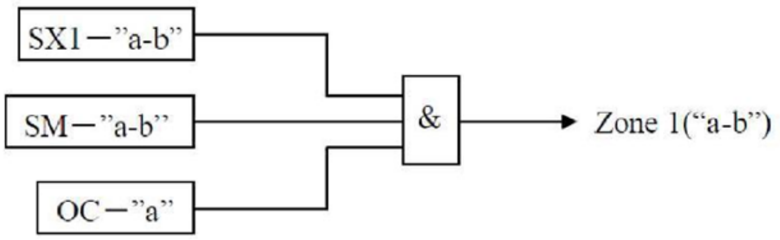


Fig.5.3 A solution using OC

[2]Prevention of overreach using an overcurrent relay

Operation of the leading phase relay can be prevented by adding an overcurrent relay (OC) for the leading phase to AND with the first stage (zone 1) element of short-circuit distance relay.

6. Measuring Error Component

(4) Leading-phase Fault

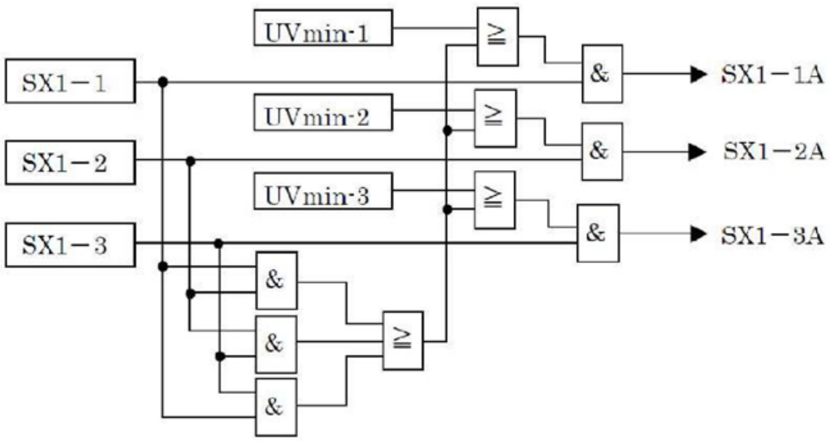


Fig. 5.4 A solution using minimum voltage selection

As faulted phase selection in a short-circuit failure, the zone 1 output of a distance relay of the applicable phase selects the minimum phase voltage.

6. Measuring Error Component

(4) Leading-phase Fault

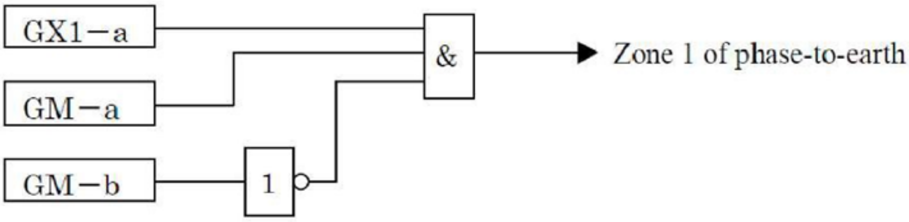
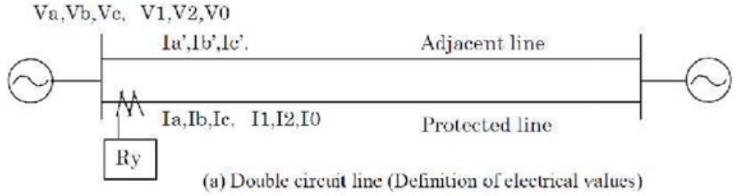


Fig. 5.5 A solution for overreaching of the leading phase of phase-to-earth distance

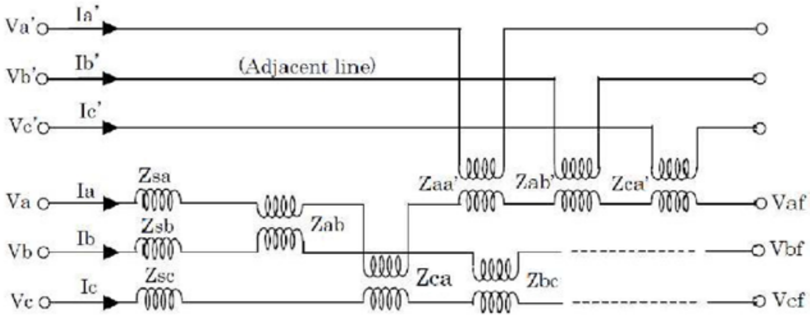
[3]Measures used to prevent overreach in earth-fault distance relays
Although the earth-fault distance relay element makes an accurate measurement in the event of single-line earth fault and three-phase faults, the relay element on the leading or lagging side of the phase can overreach depending on the system conditions in the event of a double-line ground fault. As a measure for this event, the relay element on the leading phase blocks the relay element on the lagging phase.

6. Measuring Error Component

(5) Zero-phase Coupling in Parallel line



(a) Double circuit line (Definition of electrical values)



When applying a earth-fault distance relay to double-circuit transmission line, zero-phase sequence current compensation for the adjacent line and the protected line is required.

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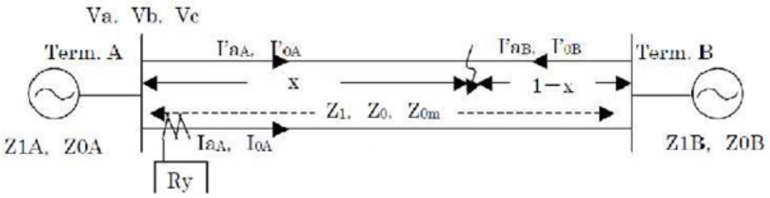
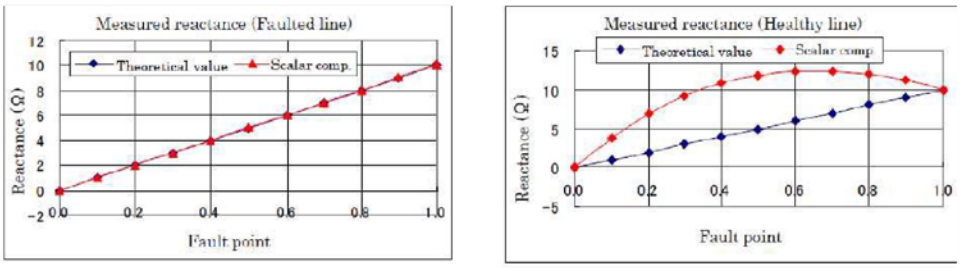
6. Measuring Error Component

(5) Zero-phase Coupling in Parallel line





A relay in the faulted line will measure a distance more accurately if both the self line compensation and adjacent line compensation are provided.
In particular, when an adjacent line fault occurs near the local end, the actual distance seen is shorter than the local section distance. It means the health line relay tends to become overreach.

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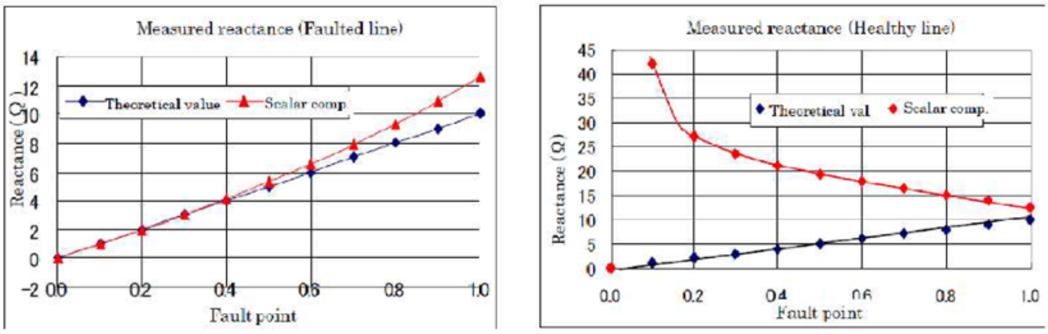
6. Measuring Error Component

(5) Zero-phase Coupling in Parallel line



(a) Relay in faulted line (b) Relay in healthy line

Fig. 3.5(b) Single infeed system (Self compensation)

For compensation only for self line, underreach tendency is shown.
Healthy line relay does not become overreach.

6. Measuring Error Component

(5) Zero-phase Coupling in Parallel line

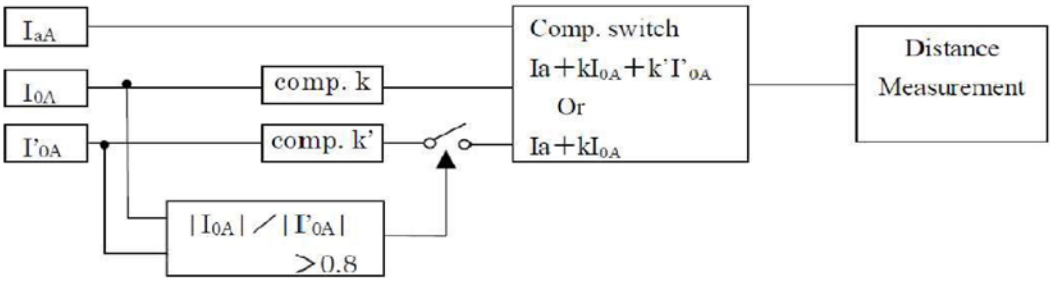


Fig. 3.6 Adjacent line compensation switching

Although a relay on the faulted line side will measure distance accurately if self compensation for the protected line and compensation for the adjacent line are provided, care needs to be taken with regard to adjacent line compensation because a relay on the healthy line will exhibit a tendency to overreach.
Here, as an effective means in providing adjacent line compensation, the method by which the zero-phase sequence currents of each line are compared and whether or not adjacent line compensation is selectable.

6. Measuring Error Component

(5) Zero-phase Coupling in Parallel line

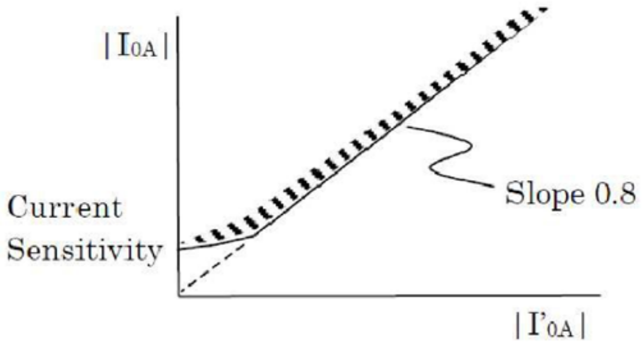


Fig. 3.7 Swithcing Characteristic

The characteristic diagram of the adjacent line compensation changeover relay

7. Application Problems

1. BASICS
2. RELAY CHARACTERISTICS & SCHEME LOGIC
3. ANALYSIS OF TRANSMISSIONLINE FAULT
4. PRINCIPLE OF RELAY OPERATION
5. CONSIDERATIONS OF SETTING
6. MEASURING ERROR COMPONENT
7. APPLICATION PROBLEMS

7. Application Problems

7. APPLICATION PROBLEMS

(1) Switch onto fault

(2) Measures for (lower) harmonics

(3) Measures against inrush current

(4) Reactance coordination

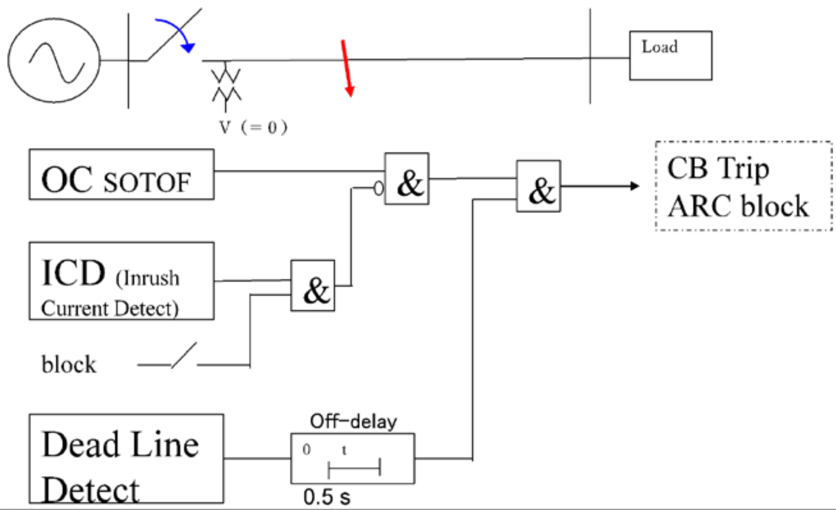
(5) Responsive action with no power source supplied to positive phase

(6) Relay error when grounding adjacent line of a double-circuit transmission line

7. Application Problems (Switch onto fault)

(1) Switch onto fault

The Switch onto Fault function is used to detect and clear faults when CBs are closed onto a pre-existing fault in the protected zone. Generally distance relay cannot operate on switch-onto-fault especially 3LG because no-voltages continues after CB-closed. Therefore, overcurrent element is applied.



7. Application Problems

(2) Measures for (lower) harmonics

The transient harmonic current is experienced, when the electrical charge stored in capacitance (C) is discharged at the fault point in the event of fault, the damped oscillatory waveform of the frequency component which resonates between the inductances (L) which exist in the discharge path.

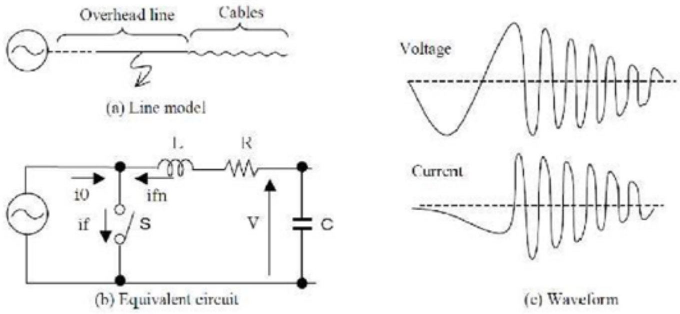


Fig. 6.1 Oscillation

$$ifn = \frac{Vm \sin\phi}{\sqrt{\frac{L}{C}-\frac{R^2}{4L}}}\, e^{-Rt/2L} \sin\left(\sqrt{\frac{1}{LC}-\left(\frac{R}{2L}\right)^2}\right)t \quad \cdot\cdot\cdot \quad \text{Equation 6.1}$$

7. Application Problems

(2) Measures for (lower) harmonics

Table 5.1 Order and content rate of harmonics (Example) 1000MVA Base

	System A	System B
Frequency ($\omega n / \omega o$)	1.7 - 2.8	1.6 - 3.9
Ifn (p.u.)	12 - 27 (16 p.u.)	4.7 - 29 (11 p.u.)
Rate of content ρ_I (%)	117 - 135 (123 %)	47 - 143 (100 %)

Under the condition that such lower harmonics exist, the lower harmonics cannot be removed from distance relays that are equipped with only a conventional analog filter, and the relay characteristic.

7. Application Problems

(2) Measures for (lower) harmonics

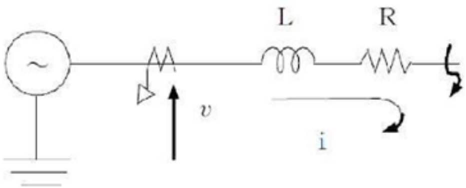


Fig. 6.4 Line model

$$V = R \cdot i + L\frac{di}{dt} \quad \cdots \quad \text{Equation 6.5}$$

$$\int V \cdot dt = R\int i \cdot dt + L \cdot i \quad \cdots \quad \text{Equation 6.6}$$

The principle used to calculate impedance directly is the method to calculate the resistive component, R and the reactive component, X directly, based on one of the following line equations as differential equations which can be derived from the transmission line model shown in this figure.

7. Application Problems

(2) Measures for (lower) harmonics

R and X can be calculated exactly and directly even when higher harmonics are contained, if it is solved simultaneously at two different times.

$$\begin{cases} X = \dfrac{i_m \cdot v_{m-n} - i_{m-n} \cdot v_m}{i_m \cdot j_{m-n} - i_{m-n} \cdot j_m} \\ R = \dfrac{v_m \cdot j_{m-n} - v_{m-n} \cdot j_m}{i_m \cdot j_{m-n} - i_{m-n} \cdot j_m} \end{cases} \qquad \begin{cases} X = \dfrac{Si_m \cdot Sv_{m-n} - Si_{m-n} \cdot Sv_m}{Si_m \cdot i_{m-n} - Si_{m-n} \cdot i_m} \\ R = \dfrac{Sv_m \cdot i_{m-n} - Sv_{m-n} \cdot i_m}{Si_m \cdot i_{m-n} - Si_{m-n} \cdot i_m} \end{cases}$$

$\cdots$ Equation 6.7

(Where, $j = \dfrac{di}{dt}$, $S_V = \Sigma v$, $Si = \Sigma i$)

7. Application Problems

(3) Measures against inrush current

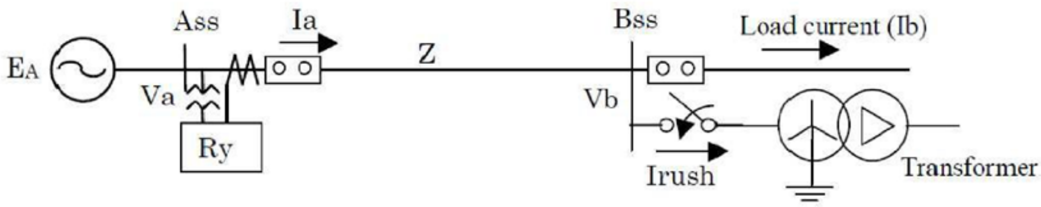


Fig.4.7 Transformer inruch current

When a transformer is energized a magnetizing inrush current will flow.
This current flow is about 3 to 10 times larger than the rated capacity of the transformer.
An unwanted operation of the relay is prevented generally by considering the time setting and impedance setting or alternatively that the relay is locked when inrush current is detected.

7. Application Problems

(3) Measures against inrush current

The impedance locus which the distance relay at this time looks at changes, as shown in the right figure if the relay algorithm uses R and X direct calculation.
The impedance may stay and carry out malfunction to a domain of operation.
Change of impedance is detected for this measure and the method to block is in it.

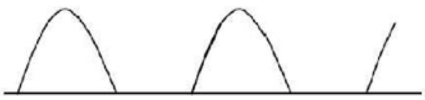


Fig. 5.29 Waveforms of inrush current

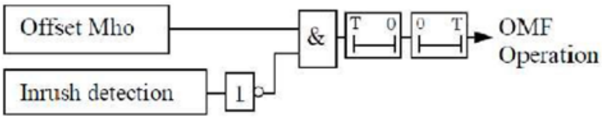


Fig. 5.31 Inrush blocking for OMF

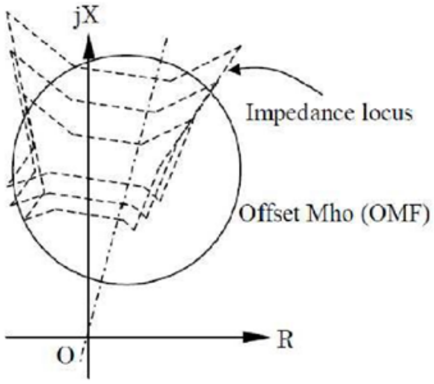


Fig. 5.30 Impedance locus during cycles

7. Application Problems

(4) Reactance coordination

Because a distance relay detects faults using a combination of various elements whose principle of operation varies, such as the reactance element (X element) and the mho element, time coordination between operation and recovery time among each of these elements should be considered.

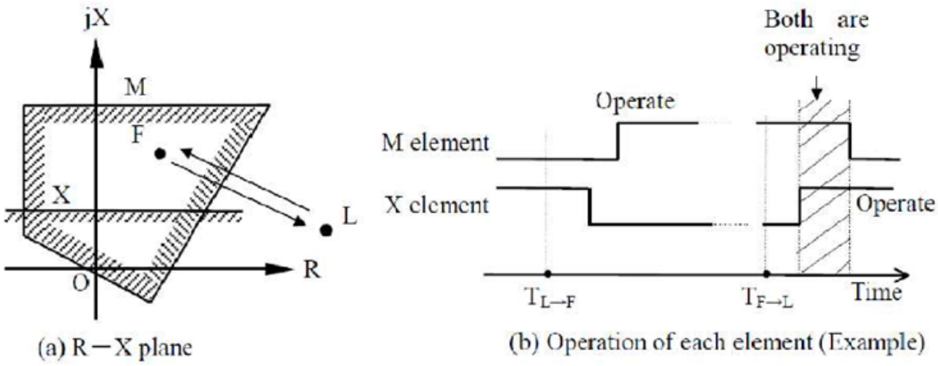


Fig. 5.8 Co-ordination of reactance

7. Application Problems

(4) Reactance coordination

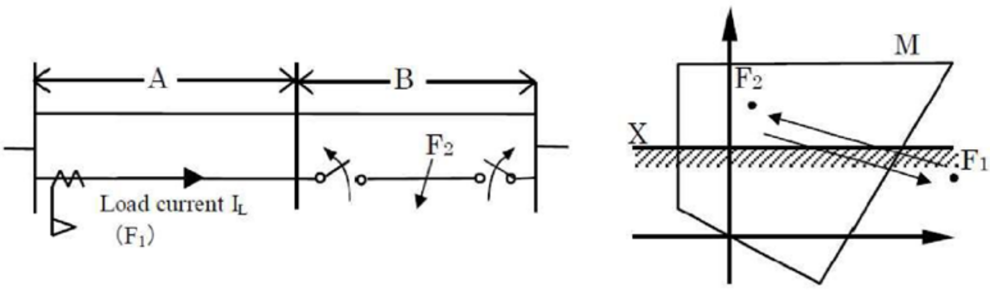


Fig. 5.9 Co-ordination between reactance and blinder element

For coordination in this case, measures must be taken such that 'M' element operation is delayed during the transition from F1→F2.
When the 'M' element operates continues for a certain period of time, the reactance element is rendered inoperative for the transition from F2 → F1.

7. Application Problems

(4) Reactance coordination

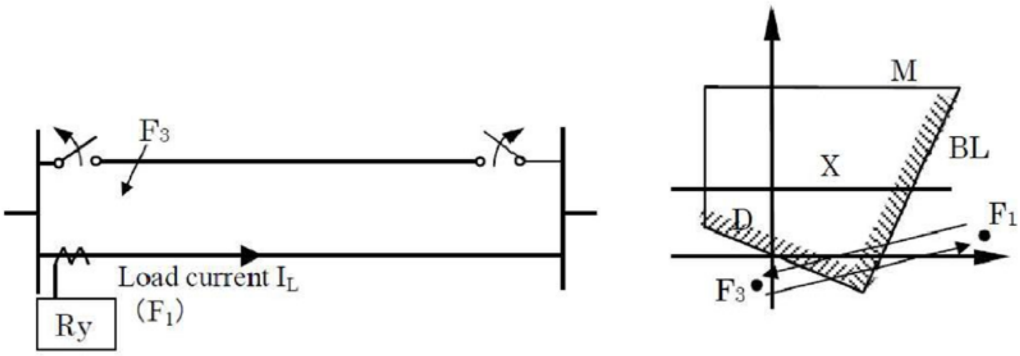


Fig. 5.10 Co-ordination between blinder and Directional element

In the direction F1→F3, the directional element must recover before within the time available before the binder element operates, whereas in the direction F3→F1, the blinder element must recover within the time available before the directional element can operate.

7. Application Problems

(4) Reactance coordination

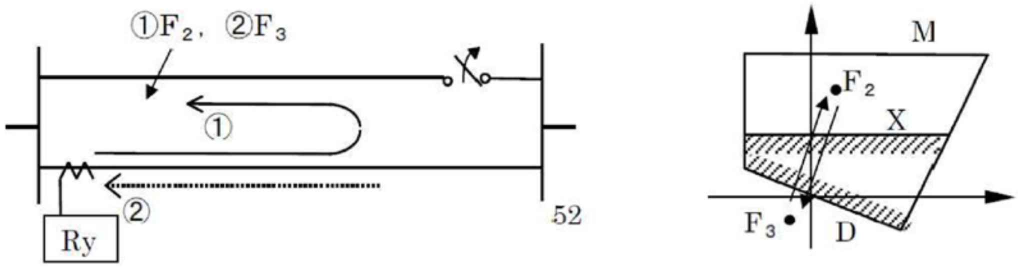
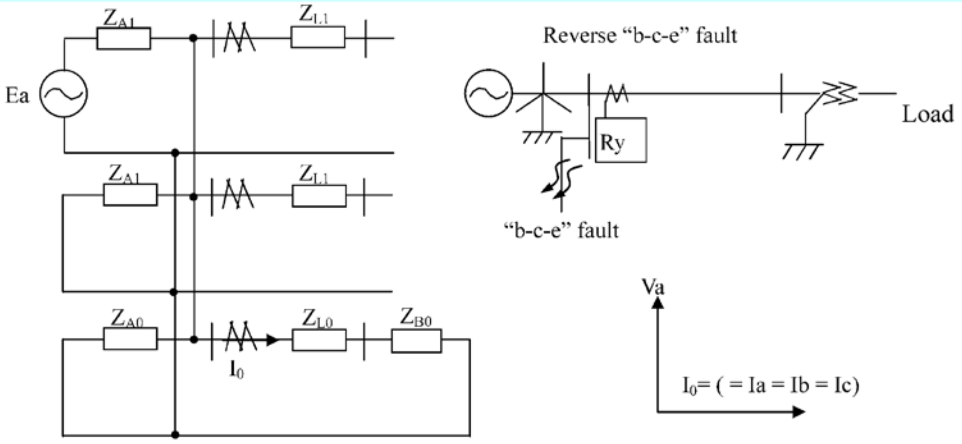


Fig. 5.11 Co-ordination between reactance and Directional element

For the direction F3→F2, measures should be taken in such a way that 'M' element operation is delayed, and for the direction F2→F3, measures should be taken in such a way that reactance element operation is delayed after state in which 'M' element operation continues for a certain period of time under the condition that the reactance element (X) is rendered inoperative.

7. Application Problems

(5) Responsive action with no power source supplied to positive phase



(a) Equivalent circuit (b) Relationship between V and I

Fig. 3.8 Reverse "b-c" fault in case of no infeed from the remote end

In the 'bc' phase 2ϕG behind the power source terminal when no power source is supplied to the positive phase of the remote terminal, only the zero-phase current I0 flows.

7. Application Problems

(5) Responsive action with no power source supplied to positive phase

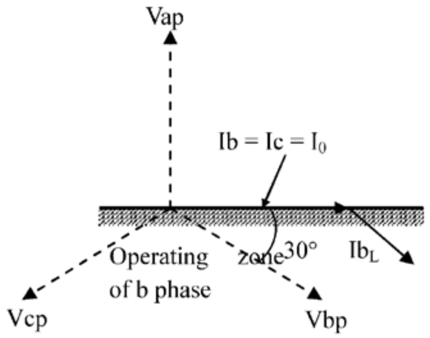


Fig. 3.9 Voltage and current for reverse two-phase to earth fault

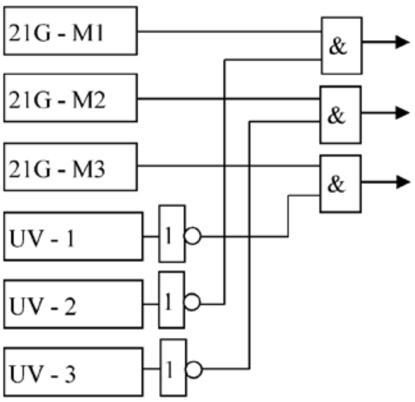


Fig. 3.10 Logic of contermeasure

In the 'b' phase of a earth-fault distance relay, the phase defference between the polarising voltage Vbp and current Ib is 30degrees. It is likely that a forward direction is determined. In particular, this tendency may be prominent if the load current IbL exists. An unwanted operation should be prevented by the lagging phase UV relay.

7. Application Problems

(6) Relay error when grounding adjacent line of a double-circuit transmission line

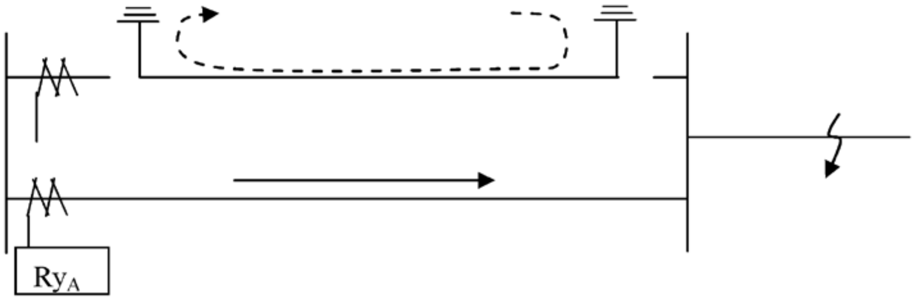


Fig. 3.12 Fault while the adjacent line is earthed

	a	b	c	a'	b'	c'
a	0.4371	0.1718	0.1156	0.1054	0.1408	0.1623
b		0.419	0.1478	0.1195	0.1474	0.1408
c			0.3874	0.1212	0.1195	0.1054

When the reactance element of a earth-fault distance relay uses the adjacent line zero-phase sequence current compensation, the induced current flows through the deactivated line may affect to the distance relay as overreach.

THE END

2.3. WG3_System_Integration_Protection (2022-12-5)

Project for Enhancing Grid System Operation and Maintenance Capacities through Strengthening National Transmission and Despatch Company TSG Training Center

- System Integrity Protection -

December, 2022

Asia Engineering Consultant

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Contents

1. Summary of SIPS (System Integrity Protection Scheme)
2. Rotor angle instability
3. Frequency instability
4. Abnormal voltage
5. Overloads and countermeasures
6. Classification of stabilization method of SIPS
7. Examples of applied SIPS

2

1. Summary of SIPS (System Integrity Protection Scheme)

Power System Abnormal Phenomena

The target power system abnormal phenomena addressed by SIPS

(1) Rotor angle instability ('Out-of-Step')

- Generators becomes unstable losing synchronous

(2) Frequency instability (Abnormal frequency)

- The frequency deviation caused by a significant unbalance between active power supply and demmand

(3) Abnormal voltage

- Voltage deviation caused by power system faults, sudden increases in power demand etc.

(4) Overload

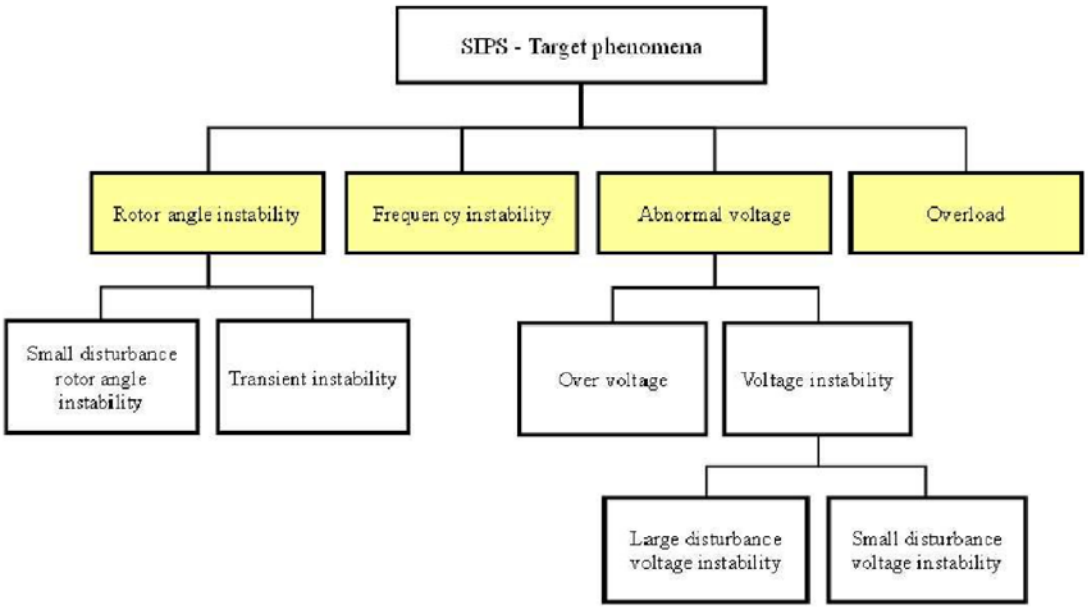
- Caused by the sudden unavailability of an element of a power system, such as a transmission line, transformer etc., due to the occurrence of a power system fault

3

1. Summary of SIPS (System Integrity Protection Scheme)

Power System Abnormal Phenomena

The classification of system abnormal phenomena



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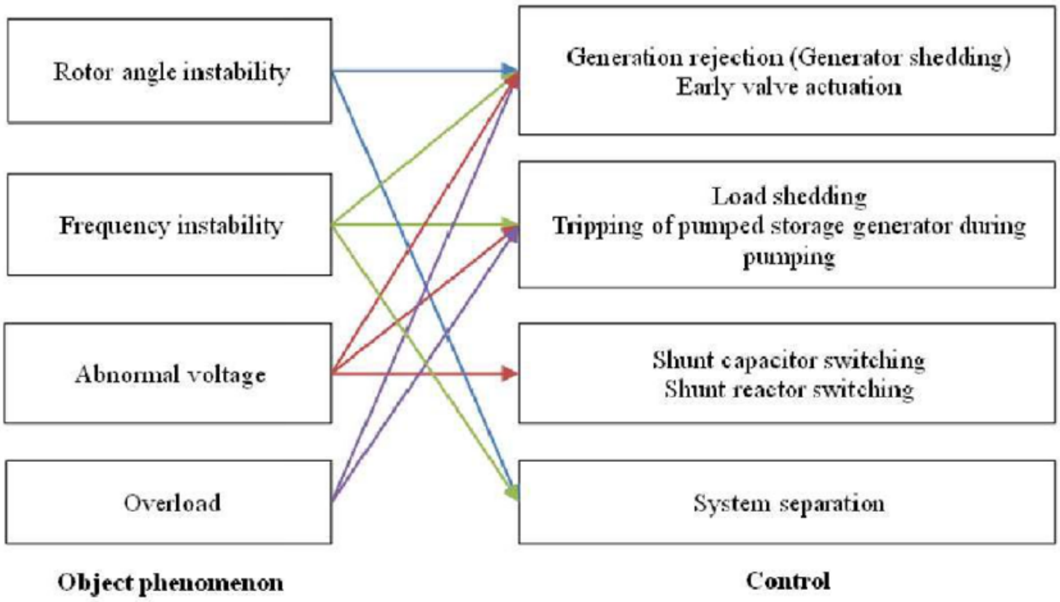
1. Summary of SIPS (System Integrity Protection Scheme)

Countermeasures

System stabilization control methods utilized by SIPS



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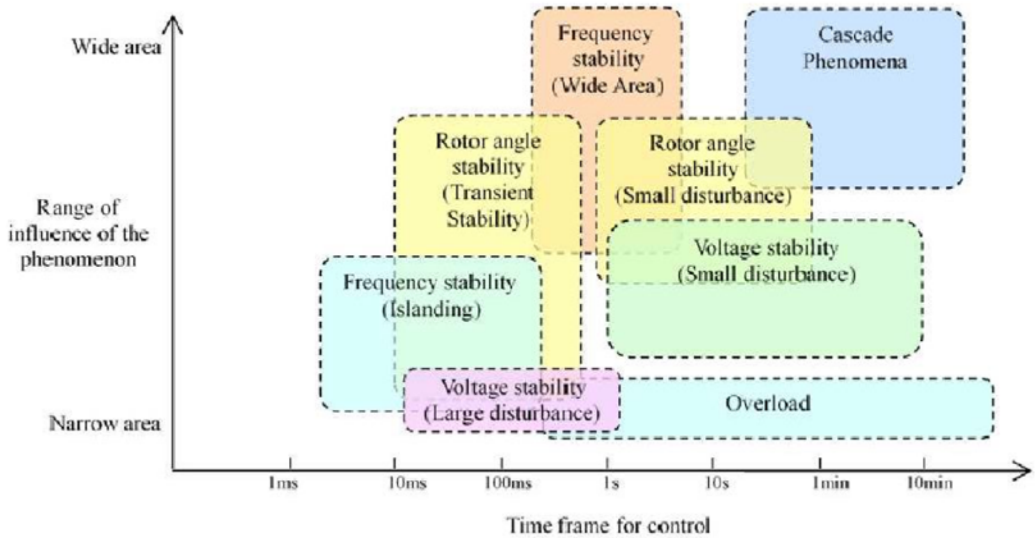
1. Summary of SIPS (System Integrity Protection Scheme)

The relationship between the time frame for control



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2. Rotor angle instability

'Synchronous stability' or 'Rotor angle stability' is the degree to which generators connected to a power system can operate in synchronism.
There are two forms of Rotor angle stability, referred to as 'Transient stability' and 'Small disturbance rotor angle stability'.

Transient stability

- A condition where a generator maintains synchronous operation in the event of a large power system disturbance

Small disturbance rotor angle stability

- A condition where a generator is able to maintain synchronous operation without continuation and expansion of the disturbance triggered by a small disturbance

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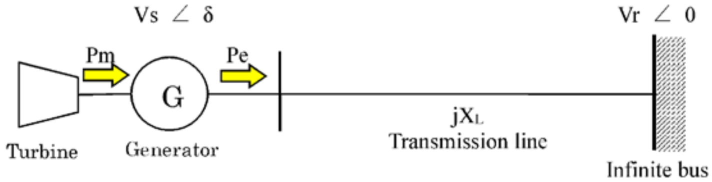
2. Rotor angle instability

Transient stability (1)

Transient stability can be explained by using the single machine infinite bus system model shown in the Figure.

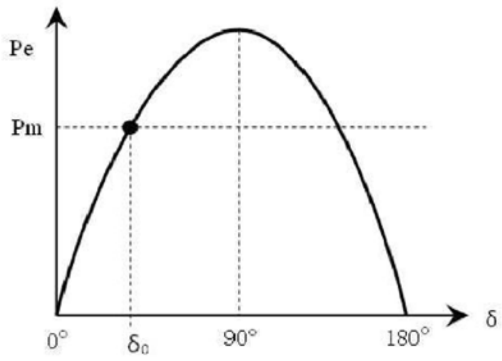


Equation 2.1 is used to determine the power output of a generator.

$$P_e = \frac{V_s \cdot V_r}{X} \cdot \sin\delta \qquad (2.1)$$

where,

- V_s: Internal voltage of the generator
- V_r: Voltage of the infinite bus
- δ: Phase angle of Vs (reference: Vr)
- X: Reactance of the transmission line



'P-delta' curve

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2. Rotor angle instability

Transient stability (2)

Equation 2.2 describes the equation of motion of a generator.

Stable state: Pm = Pe,
and the differential ratio of angular acceleration dΔω/dt is zero.

The angular velocity of all of the generators connected: ω0

$$M \cdot \frac{d\Delta\omega}{dt} = P_m - P_e - \omega \cdot \mathrm{D} \cdot \Delta\omega \qquad (2.2)$$

$$\frac{d\Delta\delta}{dt} = \Delta\omega \qquad (2.3)$$

where,

M: Inertia constant
ω: Rotational speed
Δω: Deviation of rotational speed
P_m: Mechanical input
P_e: Electrical output
D: Damping constant
Δδ: Deviation of phase angle

$$\omega = \omega_0 + \Delta\omega \qquad (2.4)$$

$$\delta = \delta_0 + \Delta\delta \qquad (2.5)$$

Here,

ω: Rotational speed
ω_0: Rated angular velocity ($\omega_0 = 2 \cdot \pi \cdot f_0$)
f_0: Rated frequency
δ: Phase angle
δ_0: Initial value of phase angle δ

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2. Rotor angle instability

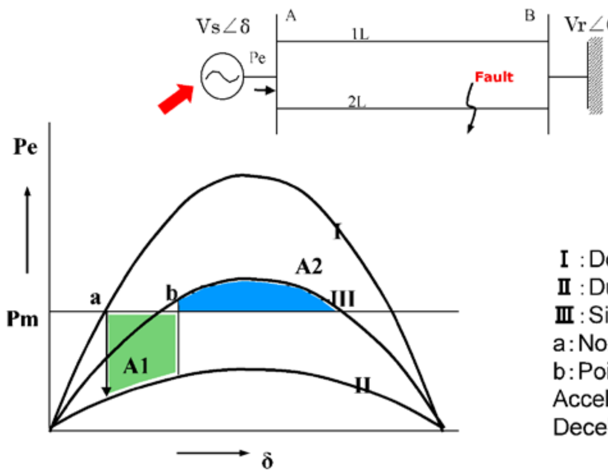
Transient stability (3)

When a fault occurs near a thermal power station,

Vs and Pe of the power station will reduce.

Pm constant for the short period of time

Pm > Pe ⇒ the angular velocity ω will rise: δ becomes larger.



Ⅰ : Double circuit in operation
Ⅱ : During fault
Ⅲ : Single circuit in operation
a : Normal operating point
b : Point at which the CB trips
Accelerating Energy(A1) > Decelerating Energy(A2)

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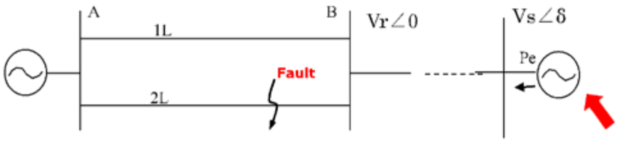
2. Rotor angle instability

Transient stability (4)

When a fault occurs near a thermal power station, generators remote from the fault point will experience an increase in their load due to the decrease in power supplied from the thermal generators located near the fault point.

Pm < Pe ⇒ the angular velocity ω will reduce: δ becomes smaller.



In the event that a large disturbance occurs, the unbalance between the mechanical input energy to a generator Pm and the electrical output energy from a generator to a power system Pe may occur and cause a loss of synchronization.

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2. Rotor angle instability

Small disturbance rotor angle stability

'Small disturbance rotor angle stability' is the degree to which generators are able to maintain synchronous operation and transmit power in a stable manner in the presence of a small disturbance, for example small changes in load and generation with changes in power demand, circuit breaker open or close operations in transmission lines etc.

Stability can be evaluated from the dynamic characteristics of a power system, including the generator controllers, for example AVRs (Automatic Voltage Regulators), generator governors, PSS etc.

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2. Rotor angle instability

Stabilization methods for Rotor angle instability

1) "Generation rejection"
that removes some generators forcibly from the power system. The level of mechanical input from the remaining generators is maintained before and after the operation of the "Generation rejection". The electrical output of the remaining generators increases, and hence the acceleration of the generators is controlled.

2) EVA (Early Valve Actuation), PSS
EVA temporarily controls the mechanical input to the generator. PSS (Power System Stabilizer) is added to generator systems to enhance the effect of swing attenuation.

3) 'System separation'
that opens interconnection lines between power systems. This method is used to prevent the influence of out-of-step phenomenon in the event of the out-of-step occurring between two interconnected systems where the generators in one system accelerate and the generators in the other throttle.

"Generation rejection" can be initiated readily and rapidly, and is more effective than other measures as a countermeasure to transient instability.

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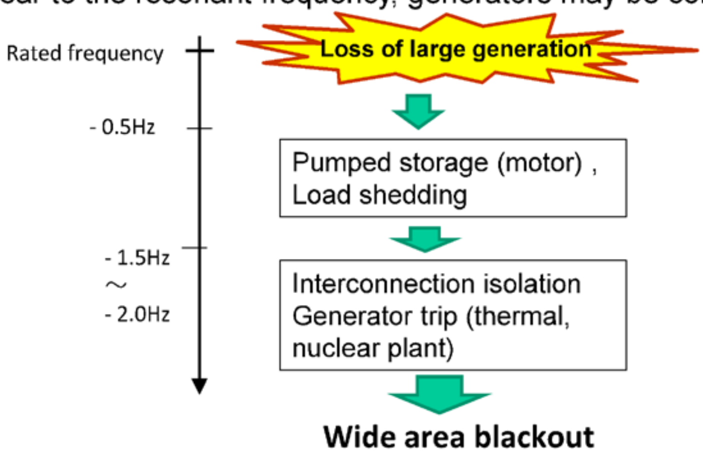
3. Frequency instability

Frequency drop

In the event that the balance of power supply and demand collapses in a power system, frequency instability occurs.

The resonant frequency of a turbine generator is rather less than rated frequency, if the frequency of the power system reduces and settles close or near to the resonant frequency, generators may be consecutively tripped.



Large-scale blackout process following frequency drop

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3. Frequency instability

Frequency rise

A rise in frequency usually can be controlled by a reduction in the mechanical input to the generator by the operation of governors.

The night or lightly loaded periods, thermal generators output may be adjusted at the minimum output.

↓

An adjustment to the frequency may become impossible at frequency rise

↓

A reactor scram (emergency shutdown) in nuclear power plant may occur caused by an increase in the number of neutrons.

The number of burners in operation is reduced under low output operation, and a boiler trip may occur for thermal generators.

↓

Large generators may trip simultaneously

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3. Frequency instability

Stabilization method

1) Small fluctuation in frequency

Frequency control maintains the balance between power supply and demand by adjusting generator outputs. This method controls a generator output directly by either governor-free operation of generators or LFC (Load Frequency Control).

2) Large fluctuation in frequency

Emergency control

- "Generation reduction" to frequency rise
- to frequency drops "Pumped-storage motor rejection" or "Load shedding"
- "System separation" to prevent widespread blackouts

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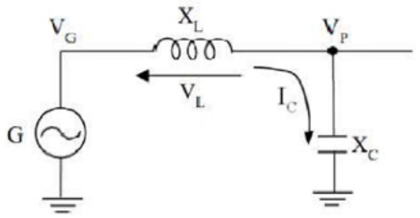
4. Abnormal voltage

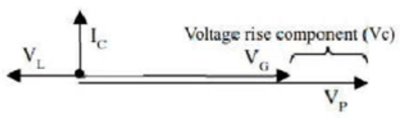
Overvoltage

An overvoltage at rated power frequency,

- The ‘Ferranti effect’:
  The result of a sudden change in reactive power distribution caused by load shedding or system separation
- The consequence of a power swing:
  The phase angle between the sending terminal and the receiving terminal is repetitively increasing and decreasing periodically

The Ferranti effect tends to occur under light load or no load conditions for either large charging-capacity cables or long distance overhead lines.





4. Abnormal voltage

Voltage Instability

A power system which has the optimal installed capacity of condensers, whose operational limit is to supply the load system,

↓ an increase in the load or an increase in power flow

The voltage will drop at the receiving terminal
As a consequence the voltage may collapse

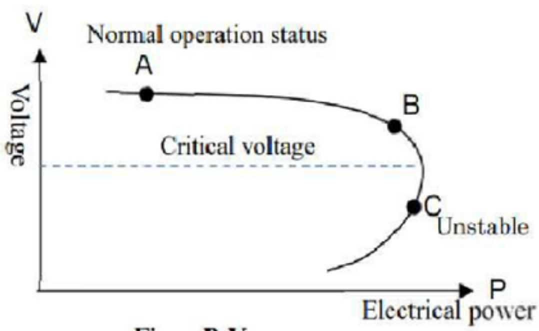


Fig. P-V curve

Point ‘A’: under normal operating conditions where the gradient dV/dP is small with increasing power ‘P’, and decreasing voltage ‘V’.

Point ‘B’: the point around the nose of the P-V curve, where the voltage ‘V’ decreases significantly for an increase in power ‘P’.

Point ‘C’ : an unsatisfactory operating condition, where the gradient dV/dP is positive.

4. Abnormal voltage

Countermeasures for overvoltage

The opening and closing of phase modifying equipment and the control action for reactive power using a SVC (Static Var Compensator) are used to restrain over voltages.

The phase modifying equipment:
'Shunt Capacitor (SC)' which compensates for lagging reactive power
'Shunt Reactor (ShR)' which compensates for leading reactive power

A power system condenser is applied for the prevention of voltage drop, a shunt reactor is applied for the prevention of over voltage.

Countermeasures for voltage instability

The operation point should be on a sufficiently more stable point than the tip (nose) of the P-V curve.
The timely introduction of the condenser is necessary.
In the event that the operation point enters the lower voltage domain, load shedding is then the unique countermeasure.

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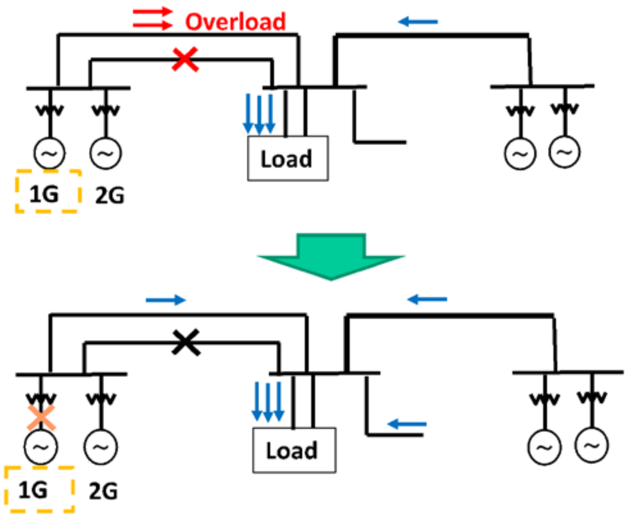
5. Overloads and countermeasures

In the event that a route interception fault occurs on a transmission line, power may continue to flow, bypassing the faulted route via an alternative transmission line after flowing through other power system apparatus, this can lead to the occurrence of overloads on electrical equipment such as transmission lines and power transformers.



For example, when line fault occurs, the remaining line becomes overload.
To mitigate overload, 1G output will be restrained or 1G shed.

Example overload countermeasure using generator restraint/shedding

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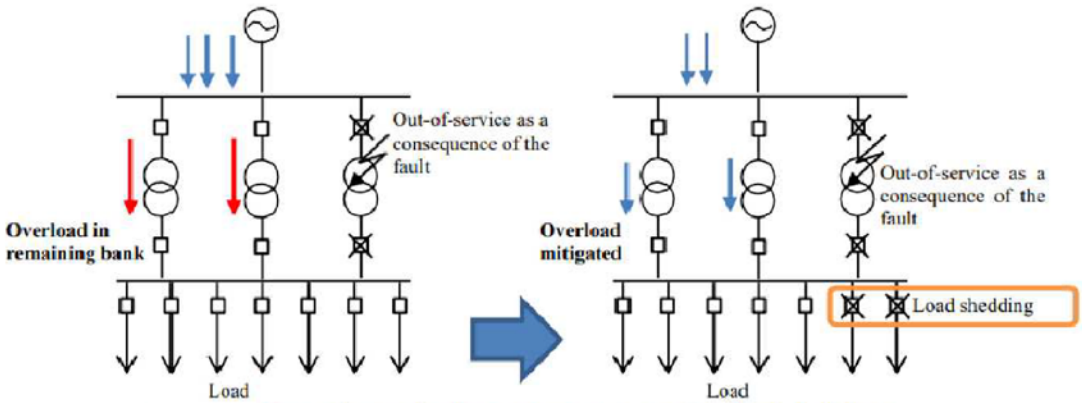
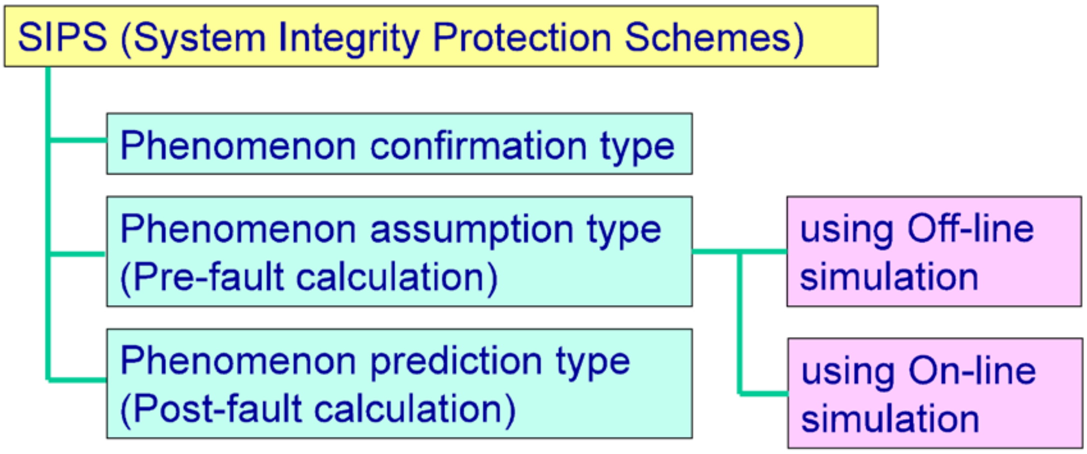
5. Overloads and countermeasures

Example of transformer overload and countermeasures



Example overload countermeasure using load shedding

6. Classification of stabilization method of SIPS

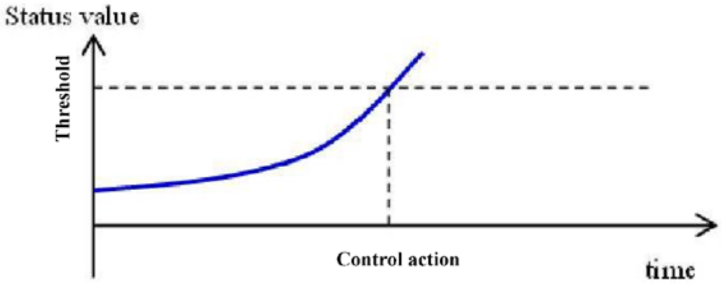


SIPS can be classified within the following groups or types: 'phenomenon confirmation', 'phenomenon assumption' (using a pre-fault calculation) and 'phenomenon prediction' (using a post-fault calculation).

6. Classification of stabilization method of SIPS

'Phenomenon confirmation' type

It asserts control functions following confirmation of the occurrence of a disturbance, such as an out-of-step, abnormal frequency, voltage instability or overload cascading, in order to prevent the disturbance from spreading further.



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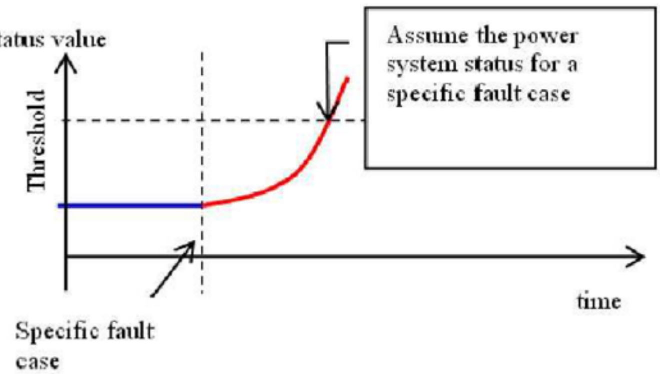
6. Classification of stabilization method of SIPS

'Phenomenon assumption' type (Pre-fault calculation)

This SIPS type assumes the potential or predicted occurrence of an unstable phenomenon following severe contingencies for various power system conditions. The appropriate control measures are pre-determined.



A typical SIPS control scheme of this type in common use is in generator shedding or for prompt isolation of accelerating generators. These schemes are based upon off-line simulations for which various severe contingencies have been anticipated along with the various control action(s) necessary to prevent the out-of-step condition, from occurring.

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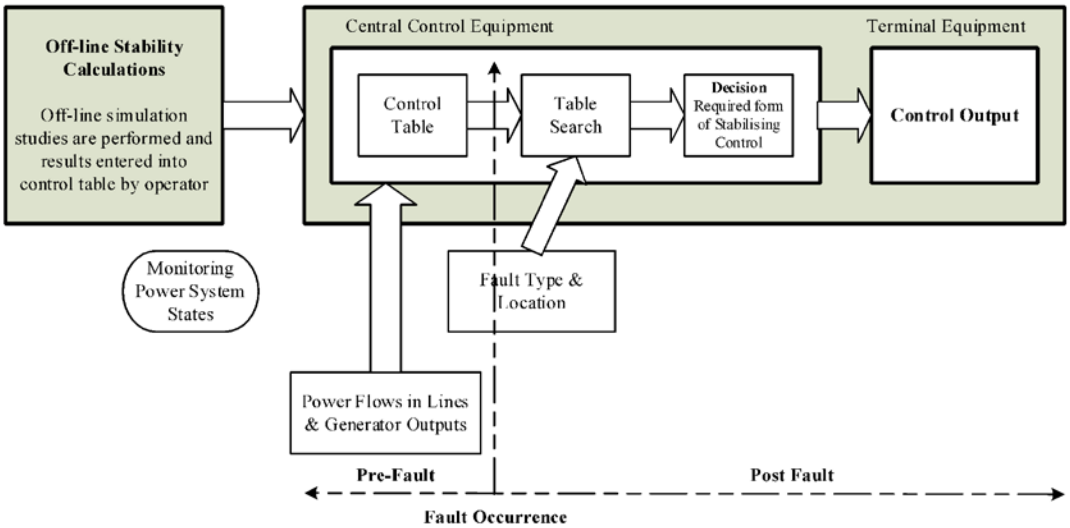
6. Classification of stabilization method of SIPS

'Phenomenon assumption' type (Pre-fault calculation): an off-line simulation

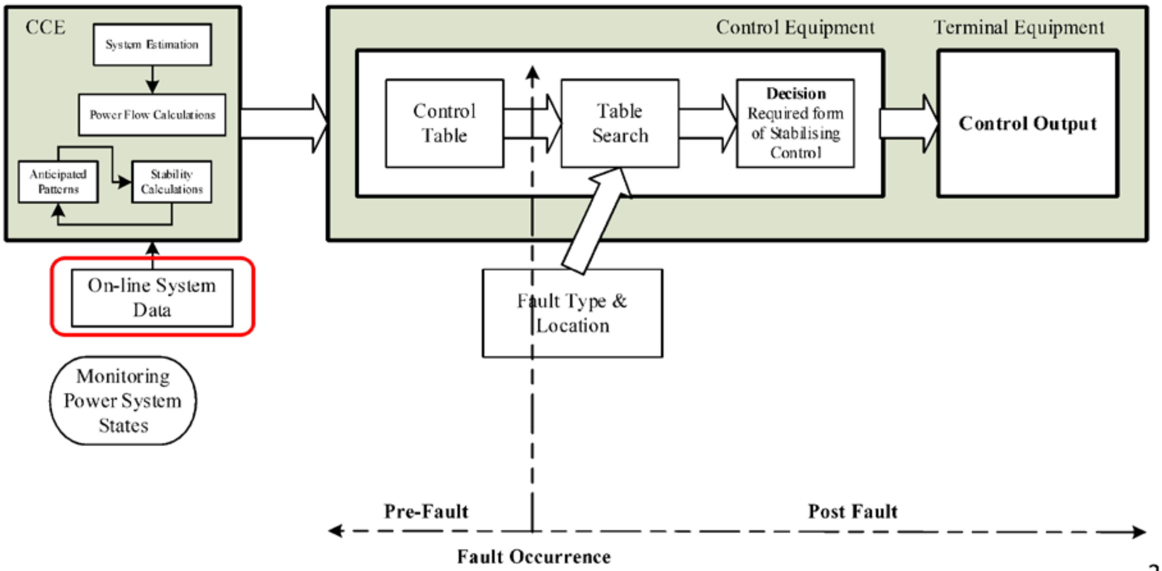
This type uses mathematical functions and tables to determine the conditions that could lead to the onset of an out-of-step condition based upon off-line simulations of power system disturbances using pre-fault electrical information such as load flow.



6. Classification of stabilization method of SIPS

'Phenomenon assumption' type (Pre-fault calculation): an on-line simulation

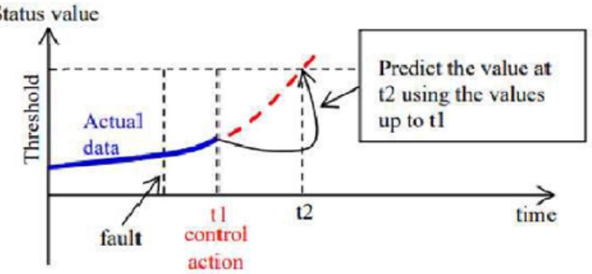
This type evaluates the stability by performing simulations for assumed faults on main transmission lines or bus-bars using the electrical information for each pre-defined power system node before the occurrence of an actual fault. It executes the simulation on-line and determine the control action in accordance with the measured on-line information.

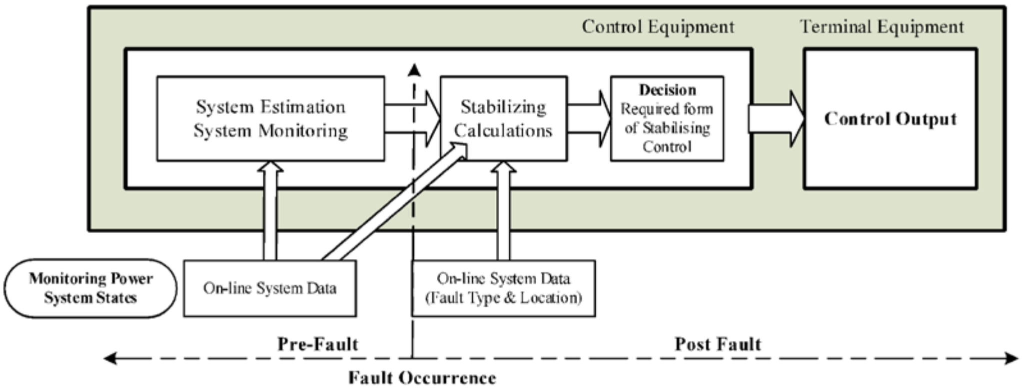


6. Classification of stabilization method of SIPS

'Phenomenon prediction' type (Post-fault calculation)

It commences the calculation following the occurrence of a fault based on real-time measured values, and executes predictive control actions required.





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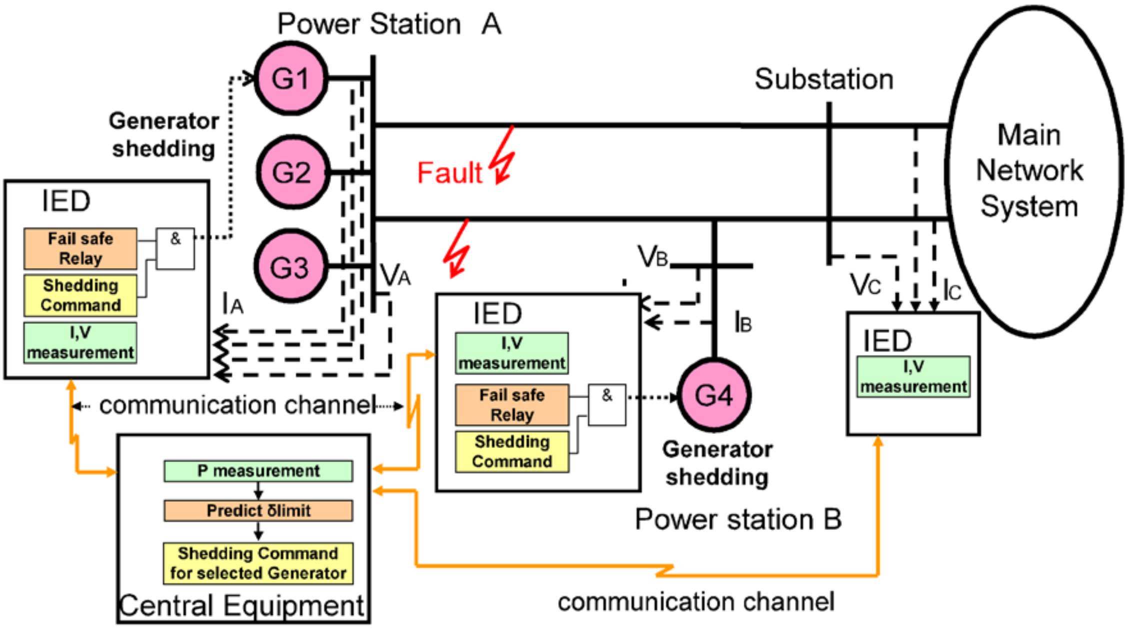
7. Examples of applied SIPS (1)

Experiences (Prediction Type)

A large power station connected to main power network system via long transmission line.



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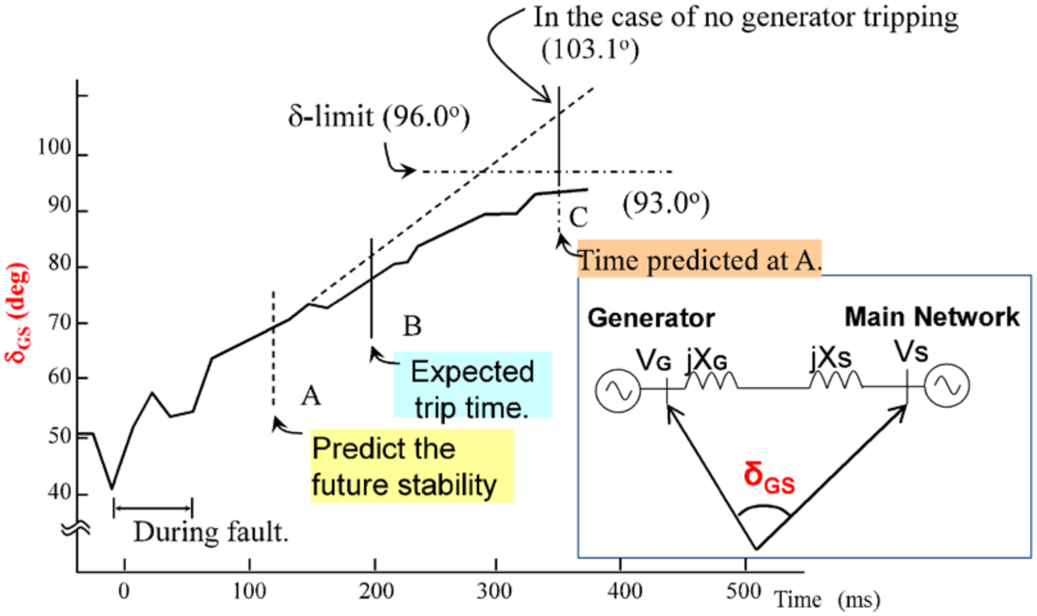
7. Examples of applied SIPS (1)

Experiences (Prediction Type)

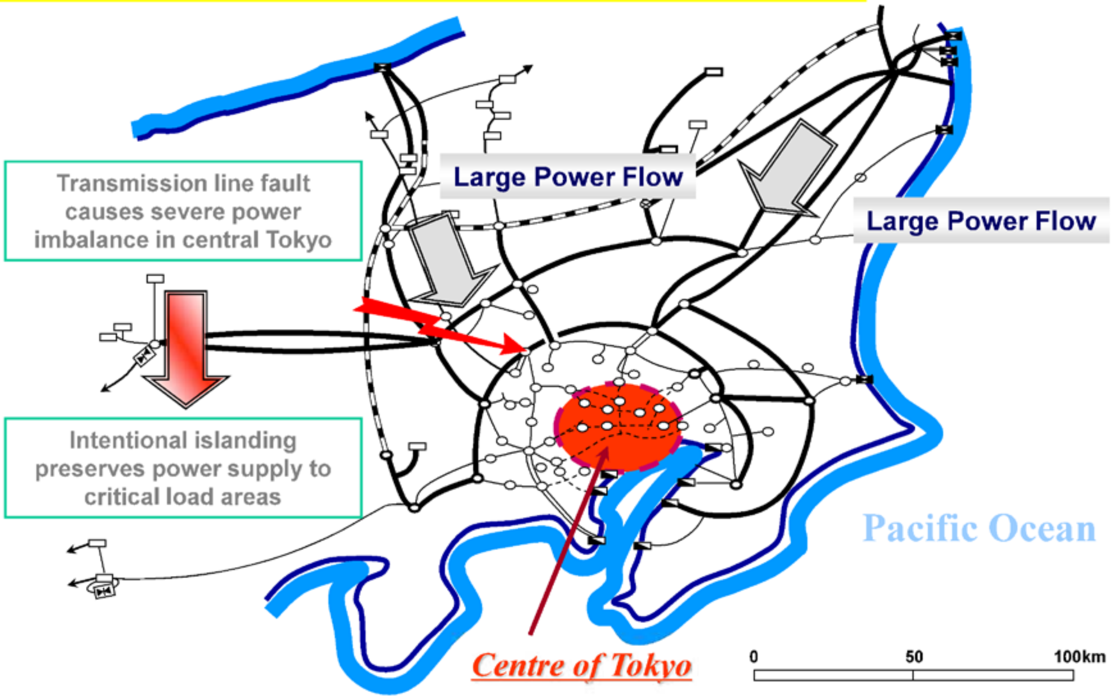
Predict the future stability by calculating δ_{GS} at C

δ_{GS} > δ-limit: unstable and calculate the number of generators to be shed



7. Examples of applied SIPS (2)

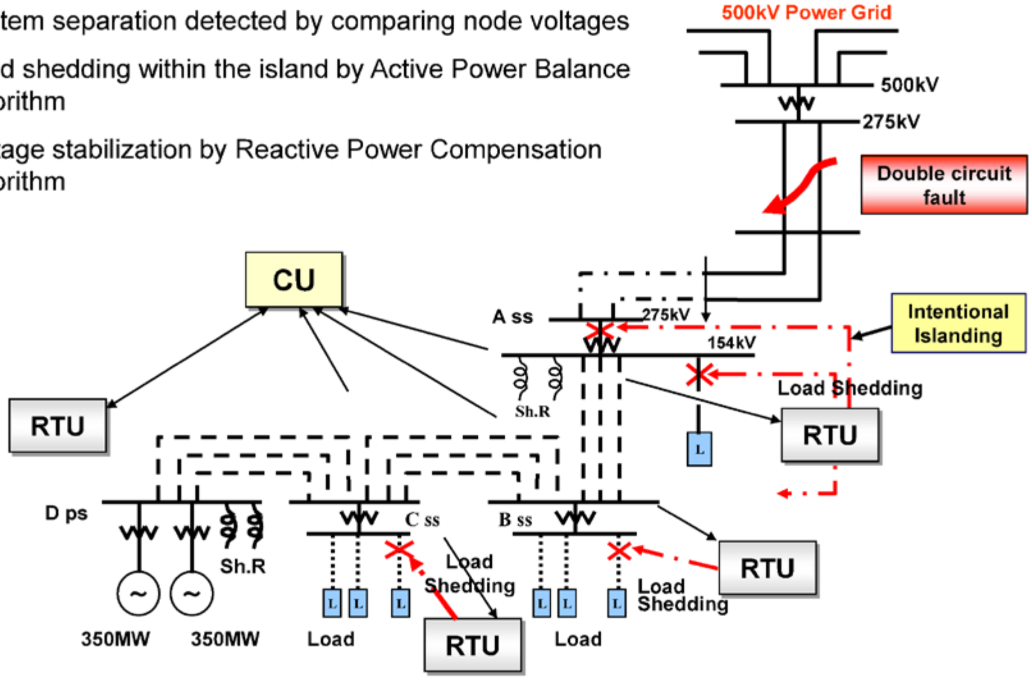
Islanding Protection System for Metropolitan Power System



7. Examples of applied SIPS (2)

Islanding Protection System for Metropolitan Power System

- System separation detected by comparing node voltages
- Load shedding within the island by Active Power Balance algorithm
- Voltage stabilization by Reactive Power Compensation algorithm



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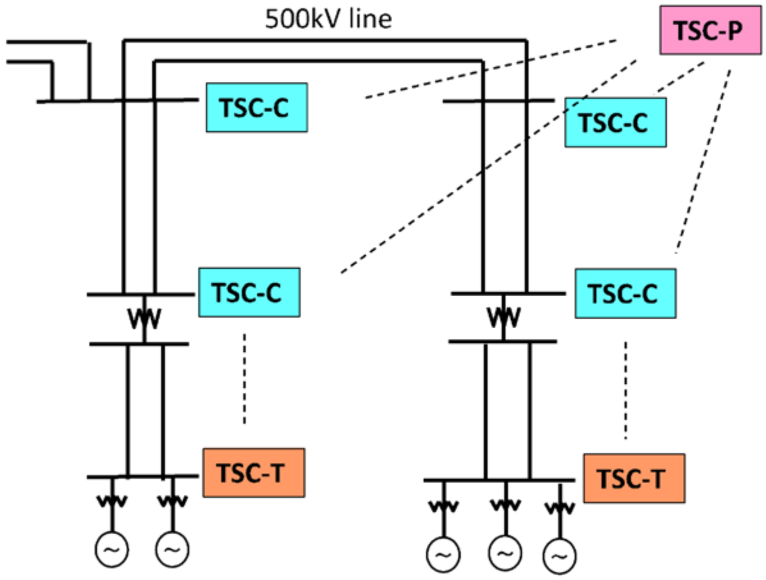
7. Examples of applied SIPS (3)

'Phenomenon assumption' type (Pre-fault calculation): an on-line simulation

Target is line faults, busbar faults and transformer faults on 500kV system.



TSC: Transient Stability Controller

TSC-P: (computer system)
- Calculation power flow, stability, control pattern every 30 seconds from on-line data.

TSC-C: (IED based)
- Fault detection
- Search control table
- Control decision

TSC-T: (IED based)
- Control output (generator shedding)

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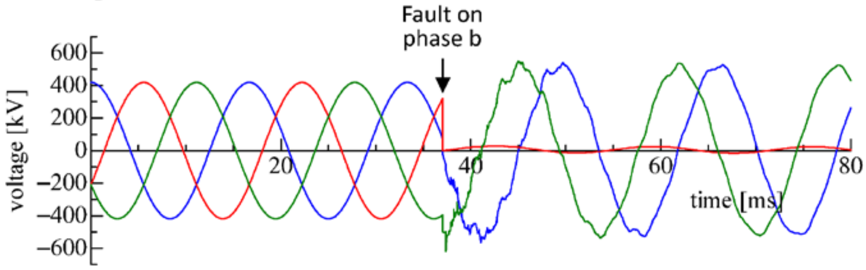
THE END

Appendix 3　Introduction of Power System Analysis (XTAP)

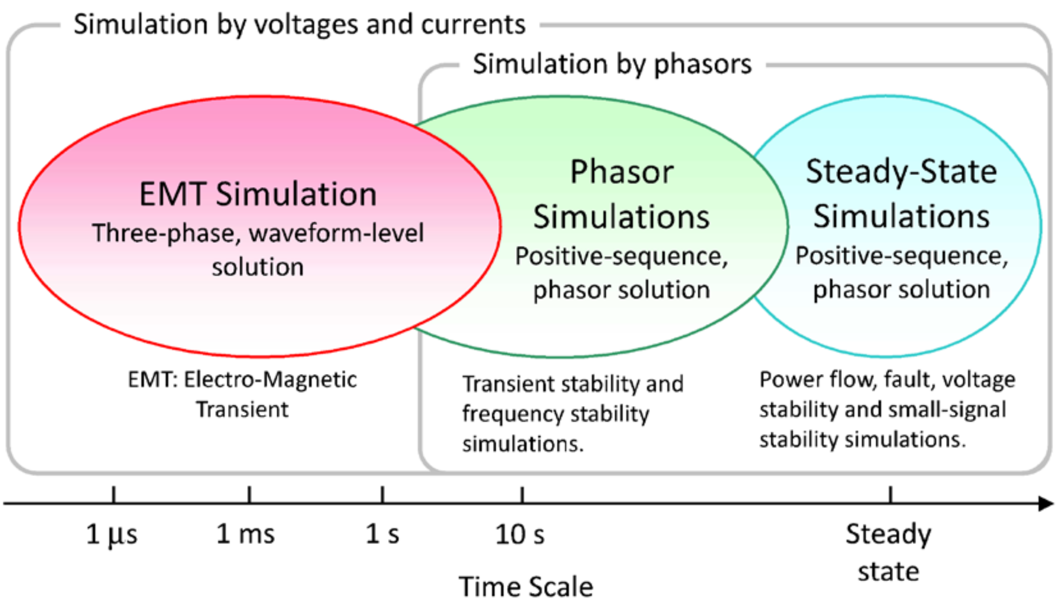
Appendix 3. Introduction of Power System Analysis (XTAP)

An Introduction to the Simulation Program XTAP for the Analysis of Electromagnetic Transients in Power Systems



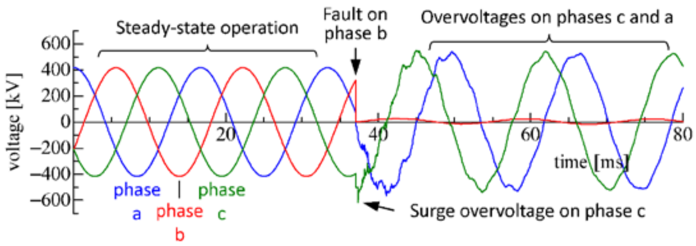
https://www.xtap.org/

Power System Simulation Methods



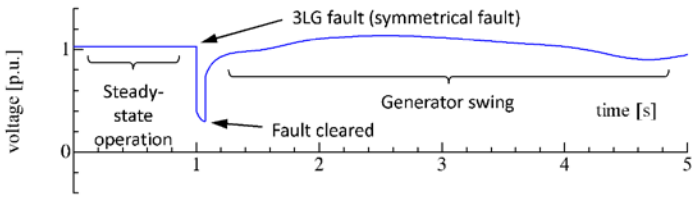
EMT versus Phasor

- EMT simulation … calculates voltage and current waveforms actually occurring in a power system.



Since the EMT simulation gives detailed waveforms of all phases, momentary overvoltage and current values are obtained. It is suitable for detailed simulations of a particular part of a power system.

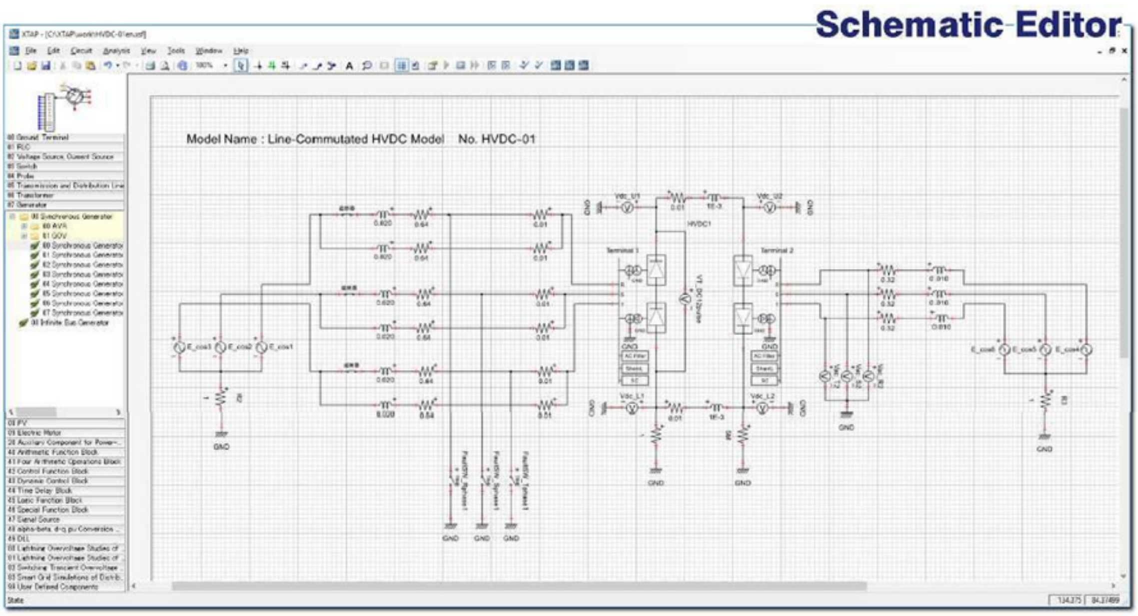
- Phasor simulation … calculates 50- or 60-Hz voltage and current phasors in a power system.



The phasor simulation traces the variations of the magnitudes and the phase angles of voltages and currents and ignores their momentary variations. It is suitable for simulations of a large power system.

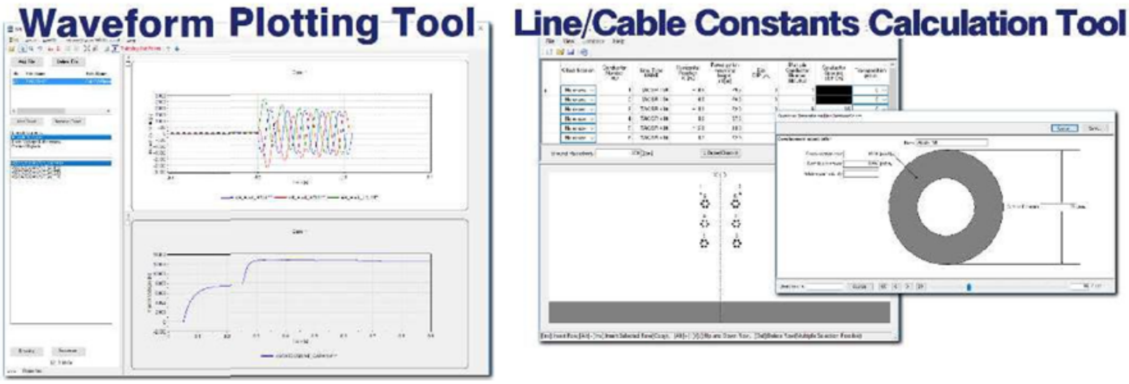
XTAP (e**X**pandable **T**ransient **A**nalysis **P**rogram)

is an industrial-grade EMT or waveform-level simulation program.



XTAP (eXpandable Transient Analysis Program)

is equipped with a waveform plotting tool with useful functions, a line/cable constants calculation tool, an automated consecutive simulation function, a statistical simulation function, a PV panel modeling tool, and so on.



Components and Models

- Comprehensive electrical and control components.
- Synchronous generator model with saturation and torsional dynamics.
- Line models (π equivalent, constant-parameter and frequency-dependent).
- Transformer models (2, 3-winding and autotransformers).
- HVDC and FACTS converter models (line-commutated, PWM and MMC AC/DC converters; SVC and STATCOM).
- PV power generation systems.
- User-defined models: You can create your own models – You can even draw your own icons for them!
- DLL-defined blocks.

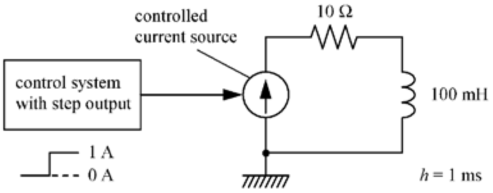
Applications

- XTAP can be used not only for traditional EMT simulations but also for new simulation needs.
- Abnormal Overvoltages, Currents and Oscillations:
  - ✓ Lightning, switching and black-start overvoltages.
  - ✓ Transformer and induction motor/generator inrush currents.
  - ✓ Ferroresonance and subsynchronous resonance.
- Power Quality Assessments:
  - ✓ Harmonics, flicker and voltage interruptions/drops/swells.
- Performance Studies of Power Electronics Converters:
  - ✓ HVDC systems, FACTS devices, power electronics converters used in renewable energy (PV and wind) generation systems and battery storage (EV) systems.

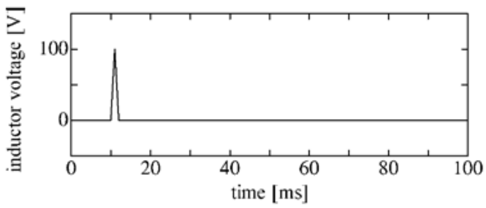
2S-DIRK versus Trapezoidal

- XTAP uses the 2S-DIRK method for the numerical integration. It is mathematically guaranteed that the 2S-DIRK method never produces fictitious numerical oscillation due to sudden changes of inductor currents and capacitor voltages unlike the trapezoidal method used in other programs.

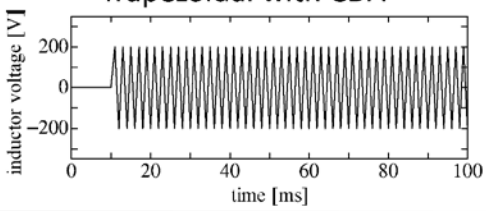
Simple Test Circuit



2S-DIRK



Trapezoidal with CDA

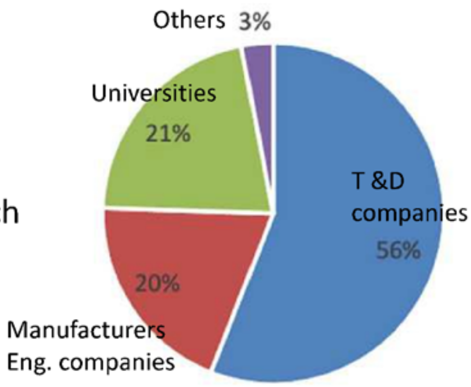


Strong Research Base

- XTAP has been developed with incorporating recent research results obtained at CRIEPI:
  - ✓ The 2S-DIRK (two-stage diagonally implicit Runge-Kutta) method is used for the numerical integration of differential equations. It is especially suitable for power-electronics (switching-circuit) simulations.
  - ✓ A practical three-phase (unbalanced) steady-state initialization method is implemented.
  - ✓ A robust and efficient solution method, in which the Newton-Raphson (NR), the biaxial NR and the Katzenelson algorithm are combined, has been developed and is used to solve nonlinear circuit equations.
  - ✓ An efficient sparse-matrix manipulation algorithm accelerates the solution process.
  - ✓ The last two are patented but free to use in XTAP.

User Community and Development

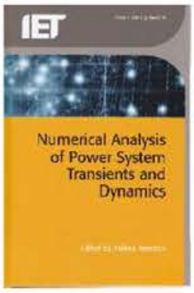
- User Community
  - ✓ In Japan, all T & D companies use XTAP as their standard, and major manufacturers, engineering companies, universities and research institutes form a user community. The total number of users is more than 3,300 as of Sep. 2021.



- Development
  - ✓ Hokkaido Electric Power, Tohoku Electric Power, TEPCO Holdings (Tokyo Electric Power), Hokuriku Electric Power, Chubu Electric Power, Kansai Electric Power, Chugoku Electric Power, Shikoku Electric Power, Kyushu Electric Power, Okinawa Electric Power and Electric Power Development Company financially support the development, and CRIEPI performs the development project.

Education Opportunities

- XTAP comes with a 178-page manual and 42 introductory and practical test cases for self-learning.
- A summary of XTAP is given in the IET Book below.
- Courses by EMT specialists are offered in Japan (English on-line courses can be arranged).



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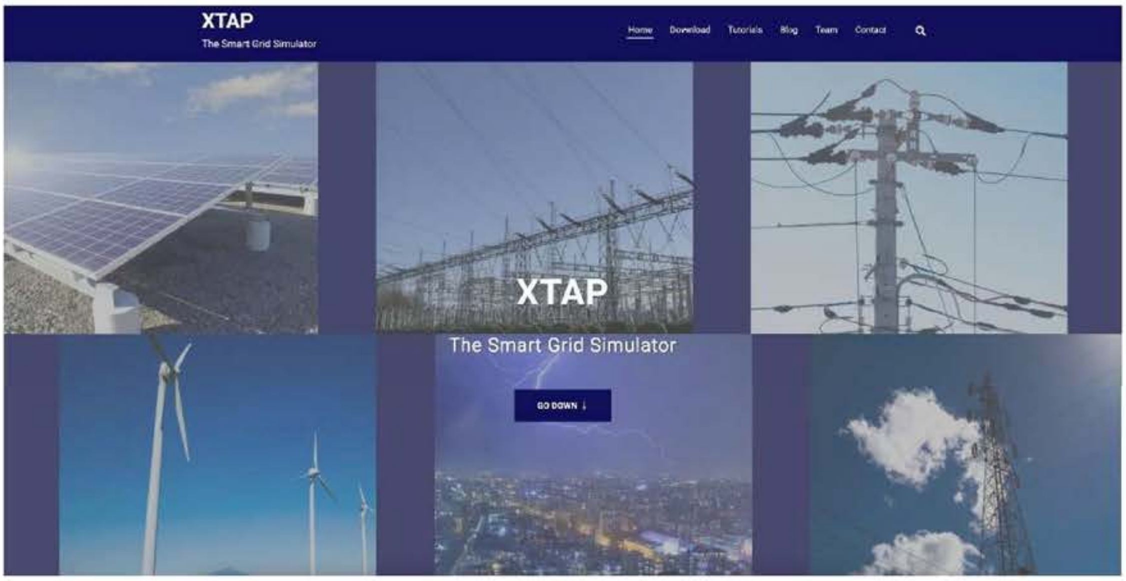
Central Research Institute of
Electric Power Industry

Web Site - www.xtap.org



XTAP is available to everyone for free of charge and can be downloaded from this site.

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XTAP

https://www.xtap.org/

Appendix 4 Training and evaluation system for power system engineers in Japan

Appendix 4. Training and Evaluation System for Power System Engineers in Japan

Asia Engineering Consultant Co. Ltd

Training System and Evaluation of Electric Power Engineers in Japan

(With reference to TEPCO)

Sep. 2023

ASIA ENGINEERING CONSULTANT CO.,LTD.

1

Asia Engineering Consultant Co. Ltd

This document summarizes what kind of human resources are needed in electric power companies and what kind of system is in place to develop them.

The examples in this report are based on TEPCO, but we believe that they are common to all electric power companies in Japan.

TEPCO has been promoting a company-wide response to the accident at the Fukushima Daiichi Nuclear Power Plant following the major earthquake in 2011.

In addition, TEPCO's human resource development system differs from the current system in some parts due to the division of TEPCO into power generation and transmission companies.

Although there are some differences from the current situation, we believe that this document can be used as a basic approach to human resource development, including in the future.

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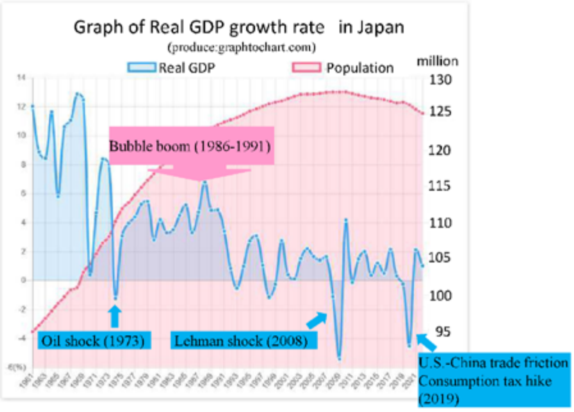
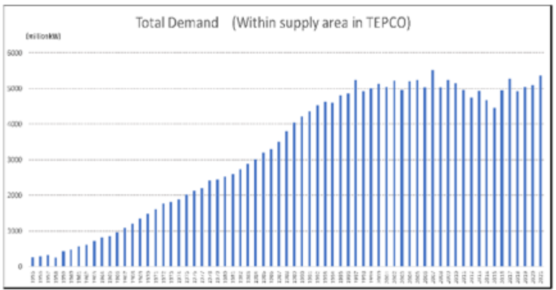
1. Number of people employed by TEPCO





・1970-2000 : 1,000-1,500 hires
Construction of electric power facilities to meet strong growth in demand for electric power and ensure stable supply.

・2000-2005 : About 500 hires
Slowdown in demand for electric power due to low economic growth after the collapse of the bubble economy and changes in the structure of electric power demand.
In addition, the deregulation of the electric power from 2000 promoted cost reduction to strengthen competitiveness.

・2006-2010: About 800 hires
Strengthen sales force and promote new businesses due to intensifying competition among energy companies.
In addition, ensure facility safety and operational quality in the future.

・Since 2011
Recruitment was reduced due to the 2011 Tohoku earthquake and Fukushima nuclear power plant accident, but is now back to around 500 employees.

Number of recruits (in TEPCO)

Year	1995	2005	2010	2022
Total number of recruits (persons)	**1462**	**485**	**770**	**520**
Universities & Graduate Schools	508	209	265	317
College of Technology & High School,etc.	954	276	505	203

※70-80% of the recruits are in the technical field

3

2. Human Resources sought by TEPCO

"Dependable human resources" to support the stable supply of electricity, a social mission

・Contributing to the realization of affluent lifestyles and a comfortable environment through the stable power supply and optimal energy services

This requires "fundamental human resources" with solid technologies and skills and a strong sense of mission.

In addition, we place importance on the following human skills that "fundamental human resources" possess.

・"Ability to cooperate"" Sense of responsibility and mission" "Ability to think logically and from multiple perspectives" "Communication skills"

+

・Active efforts for business innovation and service development & improvement in the current deregulation of electric power

This requires "self-improving human resources" who will boldly take on the challenges of management objectives.

In order to secure such human resources, we place importance on the following potential abilities.

・The 3C's:" Change (willingness to change)"" Challenge (initiative and spirit of challenge)" "Communication (collaboration and involvement)"

4

3. Human Resource Development of Electric Power Engineers at TEPCO

Management philosophy:
It is "people and technology" that will open up the future of the company, requiring the ability, motivation, and practice of each and every employee.

・**The basis of "human resource development and capacity building" is a combination of the following**

✓ **"Work is what develops people"**

➡ "OJT (on the Job Training)" : in-work guidance through daily work

✓ **"Self-development through employees' voluntary will and efforts"**

➡ "Off-JT (Off the Job Training)" : Training and self-development conducted away from the workplace (attending training, acquiring qualifications, etc.)

⬇

The most important thing is to enhance the perspective and awareness of each individual's work and to develop their abilities by practicing problem-solving in daily work, developing technologies, and demonstrating their skills.

4. Human Resource Development Promotion System for Electric Power Engineers

Training related to core technologies and skills in specialized fields is conducted by each facility's competent departments and skills training centers.

・**Roles at regional branches, etc.**

✓ Implementation of systematic and continuous training

✓ Promote comprehensive human resource development with emphasis on accumulation and improvement of technology and skills through work

✓ Develop and upgrade on-site technologies and skills that support facility management and customer service

・**Roles of each facility management department and each skills training center (belonging to Human Resources Development Office)**

✓ Operation of the core training system and capacity development systems for the facilities under their management.

✓ Planning and implementation of training programs related to on-the-job techniques and skills

・**Role of the Human Resources Development Office (General Training Center)**

✓ Formulate and implement basic policies and plans for overall training

✓ Coordination and support of training programs of each supervising department and training programs of branch offices, etc.

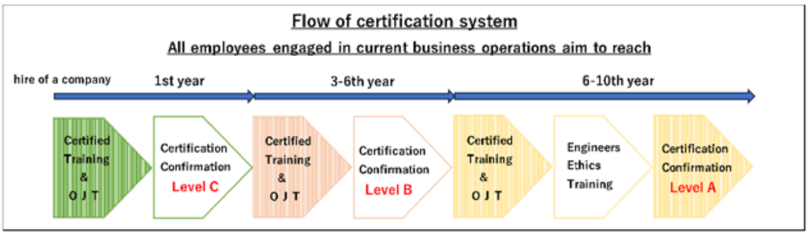
5. Company certification system for technology and skills ①

Purpose of the On-Site Technology and Skills Certification System

- Clarification of the level of on-site technology and skills required
- Enhance training programs for on-site work and further improve the technology and skills of the workers
- Fairly recognize the skills and techniques acquired by employees. Assign employees to appropriate tasks to further enhance their vitality

Certification Levels

- Level A: A level that enables the candidate to responsibly perform advanced applied work and to detect and respond to abnormal situations, etc.
- Level B: Responsible for performing normal field work
- Level C: Responsible for performing basic field work.



5. Company certification system for technology and skills ②

Almost all employees obtain Level A certification after about 10 years with the company, so incentives are needed for improvement of techniques and skills

Establishment of Certification Level S

Certification Criteria for Level S

- High level of expertise in key technologies specified for each department
- Able to make technical decisions and make proposals internally and externally regarding safety assurance, efficiency improvement, and quality improvement based on specialized skills
- Responsible for succession of technology and human resource development

How to Certify Level S

Certification Method for Level S

- Confirmation of specialized skills specified for each division
- Confirmation of aptitude, ethics, etc. as a leader common to all divisions
- Certification examinations from various internal and external perspectives

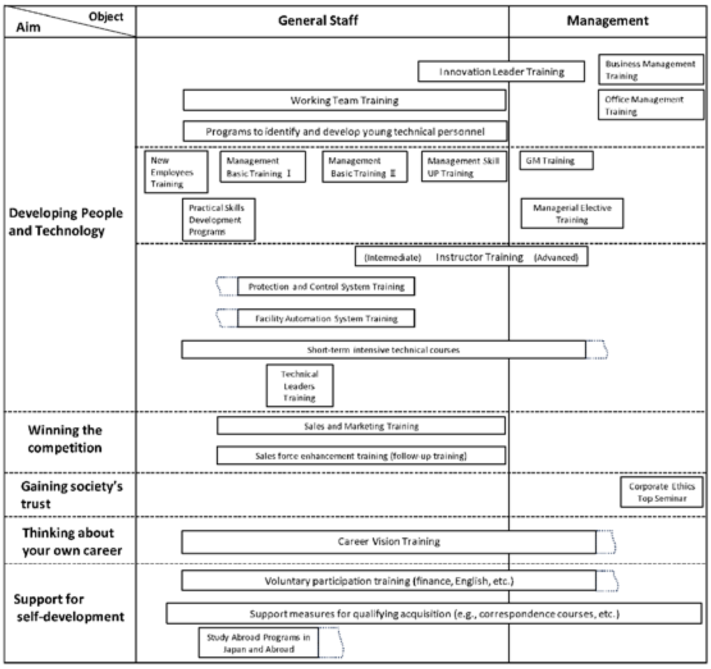
Appeal by wearing special S-class uniforms and displaying business cards

Other internal certification systems

- Professional certification: Personnel with a high level of expertise that is useful to the company and who are willing to pass on their skills and techniques
- Specialist certification : Personnel with rare and valuable expertise who can make a significant contribution to organizational performance

6. Training structure (common to all companies)

Company-wide common training system of the Human Resources Development Office (General Training Center)



7. Efforts to maintain the level of technology and skills

Field Operations in Recent Years

In recent years, outsourcing of construction and inspection work has been promoted at front-line sites for more efficient operations. This has led to an increase in construction management and other administrative tasks. In addition, the number of employees with experience in front-line field work has been decreasing due to slow demand growth and decreased facility upgrades.

Issues to be resolved

The effective use of the existing facilities has become important due to the increase in the number of aged facilities. To this end, there is a need to improve diagnostic and inspection techniques and skills for making decisions on equipment maintenance and operation.

In addition, the number of engineers on the makers' side is decreasing due to the decrease in the facility expansions, and it is becoming increasingly important to develop the technical skills to maintain aging facilities on their own.

Creation of specialized technical teams

- Maintain appropriate construction management skills, emergency response skills, and direct management skills
- To this end, maintain and improve the quality of management, judgment, and response skills through hands-on experience of their own work

- Creation of "**Technical Specialty Teams**" specializing in specific tasks, with the aim of acquiring on-site skills through concentrated work experience in a short period of time
- The team will visit the site where the work is to be performed to gain practical experience. After the activity is completed, the team will provide guidance and training to younger workers

7. Efforts to maintain the level of technology and skills

Technical Expert Teams and Main Practices

Department	Technical expert team	Main practices
Hydro electric power	Water turbine generator technical team	・Water turbine precision inspection, disassembly, adjustment, and parts replacement ・Various measurements and tests after overhaul
Substation	Protection and Control Engineering Team	・Design, installation, and testing of switchboard construction ・Investigation to identify abnormalities in protection control circuit boards
Overhead power transmission	Tower Maintenance Engineering Team	・Foundation mutation diagnosis, component damage diagnosis, steel tower strength determination, etc. ・Quantitative survey of deteriorated components
Underground power transmission	CV Cable Engineering Team	・Connection work in the middle part of the cable, diagnosis of CV deterioration ・Insulator survey (slice and thermal history survey)
Power Distribution	Emergency Response Engineering Team	・Repeated training in judgment and treatment of equipment accidents
	Maintenance Engineering Team	・Accident point evaluation (pulse radar method, high voltage bridge method, etc.)
	Equipment Engineering Team	・Investigation and cause analysis of defective equipment such as poles, wires, transformers, etc.
Thermal power	rotection and Control Expertise Team	・Inspection and testing of protection relays, AVR devices, etc. ・Basic design of replacement of exciter, protection relay, etc.

<u>The response of the emergency response technical team</u>

Emergency response to broken pole due to fallen tree (Actual site)

Emergency power transmission training using standing trees

7. Efforts to maintain the level of technology and skills

Company-wide Technical Skills Competition

The purpose of the competition is to demonstrate the results of technology and skills cultivated by front-line workers on a daily basis, and to raise motivation and professionalism

・Scores are given for "safety," "quality," and "efficiency (speed)

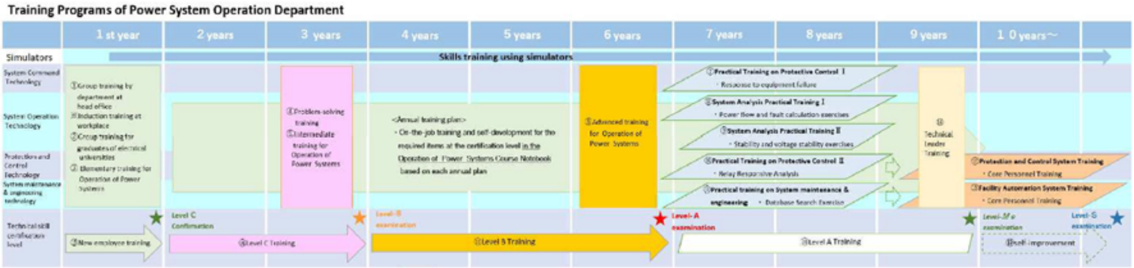
・Although the content of the competitions are separate, we expect to embody core technologies and desirable methods, share values, clarify goals, etc.

Examples of Competitions in the Companywide Technical Skills Competition

Divisions	Competition Details
Electronic Communication	Failure support for digital microwave radio equipment
Hydroelectric Power	Restoration work in case of governor failure
Public Works(Hydro engineering)	Dam operation during water outage
Power Transmission	Jumper operation at the time of a permanent accident on one transmission line
Underground Power Transmission	Disconnection of lead wires and measurement of fault phase
Substation	Restoration work for distribution substation circuit breaker failure
Power distribution maintenance	Investigation of distribution line accident points and emergency power transmission operations
Power distribution design	Design of electric power supply and pole relocation in residential areas
Power distribution control	Restoration by switching distribution lines in the event of a distribution substation bus bar failure
System operation	Restoration response in the event of a grid accident
Thermal power operation	Accident response operation during unit operation
Thermal power maintenance	Troubleshooting of air compressor and protective relay operation

8． Specific training structure（System Operations and System Planning)

Training Programs of Power System Operation Department



Training Programs of Power System Planning Department

Posted after a minimum of 3-5 years of work

① **Group training by department at head office** (System Operation Department) (40 days)	**Ⅰ Safety Training** ・Regulations and Manuals ・Personal and equipment safety Special ・training for handling electricity ・First Aid Training **Ⅱ Basic knowledge of operations** ・Manuals and manuals ・Supply & demand, and system operation terms ・Outline of power system ・Outline of protective relay ・System operation calculation method (unit method) ・System operation calculation method (approximate power flow calculation method) ・System operation calculation method (approximate voltage calculation method)	**Ⅲ System Operation Command Practice** ・Registration of the subject name system for scheduled stops ・Creation of operation procedures for scheduled stop and use of transmission lines ・Creation of procedures for scheduled stop and use of transformers ・Creation of procedure chart for grid switchover Information transmission training at the time of an accident ・Telephone command operation **Ⅳ Basics of related operations** ・Training for generator and substation equipment ・Training in power transmission equipment ・Training on telecommunication equipment ・Training in power distribution equipment	**Ⅴ Confirmation of actual equipment** ・Outline of structure and function of circuit breaker and confirmation of actual equipment ・Outline of structure and function of transformer and confirmation of actual equipment ・Outline of structure and function of Metal Clad and confirmation of actual equipment **Ⅵ Practical training** ・Basic items for on-site operation ・Basic handling of switchboards and control circuits ・Training in the use of safety belts ・Manual operation of CB, LS, etc. ・Manual operation of LTC, etc. ・On-site operation of Metal Clad ・Operation of relay panels ・Equipment characteristics test **Ⅶ Facility tour** (central feeder control station, thermal power station)

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8． Specific training structure（System Operations and System Planning)

② **Group training for graduates of electrical university (Electric power theory training)** (5 days)	**Ⅰ Overview of power systems** ・Characteristics and Issues of electric power system ・System Planning ・New technologies for distribution facilities ・Facility diagnostic technology **Ⅱ Power Supply Development** ・Power Supply development plan ・Power supply and demand planning ・Power source composition and layout plan ・Issues in power supply development planning ・Power generation system **Ⅲ Cost Reduction** ・Necessity of Cost Reduction and Initiatives ・Specific examples of cost reduction efforts ・Economic evaluation	**Ⅳ Electricity quality** ・System frequency ・System voltage and reactive power ・Various Issues to ensure the quality of electric power **Ⅴ Stable power supply** ・Basic Knowledge ・Factors hindering system operation ・Possible power flow and short -circuit currents ・System operation measures **Ⅵ Stable power supply（Plan）** ・Basic knowledge ・Hindrances in design and planning ・Assumed overvoltage ・Insulation design for overvoltage	**Ⅶ Power Supply Stability (Operation)** ・Basic knowledge ・Changes in effective power and phase angle during accidents ・Interpretation of stability by P-δ curve ・Effects on the power system when an accident spreads **Ⅷ Accidents and Prevention of accident spread** ・Accidents in power systems ・Effects of accidents on facilities ・Voltage and current during accidents ・Fault calculation and accident analysis ・Equipment to protect power systems and facilities from accidents ・Equipment to prevent the spread of accidents and how to operate it	**Ⅸ Special Lectures** **Ⅹ Case Exercises** ・Synchronous machine characteristic test ・Transformer structure and maintenance ・Distribution line expansion study ・System Analysis Exercise ・High-voltage experiments

③Elementary training for operation of power system (5 days) : To develop basic knowledge and skills for operation of power system

・Rules and manuals related to operation of power system
・Basic method of system operation calculation
・Outline of system protection relay
・Overview of system maintenance and engineering
・Overview of power system operation services

④Problem-solving training (about 6 months)

・Under the guidance of workplace supervisors and head office advisors, trainees will formulate their own solutions to problems at their assigned work sites. And then deepen business knowledge, acquire skills, and promote growth.

⑤Intermediate training for operation of power systems (5 days): Cultivate basic skills for operation of power system in case of an abnormality or trouble

・Rules and manuals related to operation of power system
・System maintenance & engineering and facilities
・Overview of voltage control
・Demand and supply and frequency regulation
・Study of accident cases, etc.
・System operation and accident analysis of system protection relays
・Current Situation of System Operation
・Operation of power system and commands
・Overview of power system stability
・System operation calculation method

8． Specific training structure (System Operations and System Planning)

⑥ Advanced training for operation of power systems (5 days): Deepen understanding of overall operation of power systems and cultivate applied skills

- Rules and manuals related to power supply (Advanced application)
- System and facilities for operation of power system
- Voltage control
- Training for calculation of system operation
- Study of accident cases, etc.
- Operation of grid protection relays and accident analysis
- Supply and demand operation
- Operation of power system
- Power System Stability

⑦ Practical training on protective control I (1 day): Deepen understanding of basic handling of protective relays and how to respond to relay malfunctions

〈Basic Handling of Protection Relays〉
- How to check relay operation in the event of an accident
- Relay test method
- Various measurement methods using relay devices

〈Basic Handling of Protection Relays in Case of Failure〉
- How to respond to relay failures
- Exercise in response to relay malfunction

⑧ System Analysis Practical Training I (2 days) : To develop skills of practitioners through exercises of power flow and voltage calculations and fault calculations using power system analysis systems

- Power flow and voltage calculation exercises
- Fault calculation exercises, etc.

⑨ System Analysis Practical Training II (2 days) : To develop practitioners through exercises in voltage stability and system stability calculations using power system analysis systems

- Voltage stability calculation exercise
- System stability calculation exercise
- Torque calculation exercise, etc.

⑩ Practical training on protective control II (2 day) : Acquire the basic skills necessary for relay settling practices that are not covered in the manual

〈Study of Relay Settlement for Protection Relays〉
- Setup of customer's power receiving protection relay
- Setup of transmission line protection relays (distance relays)

〈How to use the Relay Settlement Support System〉
- Failure calculation
- Relay response simulation

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8． Specific training structure (System Operations and System Planning)

⑪ Practical training on System maintenance & engineering (2 days) : Learn the basic configuration of computers, basic knowledge about networks, and the environment for data utilization. Understand the relationship between them and the operation of power system maintenance & engineering, and deepen the understanding of computers, networks, and data utilization methods.

- Hardware configuration of power system maintenance & engineering
  - Features of the grid control system
  - LAN connection and communication method
  - Network environment setup and confirmation
- Security measures
- Knowledge of databases
- Database search exercise
- Practical training on how to deal with system failures, etc.

⑫ Protection and control system training (about 4 months) : To acquire specialized skills in protection and control necessary for maintenance and operation of electric power facilities. To develop core personnel engaged in the front lines of the field.

- Fault Calculation
- Introduction to Protective Relay Systems
- Introduction to Power Transmission Systems
- Design of protective control circuits
- Precautions for handling protective control circuits
- Relay Settling
- General Information on IEDs
- Oscilloscope Analysis
- Relays to prevent accidental spillover
- Digital relay practice (troubleshooting)
- Digital relay practice (accident response)

⑬ Facility automation system training (about 1 month) : To acquire specialized knowledge and skills related to the operation, maintenance, and construction of automated systems, and to develop core personnel who will be engaged in the front lines of the field.

- Overview of the Power Transformation and Distribution System
- Overview of Grid Control System
- Overview of LAN
- Overview of Communication Systems
- Overview of Direct Control Line Interface
- Practical training at a maker of grid control systems
- Security measures
- Expertise and skills in initial response to system failures and analysis of abnormal data
- System maintenance
- Expertise and skills related to various types of testing during system installation

8． Specific training structure (System Operations and System Planning)

⑭ Technical Leader Training (about 1 week) : To acquire the necessary abilities and skills required of core workers in the workplace. And to develop leaders with advanced decision-making skills, specialized technical skills, and the ability to lead subordinates.

Training for technical skill certification : Training to reach the technical skill level of each of the following set ranks.

⑮ New employee training

< Technical skills to be acquired >

- Outline of rules and manuals related to supply & demand, and grid operation
- Basic method of system operation calculation
- Basics of grid protection relay technology
- How to use systems for system operation
- Basics of operation techniques of other related departments

<Skills to be acquired>

Under the guidance of superiors, be able to perform accurate operation of power system considering the supply reliability and safety at all times. In addition, restoration measures for simple system accidents can be taken precisely and promptly.

- Voltage and power flow adjustment
- Simple and constant system operation commands
- Restoration operation commands for simple system accidents

⑯ Level C training

<Technical skills to be acquired>

- Rules and manuals required for the operation of power system
- System operation calculation methods
- Grid protection relay technology
- Overview of functions and characteristics of equipment used for electric power
- Functions and characteristics of systems used for system operation, outline of emergency procedures in case of an abnormality
- Overview of operational technologies of other related departments

<Skills to be acquired>

Accurate operation of power system in consideration of supply reliability and human safety at all times. In addition, the system can take appropriate and prompt measures to deal with simple system accidents.

- Supply and demand, voltage and power flow adjustment
- Command of system operational all times
- Restoration operation commands in the event of normal grid accidents

8． Specific training structure (System Operations and System Planning)

⑰ Level B training

<Technical skills to be acquired>

- Application of rules and manuals necessary for the operation of power system
- Advanced system operation calculation methods
- Grid protection relay application technology
- Functions and characteristics of equipment used for electric power
- Functions and characteristics of the systems used for system operation, and emergency procedures for abnormalities
- Operational techniques for other related departments

< Skills to be acquired >

Accurate operation of power system in consideration of supply reliability, personal safety, maintenance of service, and efficiency at all times. Furthermore, restoration measures for complex system accidents can be taken accurately and promptly.

- Supply and demand, voltage and power flow adjustment
- Complex system operation commands on a normal basis
- Restoration operation commands in the event of widespread power outage accidents
- Advice to special high-voltage customers on accident restoration operations, etc.

⑱ Level A training

<Techniques and skills to be acquired>

Develop and refine the advanced skills held by the Certified A level. Understand the basic techniques of all aspects of system operations and be able to responsibly perform tasks that span multiple areas of expertise.

- The level of responsibility is based on OJT and self-learning

※Specific items to be checked are based on the training notebook (operation of power systems course notebook)

⑲ Me level training : System operation department's own system ... all the staff of power system operation are expected to reach this level

<Techniques and skills to be acquired>

Further upgrade Level A and take responsibility for carrying out duties such as making internal and external recommendations and technical decisions, as well as technical succession and human resource development. Emphasizes the viewpoints of safety assurance, efficiency improvement, and quality improvement in specific fields (grid command, system operation, protection & control, system maintenance & engineering, and supply & demand operation).

- The level of responsibility is based on OJT and self-learning

※Specific items to be checked are based on the training notebook (operation of power systems course notebook : Level S version)

(References)

Power System Course　Notebook

(legend) ◎: Training that should be conducted through on-the-job training
△: Training that can be conducted through self-study

organization		main items		middle items		subitem	Training level ○: Training items △: Self-study items that can be completed: New employee	C	B	A	How to take a course	Training Manual Training Materials	How to Confirm Course Completion	Course Implementation Date (or confirmation date)
System Command & Operation	1	Outline of the system operations division	(1)	Outline of the system operations division	a	Role and operation of the system operation department	○				Learn about the role and operation of the Grid Operations Department and the organization and division of duties of the Grid Operations Department	Guide to Grid Operations 1. Outline of Grid Operations Chapter 1: Overview of the Grid Operations Division	To help students judge the correctness or incorrectness of the instruction by showing correct and incorrect examples based on the content of the instruction.	
System Command & Operation	1	Supply and Demand Operation (Supply and demand operation)	(2)	Power system operation	a	Outline of system operation operations	○				Learn about the overview of grid operations, the feeder command organization and feeder operations, and the feeder command system and the power system in charge.	Guide to Grid Operations 1. Outline of Grid Operation Division Operations Chapter 2: Power System Operation	To help students judge the correctness or incorrectness of the instruction by showing correct and incorrect examples based on the content of the instruction.	
					b	Outline of Grid Protection Devices	○				Learn about protective relay systems and their application		To help students judge the correctness or incorrectness of the instruction by showing correct and incorrect examples based on the content of the instruction.	
					c	Overview of the Load Dispatching Office	○				Learn about power supply facilities and future directions		To help students judge the correctness or incorrectness of the instruction by showing correct and incorrect examples based on the content of the instruction.	
					d	Overview of Load Dispatching Operation Training Center	○				Learn about the types and content of training in power supply skills training and an overview of simulators.		To help students judge the correctness or incorrectness of the instruction by showing correct and incorrect examples based on the content of the instruction.	
System Command & Operation	2	System operation Plan (Facility Plan)	(1)	general rules	a	Classification of systems, planning approach	○				Learn the basics of the classification of one system, the concept of planning, and the procedure for planning.	Distribution Facilities Planning Rules I. General Provisions	Explain the classification of systems, the concept of planning, and the procedure for planning	
					a	Classification of systems, planning approach			○		Learn about the classification of the two systems, the concept of planning, and the procedures for planning, etc., based on the actual systems.		Explain the classification of systems, the concept of planning, and the procedure for planning	
System Command & Operation	2	System operation Plan (Facility Plan)	(2)	system operation	a	Basics of system structure			○		Learn about the basics of grid structure, the direction of grid structure, and the evaluation of economic efficiency using actual grid systems.	Distribution Facilities Planning Rules II-2 General Items II-1 General of Distribution System	Explain the basics of grid structure, the direction of grid structure, and the evaluation of economic efficiency	
					b	Voltage class, maintain voltage and voltage regulator arrangement			○		Learn the basic concept of voltage classes and voltage regulation, standard voltage, voltage transformation stages, voltage regulation measures, and voltage regulator arrangements, etc., in accordance with actual systems.	○ Distribution Facility Planning Rules II-3 Voltage maintenance II-2 Voltage class Grid Voltage Adjustment Manual Reference Document 2 Grid Voltage Adjustment Manual Reference Document 2	Explain the basic concept of voltage classes and voltage regulation, standard voltage, voltage transformation stages and voltage regulation measures, as well as the layout of voltage regulation equipment.	
					c	systematic frequency coordination			○		Learn the basic concept of grid frequency adjustment, frequency adjustment standards, and their reflection in facility planning based on the actual grid system.	Rules for Planning Distribution Facilities II-4 Grid Frequency Maintenance Frequency Adjustment and Supply/Demand Operation Manual Reference Document 2 Frequency Coordination and Supply/Demand Operation Manual	Explain the basic concept of grid frequency adjustment, frequency adjustment standards, and their reflection in facility planning	
					d	Basic Concept of Supply Confidence Level			○		Learn the basic concept of supply reliability, the expected maximum power used in planning, and its reflection in facility planning, based on the actual system.	○ Distribution Facility Planning Rules II-5 Supply Reliability System Operation Calculation Method II Economic operation calculation (theoretical reference)	Explain the basic concept of supply reliability, the expected maximum power used in planning, and its reflection in facility planning	
					e	Basic Concept of System Stability			○		Learn about the basic concept of grid stability, conditions for ensuring grid stability, and measures to improve grid stability, based on actual systems	Rules for Planning Distribution Facilities II-6. Grid stability Grid operation calculation method II (theoretical reference) in the grid operation training material	To explain the basic concept of grid stability, conditions for ensuring grid stability, and measures to improve grid stability	

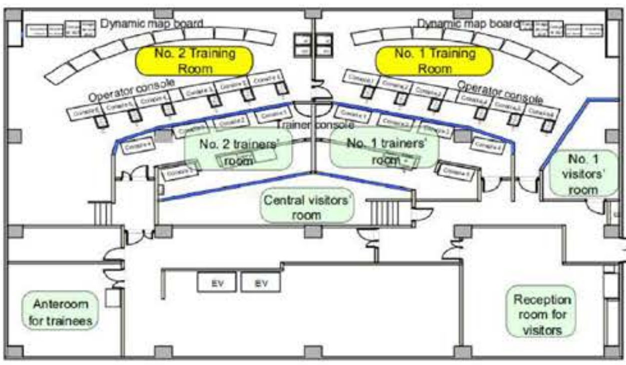
9. Training and exercises using a Dispatching training simulator

In response to the need for higher-level skills and techniques, the Supervisory Control and Data Acquisition (SCADA) system has been sophisticated. However, in the event of a complex incident, the SCADA system is unable to cope with some failures.　Skilled system operators will also be required to implement restoration procedures at their own discretion.

Installation of sophisticated training simulators

Install a sophisticated training simulator capable of dynamically and realistically simulating the movement of a huge and complex power system. Training will be conducted repeatedly under the tense conditions of an accident, in order to pass on the system operation techniques of power system operators and improve their skills and techniques. Through these efforts, we aim to further stabilize the supply of electricity.

Layout of the Load Dispatching Operation Training Center



9. Training and exercises using a Dispatching training simulator

Functions of the Dispatching training simulator

There are two training rooms, each of which can conduct training individually. In the training room, the trainees sit in the training room, and in the trainer's room, experienced trainers (mainly OB employees with S-class certification) evaluate the trainees while assuming the roles of substations and power stations. For restoration training such as blackout of the whole power system, the two training rooms can be used simultaneously to conduct joint training at the central Load dispatching office, local load dispatching office, and various power plants.

Dispatching Training simulator

We developed a high performance dispatcher training simulator in-house to reproduce various phenomena in power systems that actually occur by making real-time high-speed calculations. These phenomena could not be reproduced by conventional training systems. This has enabled more realistic simulations in the training. Acquisition of higher-level operational skills and techniques has become possible by deepening the trainees understanding of complicated phenomena in power systems such as the frequency, power flow, voltage, etc. in training scenarios.

Dynamic map board

Sixteen 70-inch large video displays have been installed in a training room to represent dynamic map boards in each load dispatching office.
A model system is also available to ensure fairness in competitions.
The training effectiveness has been further improved by reproducing the same operating environment as that in a load dispatching office.

9. Training and exercises using a Dispatching training simulator

Training courses for classified according purposes

The training using the training simulator includes the on-site technical and skill certification courses (Level S, Level A, and Level B). In addition, there is a joint training course for each department to respond to a wide range of accidents, a team training course for each group on duty at the Dispatching Office, and an individual training course for each duty worker.

Overview of each training course

Skill certification course	Level S certification course	This is a course to verify that a trainee can make recommendations to internal or external people from the viewpoint of security and improvement of efficiency and quality, make technical judgments, pass technology on to the next generation, and develop human resources and also to verify that the trainee has operational skills and techniques superior to the shift supervisor.
	Level A certification course	This is a course to provide training in operations for recovery from blackouts, to certificate operational skills and techniques for the level of core members of the shift team.
	Level B certification course	This is a course to provide training in operations for recovery from blackouts, to certificate operational skills and techniques for the level of middle-ranking members of shift teams on duty.
Joint training course		This is a training course in which the shift teams on duty at the Central Load Dispatching Office, System Load Dispatching Offices, and Local Load Dispatching Offices cooperate for recovery from wide-area blackout. The teams cooperate with substations and thermal power departments, depending on the case (training program).
Team training course		This is a training course for all the members of teams on duty at System Load Dispatching Offices and Local Load Dispatching Offices to learn operations for recovery from severe contingencies according to circumstances under the directions of the supervisor.
Individual training course	Advanced course	This is a training course for core members of shift teams at Load Dispatching Offices to learn operations for recovery from complicated contingencies according to circumstances.
	Intermediate course	This course consists of basic training in recovery from various types of contingencies from simple to complicated ones for middle-ranking system operators on duty.

9. Training and exercises using a Dispatching training simulator

Main training case contents and characteristics (1/2)

The accident cases used for training are diverse. In addition, it is necessary to consider both simple and complex accident cases, depending on the trainee's level. This section summarizes the main training cases and the items to be learned in training.

Training Cases	Items to be mastered, etc.
Transmission line 1 line accident case	i Basic operation regarding operation commands ii Determination of whether or not to implement retransmission and implementation iii Basic Relay Operating Responsibilities iv Basic Approach to Accident Recovery v How to cooperate with related departments such as power transmission and customers
Transmission line route accident case	i Assessing the situation immediately after an accident ii Determination of whether or not to implement retransmission and implementation iii Accurate understanding of the scope of power outage iv Measures to be taken at the time of substation total shutdown, etc. v Concept of congested accident recovery vi How to cooperate with related departments such as power transmission and customers
Bus bar accident case	i Understanding the congested situation immediately after an accident ii Identification of overload status and emergency response to transformer outages iii Heavy patrols (e.g., to determine usable facilities), safety operations iv Understanding of protective relays (including the relationship between Ry and CT) v Concept of congested accident recovery
Circuit breaker failure accident case	i Understanding of back-up protection relays, etc. ii Emergency Response Method iii Heavy patrols (e.g., to determine usable facilities), safety operations iv Understanding of protective relays (including the relationship between Ry and CT) v Understanding how switchgear works (e.g., interlocks) vi Concept of congested accident recovery

9. Training and exercises using a Dispatching training simulator

Main training case contents and characteristics (2/2)

Training Cases	Items to be mastered, etc.
blind spot accident case	i Determination of accident aspect from simultaneous operation of multiple protection relays ii Emergency Response Method iii Heavy patrols (e.g., to determine usable facilities), safety operations iv Understanding of protective relays (including the relationship between Ry and CT) v Concept of congested accident recovery
Isolated system occurrence accident case	i Understanding the congested situation immediately after an accident ii Understanding of grid frequency and grid voltage iii How to Parallelize isolated system with a main system iv Measures to be taken at the time of substation total shutdown, etc. v Generator mechanism and operational response vi. Concept of congested accident recovery
missing-phase accident case	i Assess the situation immediately after the accident ii Accurate determination of missing phase range and section determination iii Understanding recovery response to missing phase occurrence iv How to cooperate with related departments such as power transmission and customers
Emergency stop case	i Confirmation details and understanding of the situation at the time of advance notification and emergency stop request ii Accurate understanding of emergency stop timing and stop equipment and stop method iii Communication and supply reliability measures after an emergency shutdown iv How to cooperate with related departments such as power transmission and customers

9. Training and exercises using a Dispatching training simulator

Evaluation of Training Results

Evaluating training results is necessary to improve the level of the trainees. However, it is important that the evaluation be convincing to the trainees. The evaluation of the training should consist of three parts: the recovery response, the time required for recovery, and comments on each person's actions.

Type of Evaluation	Evaluation Method
Assessment of restoration status response	· The evaluation is based on objective numerical values on a 5-point scale, which enables the user to understand individual growth trends and analyze data in the future. · The total value of the evaluation of check items is the level of achievement. · For low scores (generally 3 or less), the reasons for the low scores should be clearly indicated.
Time management of key action items in the recovery response	· Promote awareness among trainees by objectively indicating the amount of time spent implementing each phase of the restoration process. · Also, comparison with other teams and trainees will help in future instruction.
Evaluation comments for each person	· The review should be written for each individual, so that the participants are strongly aware of the importance of their own actions. · The good and bad points of the behavior should be described, including the technical basis. · If there are repeated instances of inadequacy, such as omissions to recite, the details should be noted. This will help improve the awareness of the individual and the manager.

After the training, **a meeting should be held** to explain any problems with the team or individual movements.

This enables trainees to reflect on the training and apply it to their practical work.

(Reference) Example of each evaluation table

Assessment of restoration status response

Training Case: ○○GRID STATION (△△kV A2 B2 Bus Bar accident)

Assessment of response status (:point)

Date of implementation		March 1	March 23.	March 25.	February 26	February 18	
straightened lumber		A team	B team	C team	D team	E team	average
Assessing the accident situation	Confirmation of system summary chart	5	5	5	4	5	5
	Confirmation of outage coverage	4	5	5	4	5	5
Determination of accident facilities	Accident Facilities - Determination of Aspects	5	5	5	3	5	5
Establish restoration policy	Emergency Response Procedures	4	3	3	3	5	4
	Establish restoration policy	5	5	5	4	5	5
	patrolling (esp. using ships or aircraft) (Equipment to be used, adjacent equipment, time required)	5	5	5	4	4	5
Perform counter-recovery operations	Conduct meetings (timing and content)	4	4	5	4	4	4
	Assignment of work within the immediate area	5	5	5	4	5	5
	Creation of operating procedures chart (timing and assignment)※1	5	5	5	2	4	4
	Colic vs. colic in the operating procedures table (other than the creator)						
	Approval and execution of operating procedures. Safety checkNote 2	5	5	4	3	5	4
	Information sharing within the immediate area - Intra-industry linkage	5	3	5	3	5	4
	Accurate inquiries to electric power stations (including power transmission liaison)	4	5	5	4	5	5
	Clear policy explanations for local payrolls	5	5	5	4	5	5
	Grasping and sharing of outage load directly within the company	5	5	5	4	5	5
Disconnection of	Cut-through accident equipment disconnection	5	5	5	2	2	4
Implementation of confidence measures	Understanding the transmission load	4	4	5	4	5	4
	Identification of tidal current bottleneck areas	5	5	5	4	5	5
	Short - ground fault protection						
Handling of information	Description of serious accident (including time of dispatch)	4	3	3	3	4	3
Total		84	82	85	63	83	79
Achievement (% of full score (5 points) for the subject item)		93 %	91 %	94 %	70 %	92 %	88 %

※1: For telephone directives - make sure you are looking at the screen and making notes.
※2: For telephone commands - confirm that the command is given while looking at the screen and that the change in status and recitation is carried out.

(Reference) Example of each evaluation table

Time management of key action items in the recovery response

Response time ______ ○○ line accident, Outage power, Secondary system restoration: 1st stage, 2nd stage :minute

Teams that conducted		A team	B team	C team	D team	E team	average
Confirmation of system summary diagram (Accident determination function)		1	1	1	1	1	1
Confirmation of outage coverage		8	4	4	10	1	5
Determination of accident facilities		1	1	1	3	1	1
Execution of emergency measures (system alone, OLR, etc.)		1	1	1	2	2	1
Completion of emergency procedures							
Confirmation of the electric station where the instantaneous voltage drop occurs		12	1	1	1	1	3
Implementation of retransmission							
Implementation of re-transmission of electricity							
Understanding Power Outages		8	5	5	10	11	8
Understanding the amount of power supply dropout							
Completion of treatment at all stops							
Restoration of accidental power outage		10	8	5	10	12	9
Understand the recovery time of other systems in the secondary system		10	8	5	10	14	9
electric power station	Shin Tsukuba (GS) Bus CB020 patrol request	19	14	13	13	12	14
	Shin Sawara Line No. 2 in used	36	28	28	44	31	33
	Shin Tsukuba Line No.1 combined used	41	36	39	56	39	42
	Shin Tsukuba (GS) 4B combined used	33	31	30	49	43	37
	OLR suppression of thermal power output	40	36	29	20	17	28
systemic parallels							
Disconnection of accident facilities		45	40	42	34	25	37
Implementation of confidence measures		36	31	41	49	.43	40
First Serious Incident Alert (Phase 1) transmitted (5 minutes)		10	10	8	11	5	9
First Serious Incident Alert (Phase 2) transmitted (15 minutes)				16		12	14
Second Serious Incident Alert transmitted (25 minutes)		25	25	26	30	23	26
Third Serious Incident Alert transmitted					59		59

(Reference) Example of each evaluation table

Evaluation comments for each person

February 26 (Friday) Training Evaluation Memo – System Load Dispatching Office ○Team

	Case 1 (○○○Grid Station A2 B2 Bus bar accident	Case 2 (○○○Grid Station A・B Bus bar accident
Duty chief Mr. A	・4B should be used after the use of the Shin Sawara line No. 2 (・・・) As a result, 4B use at the request of the local	・Good to contact FC, etc. to Central Load Dispatching Office (・・・)
	・Requests for response to Central & System Load Dispatching Office, such as instantaneous adjustment due to thermal power curtailment and the presence of EPPS work, are good (・・・)	・No instructions for power flow reduction measures (switching of North Sagami loads) on Sakuma-Higashi line (・・・)
	・It is important to clearly distinguish between accident equipment disconnection and operating instructions for reliability measures. Those that lead to safety (local, operational) and early response	・The team's overall coordination is insufficient (・・・)
		・Restoration policy has not been disseminated within the team (・・・)
	・Since it is clear that the B2 bus bar can be used in this case, it is possible to use the Shin-Sawara Line No. 2 and 4B on the B2 bus bar first, and then instruct the accidental equipment disconnection. It is also possible to switch 3B and Shin-Sawara Line No. 1 to the B2 bus bar, and then disconnect the equipment. Halfway operation instructions in a hurry to get to the next step will interfere with safety	
	・Accidental equipment disconnection points are improperly indicated (・・・)	
Assistant chief Mr. B	・No comment on the Shin Tsukuba (GS) 500kV bus bar accident at the time of the accident (・・・)	・The team's linkage was not good, and I confirmed the same thing as Mr.…
	・Answer the phone calmly. (・・)	・There is a lot of rework, what to ask and what to point to before confirming contact.
	・It is meaningless to call all the thermal power plants together, we should firmly call each power plant individually (・・)	・It is important to organize what should be shown and done (・・)
	・Thermal power output suppression instruction communication should be handled properly (・・・)	・Be careful to exchange operation commands with the 500kV controlled Shizuoka Load Dispatching Office. (・・・)
	・No confirmation of OLR cutoff time(・・・)	・The restoration policy has not been fully explained to the local Load Dispatching Office (・・・).
		・Not aware of power flow reduction measures (switching of North Sagami loads) on Sakuma-Higashi line(・・)
Runner-up Mr. C	・No comment on the Shin Tsukuba (GS) 500kV bus bar accident at the time of the accident (・・)	・There was no confirmation of power outages in Anagawa(・・)
	・Well pointed out against the omission of recitation (・・). However, the name of the facility was missing when reciting(・・)	・Not aware of power flow reduction measures (switching of North Sagami loads) on Sakuma-Higashi line(・・)
	・Operation procedure notes are disorganized, concerns about erroneous commands (・・)	・In the "Restoration Status" column of the Serious Incident Report, "Sakuma-Higashi Naka・Sato Line in use", "Sakuma-Higashi Yama Line in use", and "Sakuma・Shin Toyone Power Plant in parallel" should also be listed (・・)
	・Good confirmation of information to the accident location (・・) However, the order of the interviews should be more organized and more compact in terms of the time required to complete them.	
	・Accidental equipment disconnection point is improperly operated (・・)	
General staff Mr. D	・No comment on the Shin Tsukuba (GS) 500kV bus bar accident at the time of the accident (・・)	・The team was not well coordinated. The same thing was confirmed by Mr.……(・・)
	・Instantaneous voltage drop aggregation is not enough for a second report in 20 minutes.(・・) Also, the instantaneous voltage drop aggregation should not be fractional, such as 21 minutes(・・)	・Not aware of power flow reduction measures (switching of North Sagami loads) on Sakuma-Higashi line(・・)
	・In the recovery status column of the Serious Incident Report, the accident event, load shedding due to overload, emergency suppression of thermal power, etc. should also be listed(・・)	

Appendix 5 1st to 10th Travel Reports

Appendix 5.   1st to 10th Travel Reports

1. 1st Travel Report	
Travel Period	Thursday, November 25 - Tuesday, December 14, 2021
Consultants	Yoshida, Nakazawa, Nakamura, Kawasaki
Activities	- Meetings with TSG CE, P&C CE, TSG GM, DMD, and MD. - Consultation meetings with each WG member, joint meetings of WG1, WG2, and WG3, and discussions with WG1 members regarding new system diagrams and additional modifications. - Installation and operational verification of 200 cases on the PC simulator. - Inspection of the 220kV substation. - Holding 1st t JCC meeting.

2. 2nd Travel Report	
Travel Period	Friday, January 14 - Tuesday, February 1, 2022
Consultants	Yoshida, Nakazawa, Nakamura, Kawasaki
Activities	- Meetings with TSG CE and TSG GM. - Acceptance testing of the PC simulator. - Implementation of activities for each WG. - XTAP training. - Reviewing of Blackout countermeasures, including panel discussions. - Training on the PC simulator. - Deliberation on the policy for creating simulation cases in the new system diagram.

3. 3rd Travel Report	
Travel Period	Friday, May 14 - Friday, June 3, 2022
Consultants	Yoshida, Nakazawa, Nakamura, Takeuchi, Kawasaki
Activities	- Implementation of activities for each WG. - Final confirmation and collection of necessary data for the new system diagram. - Inspection of the utilization of PC simulator (visiting two substations). - Training on the PC simulator, explanation of training case drafts based on the new system diagram. - Interim report on Black Out system analysis. - Discussion on malfunctioning protection relays during accidents. - Implementation of XTAP training for system analysis. - Meeting with DMD.

4. 4th Travel Report	
Travel Period	Friday, July 15 - Thursday, July 28, 2022
Consultants	Yoshida, Nakazawa, Nakamura, Takeuchi, Kawasaki
Activities	- Implementation of activities for each WG. - System analysis comparison with the new system diagram. - Investigate and corresponding to display issues on the GSO simulator large screen. - Confirmation of Black Out system recovery measures and proposal of improvements. - Discussion on malfunctioning protection relays during accidents. - Implementation of XTAP training for system analysis. - Meetings with MD and DMD.

5. 5th Travel Report	
Travel Period	Friday, November 11 - Thursday, November 24, 2022
Consultants	Yoshida, Nakazawa, Nakamura, Kawasaki
Activities	- Holding 2nd JCC meeting. - Consultation with NTDC Human Resources Department GM (Proposing skills certification system in the training programs utilizing simulators). - Visits to substations where PC simulators are distributed, and confirmation of their utilization status. - Gathering information on a large-scale blackout in the southern region.

6. 6th Travel Report	
Travel Period	Friday, December 9, 2022 - Friday, December 23, 2022
Consultants	Yoshida, Nakazawa, Nakamura, Kawasaki
Activities	- Meetings with MD, DMD, and Protection & Control CE. - Implementation of activities for each WG. - Installation and handover of new system diagrams to the GSO simulator. - Consideration of training case drafts based on the introduction of a skills certification system using the GSO simulator. - Follow-up on the Black Out analysis and recommendation report. - Adjustment of the content and schedule of domestic training implementation.

7. 7th Travel Report	
Travel Period	Friday, June 16 - Friday, June 24, 2023
Consultants	Yoshida, Nakazawa, Takeuchi, Nagai
Activities	- Presentation of a draft SOP based on the new system diagram for the GSO simulator. - Installation of the updated version of the GSO simulator software. - Investigation of NTDC requests for the upcoming project. - Discussion of agenda items for the next JCC meeting. - Confirmation of the progress in implementing measures based on the Black Out report. - Confirmation of the schedule and nominated participants for the second TOP Japan.

8. 8th Travel Report	
Travel Period	Friday, July 14 - Saturday, July 29, 2023
Consultants	Yoshida, Nakazawa, Nakamura, Nagai
Activities	- Holding 3rd JCC meeting. - Acceptance testing and handover of the PC simulator. - Training on operations using the new system diagram. - Inspection of the PC simulator usage status and operational training at the Okara substation. - Training on pre-considerations for power facility shutdown. - Explanation of the schedule for the second TOT Japan.

9. 9th Travel Report	
Travel Period	Friday, October 20 - Sunday, November 5, 2023
Consultants	Yoshida, Nakazawa, Nakamura, Takeuchi, Nagai
Activities	- Meetings with the new TSG CE, GM, DMD, and MD. - Implementation of activities for WG2 and WG3. - Lecture on the skills certification system using the PC simulator. - Training on operational procedures using the new system diagram on the PC simulator. - Training on the system stabilization relay. - Inspection of the PC simulator usage status and operational training at the New Lahore substation. - Visit to NPCC.

10. 10th Travel Report	
Travel Period	Friday, November 24, - Friday, December 1, 2023
Consultants	Yoshida, Takeuchi, Nagai
Activities	- Meetings with TSG CE, GM, DMD, and MD. - Final confirmation and explanation of the contents of the completion report. - Courtesy visit to the embassy of Japan.

Appendix 6 List of interviewed persons

Appendix 6. List of Interviewed Persons

Ministry of Energy (Power Division)

Mr. Hidayat Ul Laha	Joint Secretary NTDC

Ministry of Finance Revenue and Economics Affairs, Economic Affair Division

Mr. Adeela Bukhari	Joint Secretary
Mr. Hamid Karim	Deputy Secretary (Japan)

National Transmission and Despatch Company, Limited (NTDC)

Head Office

Mr. Rana Abdul Jabbar Khan	Managing Director
Mr. Qaiser Khan	Deputy Managing Director Planning & Engineering
Mr. Anwar Ahmed Khan	General Manager Asset Management/ Grid System Operation North
Mr. Waseem Younas	General Manager Power System Planning
Mr. Mir Hassan	Deputy Manager Transmission Planning, Power System Planning
Mr. Muhammad Mustafa	General Manager HVDC
Mr. Taqi Ud Din	Chief Engineer Protection & Control
Mr. Abdul Moiz Waris	Assistant Manager Technical, Protection & Control
Mr. Syed Mukkarram Hussain Jafri	General Manager Human Resources

Technical Service Group (TSG)

Mr. Safdar Ali	General Manager (Project Director)
Mr. Muhammad Ejaz Khan	Former Chief Engineer TSG North (Former Project Manager)
Mr. Muhammad Shahid Nasir	Chief Engineer TSG North (Project Manager)
Ms. Hajra Arshad	Deputy Manager TSG North
Mr. Adeel Akram	Foreman TSG North
Mr. Muhammad Adnan	Assistant Manager TSG North
Mr. Fayaz	Principal TSG Tarbela
Mr. Mansoor Akbar Hussain	Deputy Manager TSG Tarbela
Mr. Rafiq Ahmad	Chief Engineer TSG South
Mr. Abdul Aleem	Deputy Manager TSG South

National Power Control Center (NPCC)

Mr. Mubashir Khan	Deputy Manager Technical, Power Control

JICA Pakistan Office

Mr. Shigeki Furuta	Former Chief Representative
Mr. Yasumitsu Kinoshita	Chief Representative
Mr. Arshad Abbasi	Senior Program Manager
Mr. Koki Sawa	Project Formulation Advisor

Appendix 7 Photo Gallery

Appendix 7.　Photo Gallery

1st Travel (Nov.29th,2021)
CE & GM of TSG meeting

1st Travel (Nov.29th,2021)
1st JCC

2nd Travel (Jan.26th,2022)
WG3 Black Out Countermeasures
Participants of Panel Discussion

3rd Travel (May.23rd,2022)
Training for XTAP, Analysis Software

5th Travel (Nov.14th,2022)
First-Day Orientation for TSG Trainings
(to explain the content of the project)

5th Travel (Nov.16th,2022)
2nd JCC

6th Travel (Dec.20th,2022)
Meeting with NTDC CE(P&C)

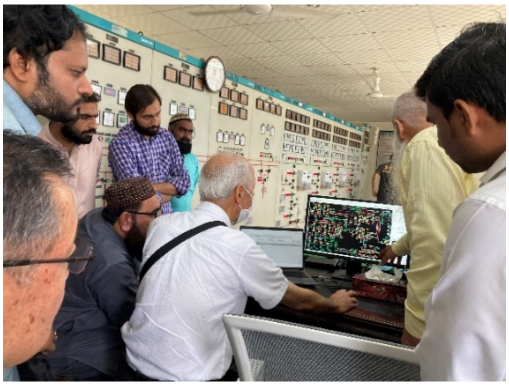
6th Travel (Dec.21st,2022)
Handover Ceremony for New Diagram Software

7th Travel (Jun.20th,2023)
TSG Visit for Training
(explanation of PC simulator)

8th Travel (Jul.17th,2023)
Additional Procurement for 10 PC Simulators, Placing ODA Stickers for Handover Ceremony

8th Travel (Jul.20th,2023)
Handover Ceremony for PC Simulator

8th Travel (Jul.25th,2023)
PC Simulator Training at 220kV Okara Grid Station



9th Travel (Oct.24th,2023)
Meeting with MD (Mr. Jabbar Khan)

10th Travel (Nov.28th, 2023)
Completion Ceremony
(MD Jabbar Khan, DMD Qaiser Khan,
JICA Sawa, CE Shahid Nazir)

1st TOT in Japan (May.23rd,2023)
Visit FC Station
(Shin-Shinano)

1st TOT in Japan (May.25th,2023)
Lecture
(Power System Analysis)

2nd TOT in Japan (Sep.20th,2023)
Visit Manufacturer (Relay test)

2nd TOT in Japan (Sep.22th,2023)
Wrap-up & Certification
(Ms. Hajra Arshad)