A STUDY OF OVERCURRENT PROTECTION FOR MAE SARIANG MICRO-GRID SYSTEM

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A STUDY OF OVERCURRENT PROTECTION FOR MAE SARIANG MICRO-GRID SYSTEM

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ABSTRACT

This thesis presents a study and a design of overcurrent protection for a distribution system in the Mae Saraing district. The Mae Sariaing system has a plan to be connected with Distributed Generations (DGs) and to be operated as a micro-grid (i.e. grid-connected operation or islanding operation). The addition of DGs and the micro-grid operation will make a direction and magnitude of short-circuit currents widely change according to different operating scenarios of the system; hence a mis-coordination of the protection system. The overcurrent protection design applied in this thesis is based on a detection and correction scheme. The method starts with a design of protection for a fundamental scenario (i.e. a scenario without DG). Then, the mis-coordination will be checked. The correction will be done before moving to the next scenario. The study has been performed using DIgSILENT PowerFactory.

KEY WORDS: DISTRIBUTED GENERATION/ MICRO-GRID/
MIS –COORDINATION/OVERCURRENT PROTECTION

83 pages

การศึกษาระบบป้องกันกระแสเกินสำหรับระบบไมโครกริดแม่สะเรียง

A STUDY OF OVERCURRENT PROTECTION FOR MAE SARIANG MICRO-GRID SYSTEM

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บทคัดย่อ

วิทยานิพนธ์นี้ศึกษาวิธีการออกแบบระบบป้องกันกระแสเกินสำหรับระบบจำหน่ายที่ อ.แม่สะเรียง เนื่องจากระบบนี้มีความต้องการที่จะเพิ่มโรงไฟฟ้าขนาดเล็กเข้าสู่ระบบ และยังต้องการพัฒนาระบบให้สามารถทำงานแบบไมโครกริดได้ กล่าวคือ เป็นระบบไฟฟ้าที่สามารถจ่ายไฟแบบอิสระได้โดยไม่ต้องเชื่อมโยงกับระบบโครงข่ายไฟฟ้าหรือทำงานโดยขนานกับระบบโครงข่ายไฟฟ้าเดิม แต่การเพิ่มโรงไฟฟ้าขนาดเล็กและการทำงานแบบไมโครกริดนั้นจะทำให้ขนาดและทิศทางของกระแสลัดวงจรในระบบเกิดการเปลี่ยนแปลงตามสถานการณ์การทำงานของระบบที่มีได้หลายรูปแบบ และอาจส่งผลให้ระบบป้องกันที่ออกแบบอิงกับสถานการณ์พื้นฐานไม่สามารถทำงานได้อย่างถูกต้องกับสถานการณ์อื่นๆ การออกแบบระบบป้องกันกระแสเกินจะทำโดยการตรวจสอบและแก้ไขปัญหาไปทีละสถานการณ์ โดยเริ่มออกแบบจากสถานการณ์พื้นฐาน หรือสถานการณ์ที่ระบบที่ยังไม่มีการเชื่อมต่อโรงไฟฟ้าขนาดเล็ก หลังจากนั้นจะมีการตรวจสอบหาปัญหาการทำงานผิดพลาดของระบบป้องกันและแก้ไขทันที เมื่อเสร็จสิ้นจะไปทำการทดสอบในสถานการณ์ถัดไปจนครบทุกสถานการณ์ โดยการศึกษานี้ได้ใช้โปรแกรมDIgSILENT PowerFactory ในการจำลองระบบ

83 หน้า

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CHAPTERR I
INTRODUCTION

1.1 Introduction

Nowadays the demand for energy is getting higher, but to build a large power plant is going to be difficult according to various factors such as a construction site, the impact on the environment, the impact of a large scale of fuels and a high investment cost. Besides this, a large power plant is always located a long way from the consumers. The energy has to be transported through a distant transmission and distribution system. When there is a fault in the transmission and distribution system, it will impact a lot of consumers. As a result, the government and the Provincial Electricity Authority (PEA) have promoted the use of renewable energy by building Distributed Generations (DGs) which are connected with the distribution system. In order to reduces the impact of the fuels and to stabilize the energy security of the country.

Because of rapid increase of the DGs, PEA has to search for the new knowledge and technology to manage the power system in order to make the distribution system ready for DG and renewable energy. Beside there is a need to develop the conventional distribution system and change it to be the micro-grid system in order to increase the Efficiency of the power supply and the reliability and the quality of the power system.

The micro-grid system is the system that can operate with two modes: a grid-connected mode and an islanding mode. The micro-grid system can reduce the System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI) and can solve the voltage drop because it can be used to replace the power supply during main power failure. Moreover it can reduce loss of power system and can extend the time to invest to leverage the system and also reduce the load capacity of a centralized. However, the micro-grid system can make the distribution system more complex because there might be more steps in planning, controlling and protecting the system.

In Thailand, the PEA is developing the distribution system in Mae Sariang District to enable its function into micro-grid system. However, this distribution system is functional with the micro-grid system, it needs to consider on many factors such as control, operation and protection. The researcher [1] has studied the feasibility to develop the power system in Mae Sariang.

Therefore, this research has studied the protection of distribution system in order to operate with micro-grid system. It will feature on overcurrent protection because of a major factor for the protection system of the micro-grid system [6-7].

1.2 Objective

- To study a procedure for design and evaluate of the overcurrent protection for Mae Sariang distribution system to be operated as a micro-grid
- To design and evaluate the overcurrent protection for Mae Sariang Micro-grid

1.3 Research Methodology

In this research, the studies and evaluates are conducted on a computer model of Mae Sariang Micro-grid. DIgSILENT PowerFactory simulator will be used to perform the simulations. The key procedures are as follows:

1. Gather data of Mae Sariang Distribution system to create the model
2. Study a design and evaluate of a protection system, in particular for micro-grid operation
3. Design the protection of Mae Sariang Distribution system for micro-grid operation
4. Evaluate the coordination of the protection system of Mae Sariang Micro-grid

1.4 Scope of the Thesis

- Design and evaluate the coordination of the protection system of Mae Sariang Micro-grid with DIgSILENT PowerFactory simulator (version13).
- There are two types of DG which are Synchronous generator and Inverter-based source.
- The design of protection focuses on main feeders and there are two protective devices (i.e. Recloser and Overcurrent Relay) being used.
- The study of micro-grid operation includes a grid-connected and Islanding modes

1.5 Outline of the Thesis

The content of this thesis is divided into six chapters as follows.

- Chapter 1 Introduction
- Chapter 2 Literature Review
- Chapter 3 Method
- Chapter 4 Simulation and result
- Chapter 5 Conclusion and future work
- Appendix

CHAPTER II
LITERATURE REVIEW

2.1 Introduction

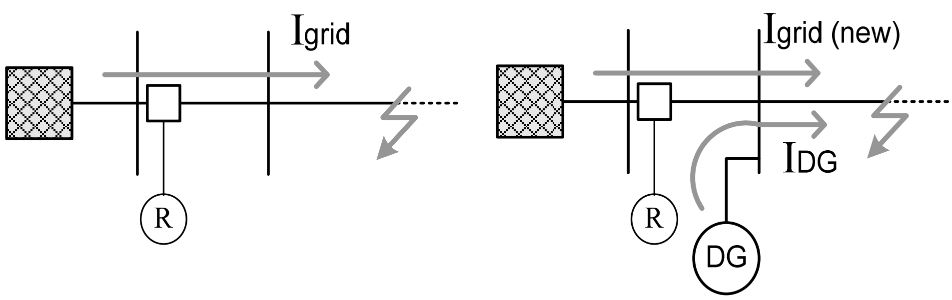
The micro-grid operation of the distribution system in Mae SaRiang District depends on many factors. Among them, the overcurrent protection is very important. The micro-grid system consists of several distributed generations (DG) connected with the distribution system. When a fault is occurred, the behaviors of distribution system with micro-grid operation will be dramatically changed from those of traditional distribution system.

IEEE Std. 1547 suggests that the protection should disconnect all DGs from the system when the fault is occurred; however, this suggestion is less practical when there are too many DGs. This is because the disconnection of all DGs would impact on a reliability of the system [5]. In addition, no suggestion about overcurrent protection for grid-connected and islanding operations is stated in IEEE Std. 1547. So, the issue of overcurrent protection for a micro-grid operated distribution system is currently studied by many researchers. In this chapter, the related researches that can be applied for the design of overcurrent protection system in Mae SaRiang District will be discussed.

2.2 Protection Problems

When DG is added in the distribution system, the existing overcurrent protection may not work properly because 1) the additional DG may extremely modify a range of fault current and 2) the fault current may have a bi-direction. These two phenomena result in well-known problems, namely, blinding of protection and false tripping (sympathetic tripping) [6], [12].

2.2.1 Blinding of protection



(2.1A) (2.1B)

Figure 2.1 Blinding of protection When DG is added in the distribution system installed [8]

Blinding of Protection is occurred when the additional DG modifies the level of fault current until it is less than the pick-up current of protective device. As such, the protective device will not detect the fault. Figure 2.1A exhibits the system before the installation of DG. The current flowing to the fault owns the Igrid that is higher than the pickup current of the relay. After DG connected, as shown in Figure 2.1B, the contribution of a fault current from DG will decrease the Igrid. This results in the lower values of Igrid (or $I_{grid\ (new)}$) and non-operation of relay.

2.2.2 False Tripping

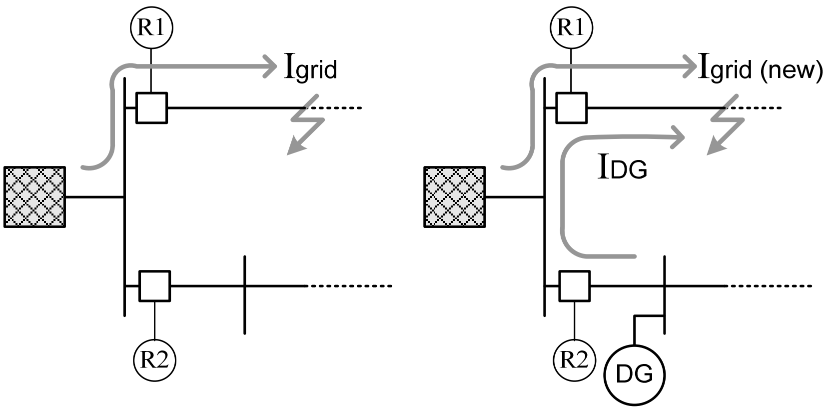


Figure 2.2 False Tripping When DG is added in the distribution system installed [8]

False Tripping is occurred when DG located on a non- fault feeder contributes a current to the fault feeder. Such contribution of current may be higher than the pickup current of a protective device on the non- fault feeder. This results in the error operation of the protective device. As shown in Figure 2.2, when the fault is occurred, the R1 relay that should first work as the main protection will not be operated as the R2 relay works faster than the R1 relay. In some literatures, the false tripping may be called a selectivity problem if R2 relay is located in the same feeder with R1 relay.

In [7], the installation position of DG causing the blinding of protection is theoretically analyzed using a line-to-neutral equivalent circuit. However, this proposed method is not much efficient when applied with a large system with several DGs. In [8], the researchers analyses a small system to investigate the blinding of protection and false tripping. The investigation starts with performing a fault simulation to every feeder for the system without DG, with 1 DG, and with 2 DGs, respectively. After that, the relay operating times will be calculated. The blinding of protection will be detected if the relay operating time of the system with DG or DGs is longer than that of the system without DG. The false tripping will be detected if the operating time of the relay located nearest to the fault is longer than the operating time of the other relays.

In [9], the guideline for detection of blinding of protection is given. The bottom line of this guideline is a comparison of fault current of a system with DG connection with a pick up current of the related relay of a base-case system (a system without DG connection). If the fault current caused by the DG-connected system is less than the pickup current, the blinding of protection is occurred. However, the detection of false tripping is not mentioned.

Apart from the blinding of protection and false tripping, the authors [7, 9, 15] investigate another mis-coordination between recloser and fuse, see Figure. 2.3

2.2.3 Recloser-fuse mis-coordination

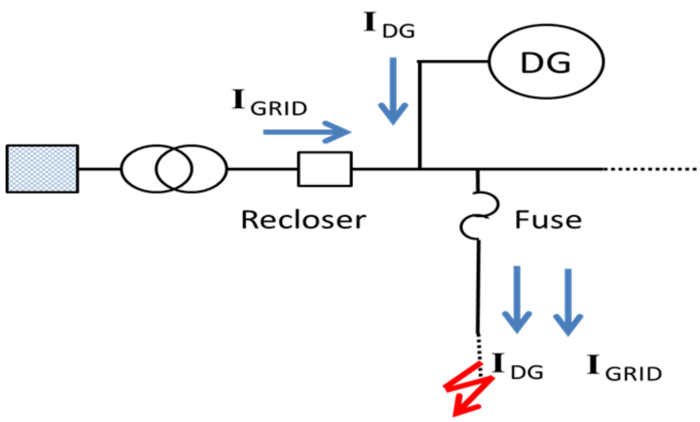


Figure 2.3 Recloser-fuse mis-coordination [7]

From Figure. 2.3 in case of no DG connection, when the temporary fault is occurred in the position exhibited in Figure. 2.3, the recloser must work with fast curve to temporarily trip the circuit. This scheme is to save a replacement of a fuse for the temporary fault. However, if the DG is connected in the exhibited position, the fuse will work before the recloser if the fault current through fuse is too high. This hence implies the mis-coordination [7, 15].

In addition to the mis-coordination of the protection devices, the fault current level between the grid-connected mode and islanding mode might be much different. In the islanding mode, the generation source is usually the inverter-base source. The fault current is limited by the power-electronic converters. So, the fault current is very trivial when compared with the one in the grid-connected mode. As the fault current can be widely changed, the existing protective devices neither are inefficient nor cannot work properly in the micro-grid mode. [10, 17, 18]

2.3 Researches Related to Design and Improvement of Overcurrent Protection System

From the previous sections, it is obvious that the main problems caused by DG connection are blinding of protection and false tripping. Many researchers have studied about these problems and have suggested different solutions as follows:

2.3.1 Solutions for Blinding of Protection

[15, 2007] proposed optimal sizing for the DG connected to the distribution system. Such capacity will not affect the coordination of the existing overcurrent protective devices. The authors formulate the protection coordination as the additional conditions of optimization problem and then apply Genetic Algorithms to find the solution.

[9, 2011] suggested the solution of blinding by selecting the proper DG installation position to avoid the blinding of protection, as exhibited in the flow chart in Figure. 2.4. The flow chart consists of two loops. The outer loop will adjust the position whereas the inner loop will adjust the DG capacity. The outer loop adjusts the position of DG from Busbar 2 to Busbar 3 with 10% of the length of the grid line for each time, see Figure. 2.5. By every position adjustment of the outer loop, the DG capacity will be increased with 2 MW until reaching 10 MW in the inner loop. The fault current will be re-calculated and stored when the DG capacity is increased. The stored fault currents will be compared with the pickup current of the relay. If there is any value higher than the pickup current, the blinding of protection is detected and the DG position associated with that fault current must be avoid.

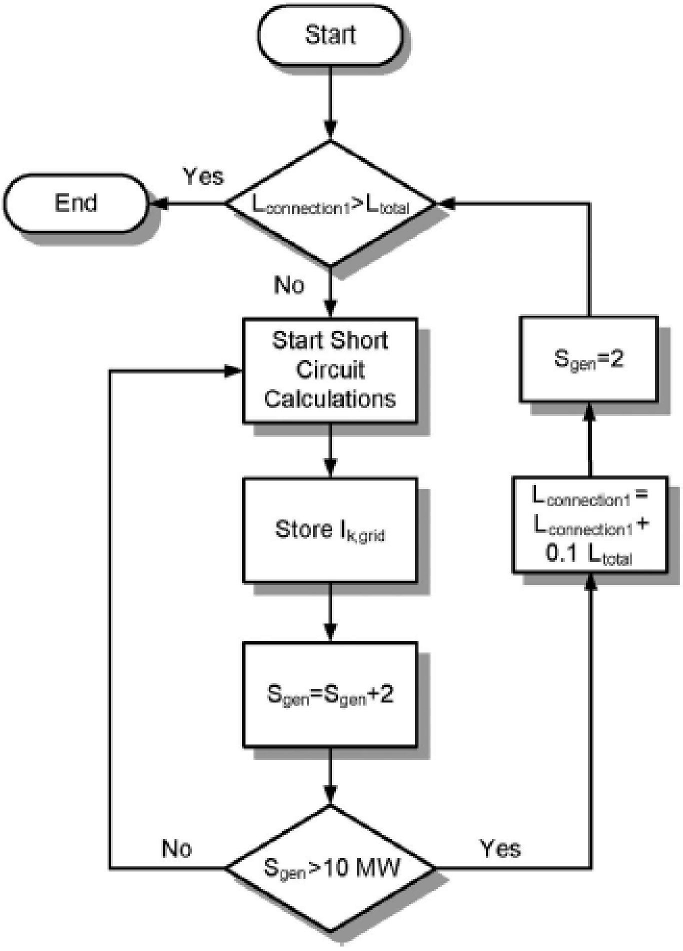


Figure 2.4 Flowchart to illustrate the repetitive calculations [9]

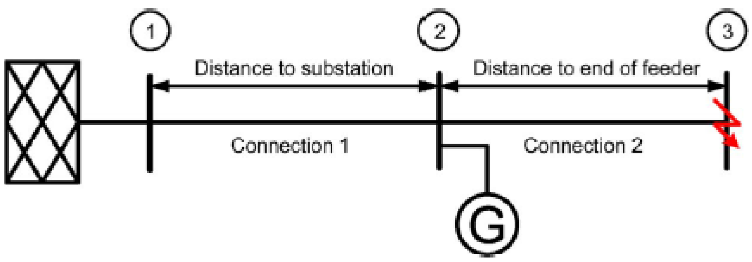


Figure 2.5 Test feeders blinding of protection [9]

[8, 2012] suggested the parameter adjustment of overcurrent relay. For example, the pickup current of the relay should be decreased to solve the blinding of protection. However, the decreasing of pickup current will impact on the selectivity of the protection system. Thus, the adjustment of relay parameters to solve the blinding might introduce the false tripping.

2.3.2 Solutions for False Tripping

According to [9, 2011], the false tripping might be solved by adjusting the relay parameters. The operating time of the false-tripping relay must be delayed by adjusting its time dial. It would rather adjust the time dial than adjust pickup current. This is because the adjustment of pickup current will decrease the sensitivity of the false-tripping relay. If the adjustment of time dial could not solve the problem, an addition of a direction overcurrent relay may be the choice.

[19, 2011] proposed the scheme adjustment of the protection system by adding the direction unit in the overcurrent protection system so that the relay can examine the flow direction in two ways (Bi-direction) and can work with the communication system to enhance the efficiency of the protective devices. [8, 2012] offered the scheme adjustment of the protection system as well. However, the authors use the differential relay rather than the direction unit to adjust the scheme of protection. [11, 2013] concluded that the change of fault current both in terms of capacity and direction led in the mis-coordination of the protective devices. So, in this research, the scheme of the protection system is changed from the overcurrent relay to the direction overcurrent relay. If the problem still cannot be solved, the differential relay will be finally applied.

[17, 2013] suggests that the DG connection results in the change of direction and magnitude of fault current. These lead finally to the mis-coordination of the existing protective devices. Hence, the direction overcurrent relay should be applied with the fault current limiter (FCL) to solve the problem. The simulation results are also given to show that this method could solve the mis-coordination for both grid-connected mode and islanding mode.

[6, 2013] improved the protection system to be the adaptive protection system by using the digital relay together and the communication system. This is

considered as the best method for the overcurrent protection system with micro-grid mode because it can solve the mis-coordination of the protective devices such as false tripping and reduction in reach of distance relay. However, this solution is high cost.

[10, 2014] presented an efficient solution that can be applied and supports the micro-grid mode. A special digital relay, called Micro-grid Protection Relay (MPR), is used instead of a traditional digital relay. This Micro-grid Protection Relay is more complicated and can be applied to the grid-connected mode and islanding mode without any protection mode swathing. Such relay usually consists of five modules, namely, 1) direction module, 2) Islanded module, 3) grid-connected module, 4) interface module, and 5) tripping module.

From the review, it is found that there are two schemes of method among the literatures, as shown in Figure 2.6.

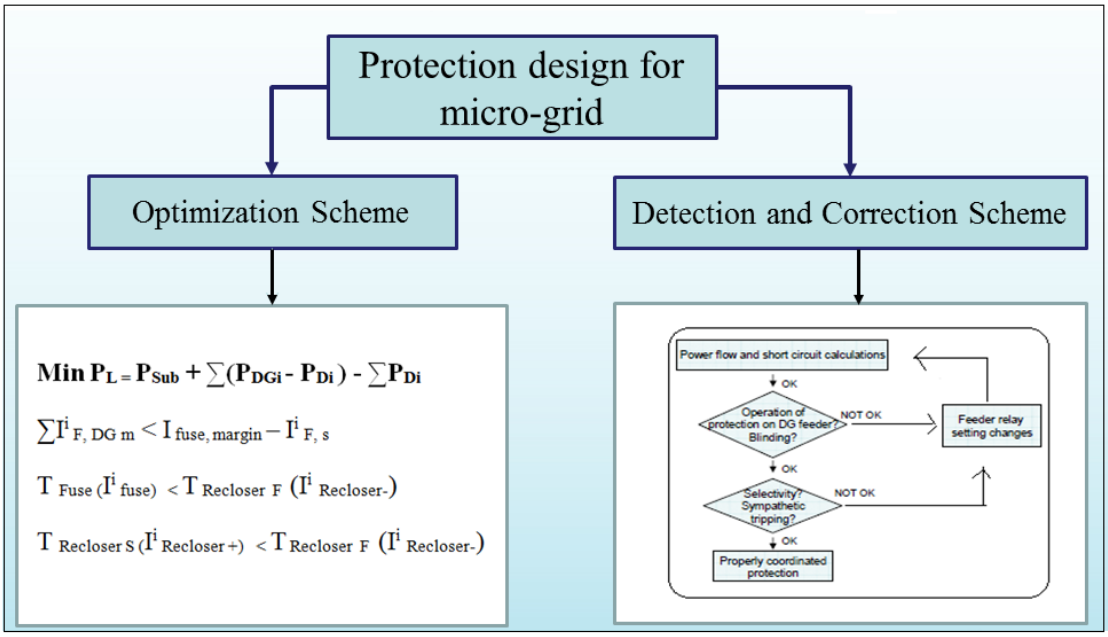


Figure 2.6 Protection design for micro-grid

Figure 2.6 shows two schemes, which are an optimization scheme and a detection and correction scheme.

1. Optimization scheme [9, 14, 17] is based on a formulation of conditions affecting system performance and protection coordination as an optimization problem

(i.e. a cost function and constraints). This scheme is usually applied to a new system whose components, such as DGs' location, can be changed.

2. Detection and correction scheme [6, 8-11, 13, 17, 19] is based on a modification of protection system (i.e. protection scheme or protection setting) to correct the mis-coordination problem. The coordination of the protection will be re-checked whenever the power system is modified, such as an addition of DG; and the correction measures will be applied if the mis-coordination is detected.

The research [23] introduces a framework for designing the overcurrent protection system connected with DG according to the detection and correction scheme, see Figure. 2.7.

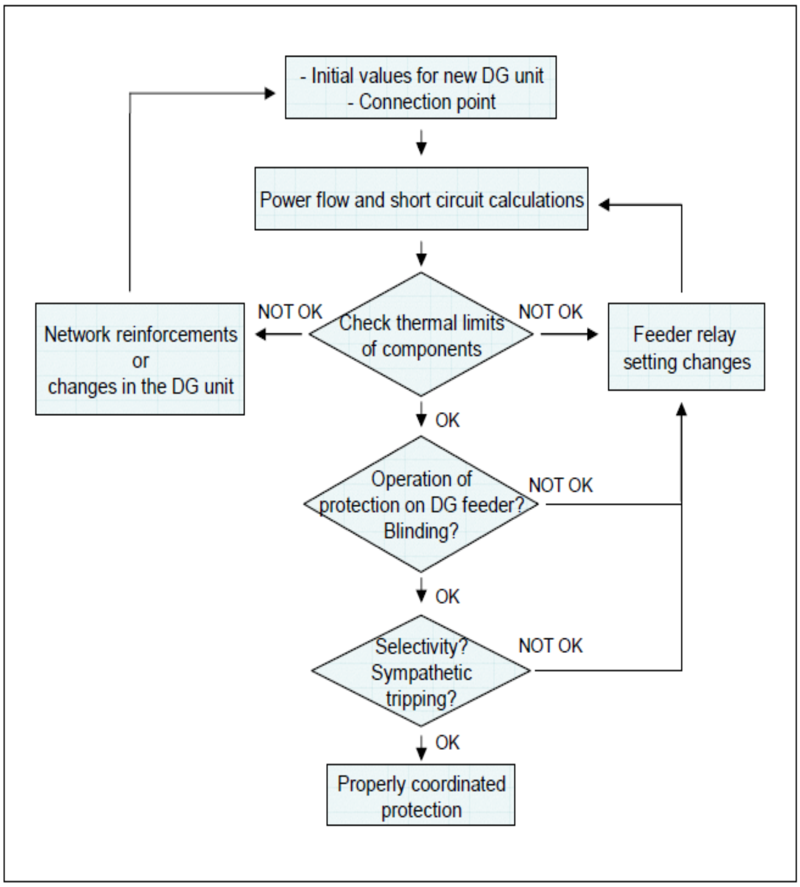


Figure 2.7 Show the design framework for distributed systems that are installed DG [23]

Actually, this framework begins with a protection system design for a system without DG connection (not shown in this figure). Next, after DG is added, a power flow and fault current are re-calculated. The thermal limits are then checked before protection mis-coordination concern. After that, the blinding and the false tripping (or Sympathetic tripping) will be investigated. If the blinding of protection is detected, the relay parameter (e.g. pickup current) will be adjusted to eliminate the blinding of protection. Further, if the selectivity or false tripping problem is found, the relay parameter (e.g. time dial) will be adjusted until the false tripping is completely eliminated.

It can be seen that the framework presented in Figure. 2.7 can be applied as the guideline for designing the protection system of a distribution system with DG connection. In this research, the guideline obtained from Figure. 2.7 is applied together with other aforementioned related researches to design the overcurrent protection system in the distribution system in Mae SaRiang District to achieve the micro-grid mode.

CHAPTER III
DESIGN OF OVERCURRENT PROTECTION FOR MICRO-GRID SYSTEM

3.1 Introduction

This chapter presents the design of overcurrent protection system for micro-grid. The design is adopt from the guidance in the previous chapters. There are four main steps as follows.

Step 1: Determine a base case of the micro grid system.

Step 2: Design the protection system for the base case.

Step 3: Determine the feasible scenarios of the base case system, e.g. additional DG connections and islanding operations.

Step 4: Detect the mis-coordination problems related to the blinding of protection and false tripping of the first scenario from Step 3:

- If a problem is detected, the protection system should be adjusted and repeat Step 4 until the final scenario.
- If not, go to the next scenario and repeat Step 4 until the final scenario**.**

The next section (Section 3.2) will present a protection system design for a traditional distribution system (a base case). In section 3.3, the determination of the possible scenarios that a base case could be operated or expanded in the future will be explained. Then, the detection of blinding and the detection of false tripping will be described in Section 3.4. Finally, Section 3.5 will state about the guidelines for adjusting the protection system to eliminate the blinding of protection and false tripping.

3.2 Determination of a Base Case for Micro-grid

The base case should be a fundamental part of the micro-grid system without DG connection. This choice of selection is to guarantee that a structure of the base case is similar to a traditional distribution system. Therefore, the knowledge about power system protection design could be applied.

For Mae Sarieng Microgrid, the base case is the part that shown in Figure 3.1. This base case consists of the overcurrent relay and the recloser given 2 overcurrent relays installed at the substation and 6 reclosers installed at the feeder.

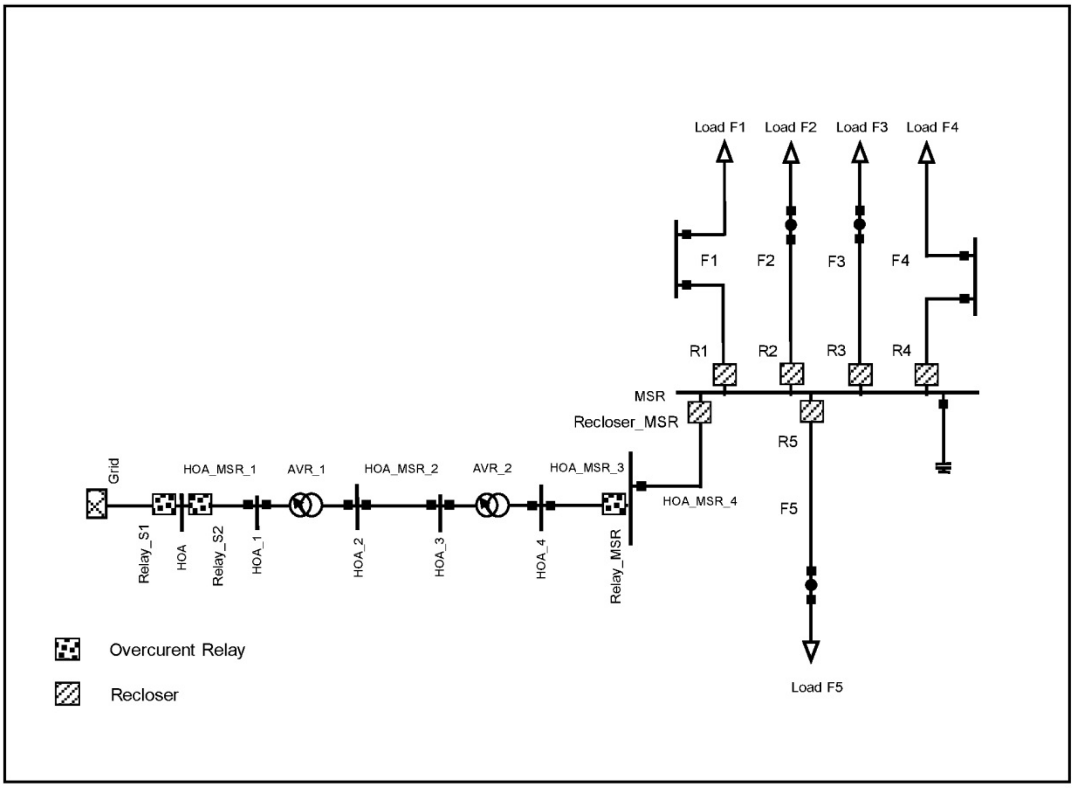


Figure 3.1 The base case system

3.3 Protection Design for a Traditional Distribution System

The structure of distribution system of PEA is radial. This structure is widely used due to the lowest cost. The protective devices normally installed to this system are a circuit breaker operated by relay, recloser and fuse as shown in Figure. 3.1

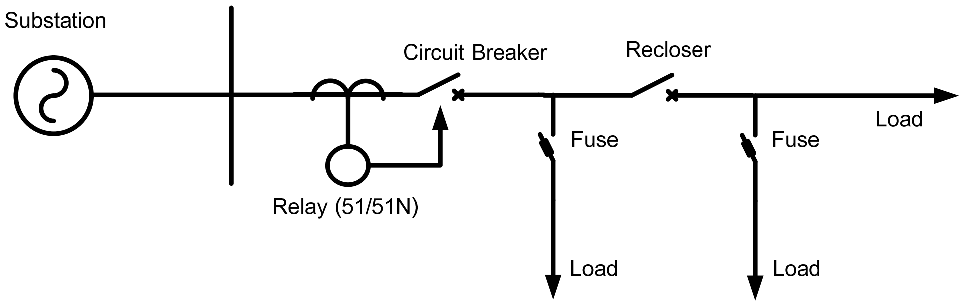


Figure 3.2 The structure of distribution system of PEA

The protection system shown in Figure 3.2 consists of the fuse that is used for a lateral protection. The recloser is installed at the significant section of the main feeder to detect and differentiate the temporary fault and permanent fault, to backup fuse and to improve the selectivity of the protection system. Finally, the whole feeder is backed up with the circuit breaker and relay at substation.

The recloser normally operates two times. The first time is based on its fast curve characteristic while the second time is based on its slow curve characteristic. When a fault is occurred at the far most lateral, the recloser will disconnect the circuit to determine whether the fault is temporary or permanent. In case of temporary fault, the system will be assumed. However, in case of permanent fault, the fuse will clear fault. If the fuse cannot clear fault, the recloser will trip with its slow curve characteristic instead. The relay will finally open circuit if the fuse and recloser cannot eliminate the fault. Figure. 3.3 exhibits the cooperation among relay, recloser and fuse.

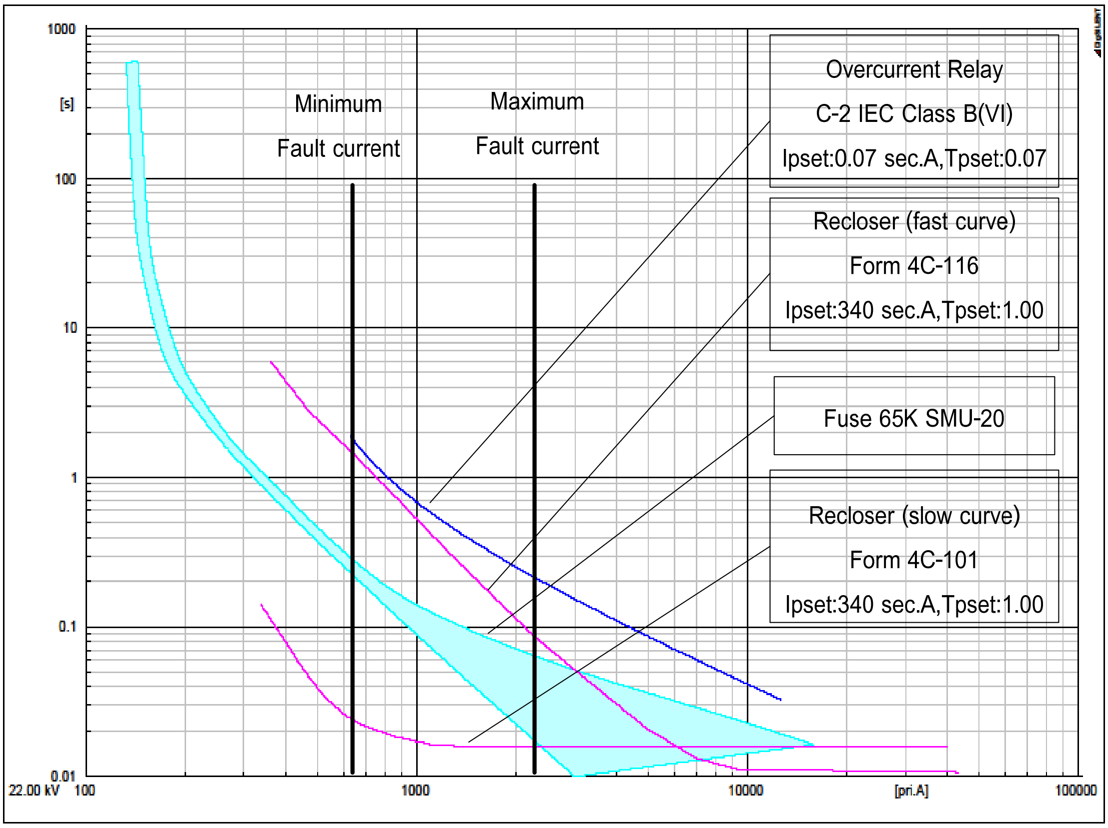


Figure 3.3 Relay, Recloser and Fuse Characteristic curves shows the coordination for a traditional distribution system [2]

3.4 Determination of Feasible Scenarios for the Base Case System

The feasible scenarios for the base case system are the feasible configurations, operations, and expansions that could be happen to fulfill the micro-grid system. These feasible scenarios are selected from all possible scenarios that are suitable to be operated. For example, the possible configurations that the system voltage profiles comply with standard; or, the possible operations that theirs cost are minimum.

Mae Sarieng Micro-grid currently consists of three DGs which are a diesel power plant, a solar power plant, and a hydro power plant. In the near future, there will be a battery plant connection and a pump hydro power plant connection.

According to the base case in Section 3.2, the feasible scenarios that will fulfill Mae Sarieng Micro-grid are shown in the Table 3.1 and Table3.2

Table 3.1 Scenario in Grid-connected Mode

Scenario	Substation	DG				
		Diesel (4.4MW)	PV (4 MW)	Dam (0.5 MW)	Pump Hydro (2 MW)	Battery (3 MW)
1	√	√	-	-	-	√
2	√	√	-	√	-	√
3	√	√	√	-	-	√
4	√	√	√	√	-	√
5	√	√	-	√	√	√
6	√	√	√	-	√	√
7	√	√	√	√	√	√

Table 3.2 Scenario in Islanding Mode

Scenario	Substation	DG			
		Diesel (4.4 MW)	PV (4 MW)	Dam (0.5MW)	Battery (3 MW)
1	-	√	-	-	√
2	-	√	-	√	√
3	-	√	√	-	√
4	-	√	√	√	√
5	-	-	-	-	√

For the grid-connected mode, the feasible scenarios have been selected from the possible scenarios whose operating voltages of every bus are in ± 5% of the norminal voltage. The islanding operation depends on various factors with the fundamental consideration that the generation capacity must be higher than the load [22] whereas the accepted voltage is than ± 5% of the norminal voltage [1].

3.5 Detcetions of Blinding and of False Trippng

The detection of blinding and the detection of false tripping in this thesis are adapted from [8-9], [21]. The procedure of blinding detection and false tripping are detected respectively are as follows:

Step 1: The fault currents of all feeders are calculated with IEC 60909 method.

Step 2: Compare the fault current obtained from the Step 1 with the corresponding relay. If the pickup current is less than the fault current, the blinding of protection is detected.

Step 3: The false tripping will be detected using a comparison of the operating time calculated with Equation (1). If the operating time of relay or recloser near the fault is slower than the operating time of relay or recloser on other positions, the false tripping is detected.

$$t = TMS \frac{0.14}{\left(\left(\frac{I_{SC}}{I_{Pickup}} \right)^{0.02} - 1 \right)} \qquad (1)$$

Where t = Operating time, second

TMS = Time Multiplier Setting of Relay

I_{SC}= fault current (A)

I_{Pickup}= Pickup current (A)

3.6 Solutions of Blinding and False Tripping

When the blinding is detected, the parameter of the overcurrent protective devices will be adjusted in accord with Figure.3.4 After all problems of blinding of protection are eliminated, the false tripping will be detected further. When the false tripping is detected, the parameter of the overcurrent protective devices will be adjusted like that of blinding.

If it cannot resolve the false tripping, the protection scheme has to be modified. For example, a direction unit could be added.

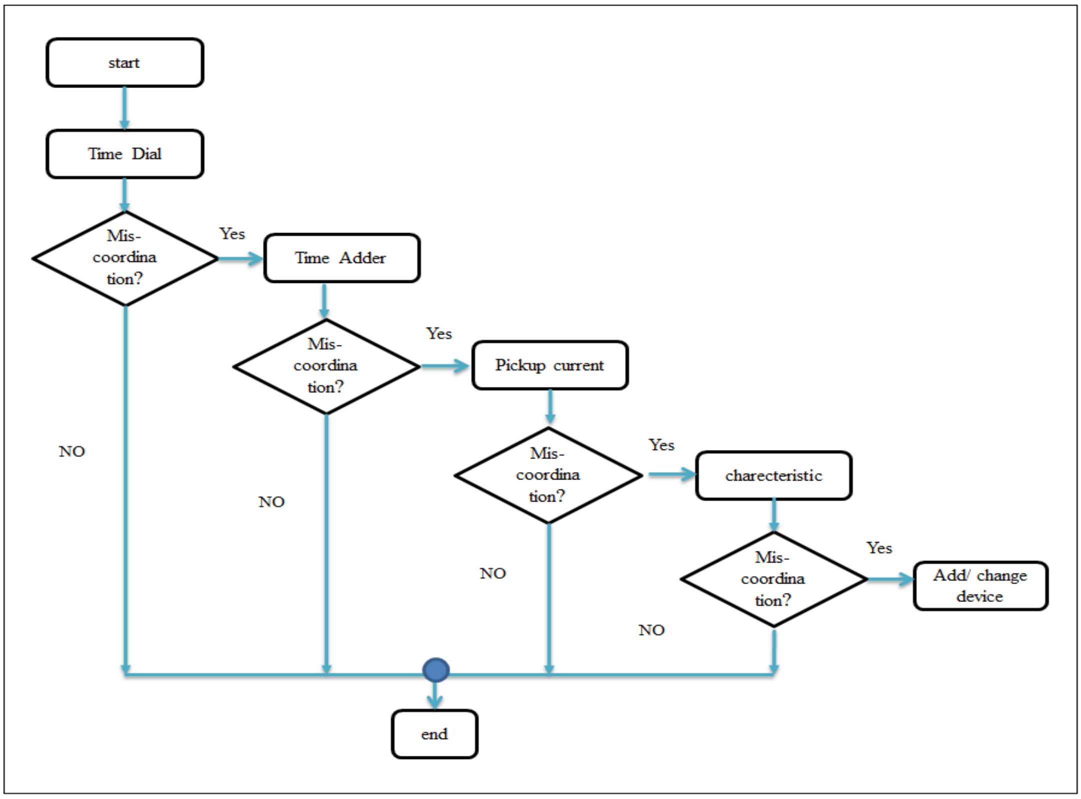


Figure 3.4 Flow chart shows the adjusted parameters in the Recloser/ Relay.

From the flowchart in Figure. 3.4, the time dial is first adjusted as it is the fundamental parameter of the relay and recloser. If the time dial is adjusted but the margin time is not improved or the devices still work wrongly, the time adder should be adjusted followed by the pickup current, respectively. If the problem cannot be still solved, the characteristics of the devices will be finally adjusted. If the error still exists, the scheme of the protection system will be changed from recloser to overcurrent relay and direction overcurrent relay, respectively.

CHAPTER IV
MODELING AND SIMULATION RESULTS

4.1 Introduction

This chapter will apply the method mentioned in the previous chapter to design an overcurrent protection of Mae Sariang Micro-grid system. The mathematical model of Mae Sariang Micro-grid system in DIgSILENT PowerFactory is obtained from the Provincial Electricity Authority of Thailand (PEA). The procedure for the design is summarized in Figure 4.1.

The procedure begins with the protection system design of the base case. After that the base case will be modified scenario by scenario towards the expected final system. For each scenario, the coordination of protective devices will be evaluated. During the evaluated, a fault current is simulated by using both IEC 60909 method and Electromechanical Transients method in DIgSILENT PowerFactory. The fault simulation happens at the position of 50% in every feeder with three types of fault, i.e. 2 phase, 3phase and single phase to ground. After the evaluated, if the protective device has a mis-coordination, there will be a primary correction by modifying parameter values of the protective device. Then, the evaluated will be repeated and retraced to all the precedent scenarios to ensure that the re-design of the protection system is functional.

This chapter is organized as follows. Section 4.2 mentions a model of Mae Sariang micro-grid system used in DIgSILENT PowerFactory. Section 4.3 will describe the scenarios and the design of protection for the base case. In section 4.4, the results of the protection design for the scenarios related to a grid connected mode will be explained. Finally, in section 4.5, the results of the final design of protection will be evaluated with the scenarios related to an islanding mode will be explained.

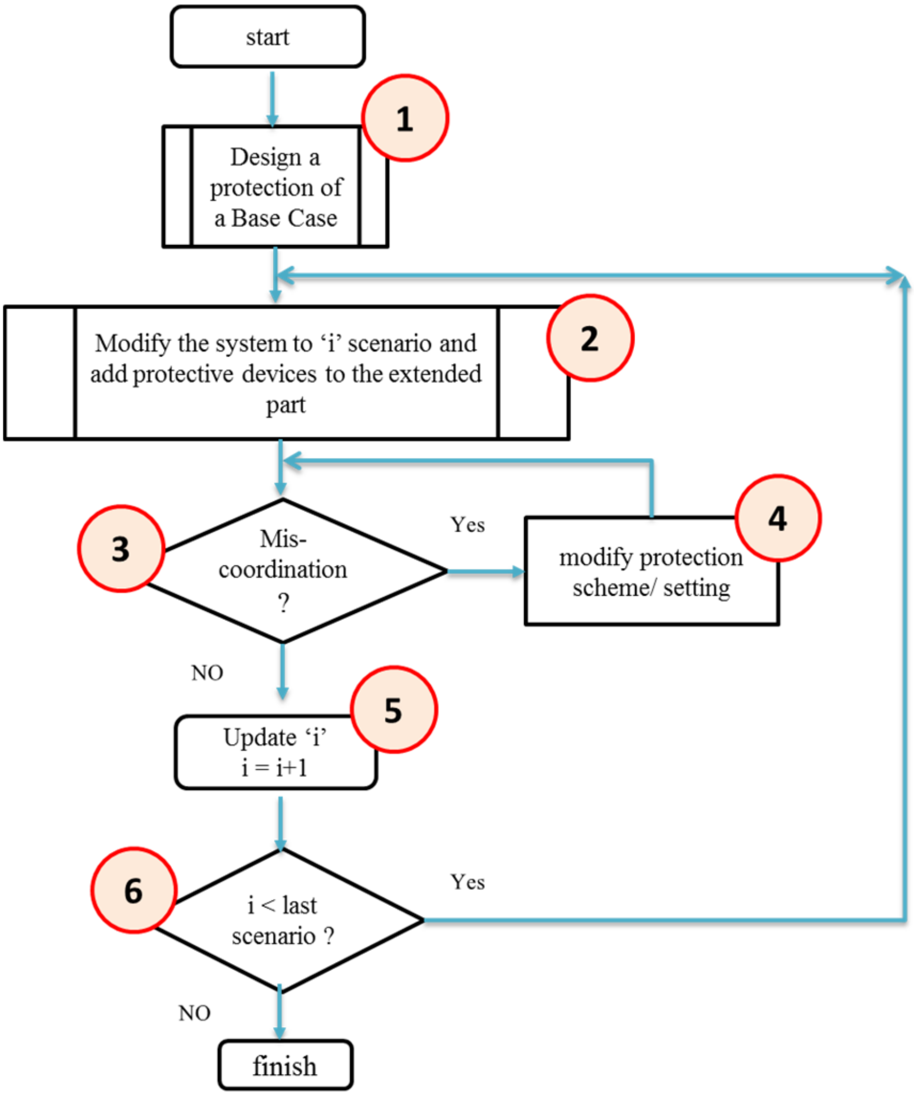


Figure 4.1 Flowchart summarizes the procedure of protection design mentioned in Chapter 3

4.2 Model of Mae Sariang Micro-grid System

The distribution system in Mae Sariang district is a radial system with voltage of 22 kV containing 14 Feeders and 2 - AVR transformers. At present, the system includes three distributed generations (DGs), i.e. Diesel generator, PV generator and Dam generator. In future, PEA needs to expand the system by adding Pump hydro and Energy storage into the system to meet the increasing needs of electricity uses, and the need that the system can operate in islanding mode as in Figure 4.2.

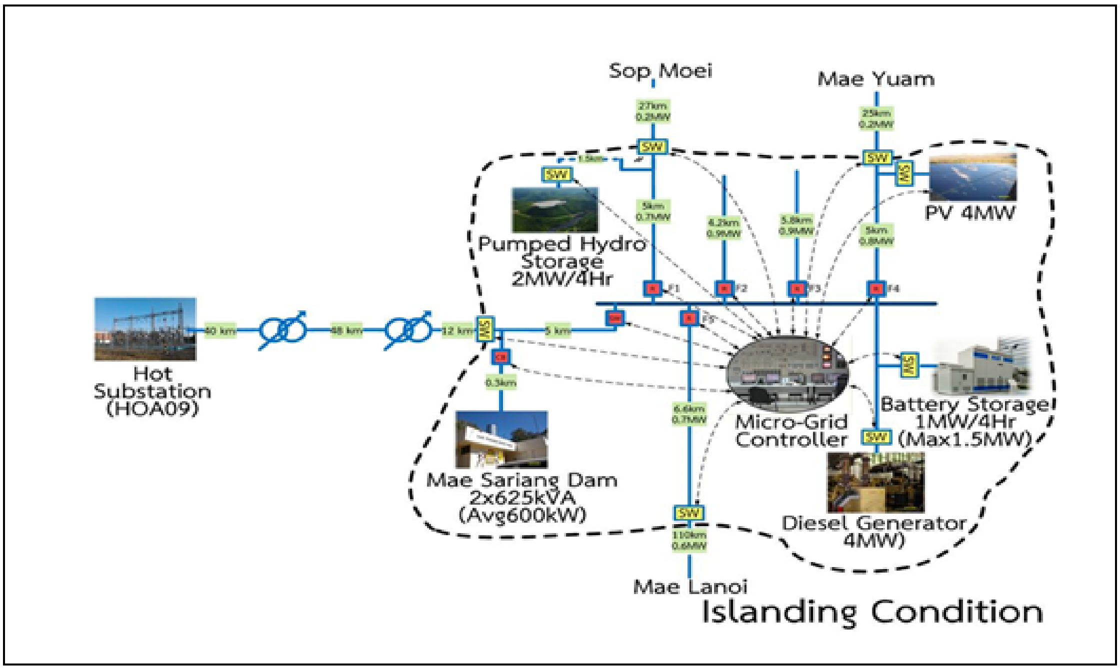


Figure 4.2 Mae Sariang Micro-grid System

4.3 Scenarios and Design of Protection for Base Case

To apply our method of overcurrent protection design, the system must be decomposed into series of scenarios. For Mae Sariang micro-grid, it can be decomposed into twelve scenarios. These twelve scenarios can be further divided into two groups, which are a group related to grid connected mode and a group related to islanding mode, as shown in Figure 4.3

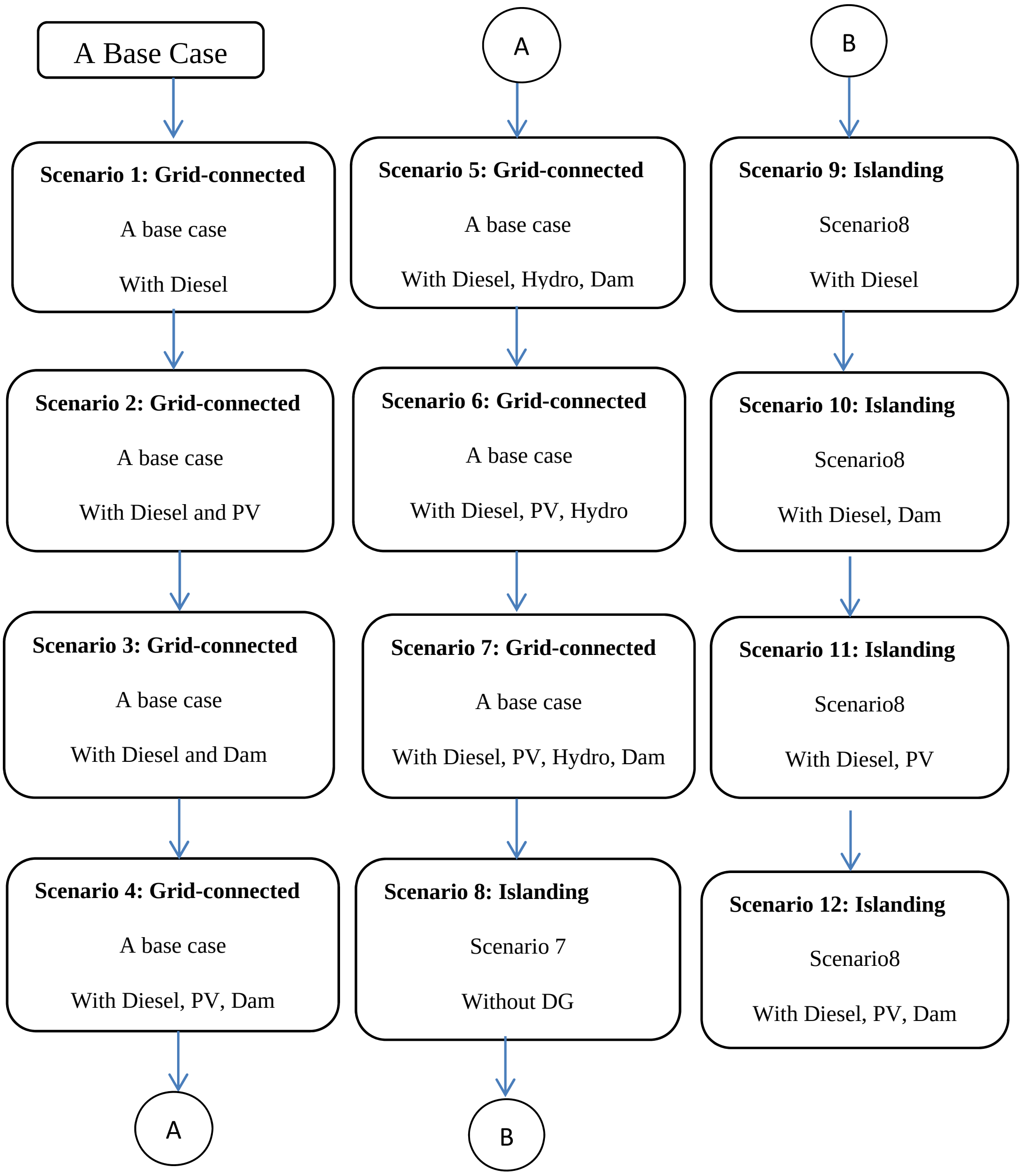


Figure 4.3 Group related to grid connected and islanding mode

The scenarios have been determined in the way that the next scenario has some improvements from its precedent scenario, such as a system expansion or a system re-configuration. For example, as seen from Figure 4.3, the scenario1 is expanded from the base case by installing the additional Diesel Generator at MSR_busbar.

However, the overcurrent protection will be firstly designed for only the base case. The overcurrent protection of the base case in Mae Sariang District contains the overcurrent relay and the recloser. Two overcurrent relays are installed at the substation and six reclosers are installed at the feeders as in Figure 4.4

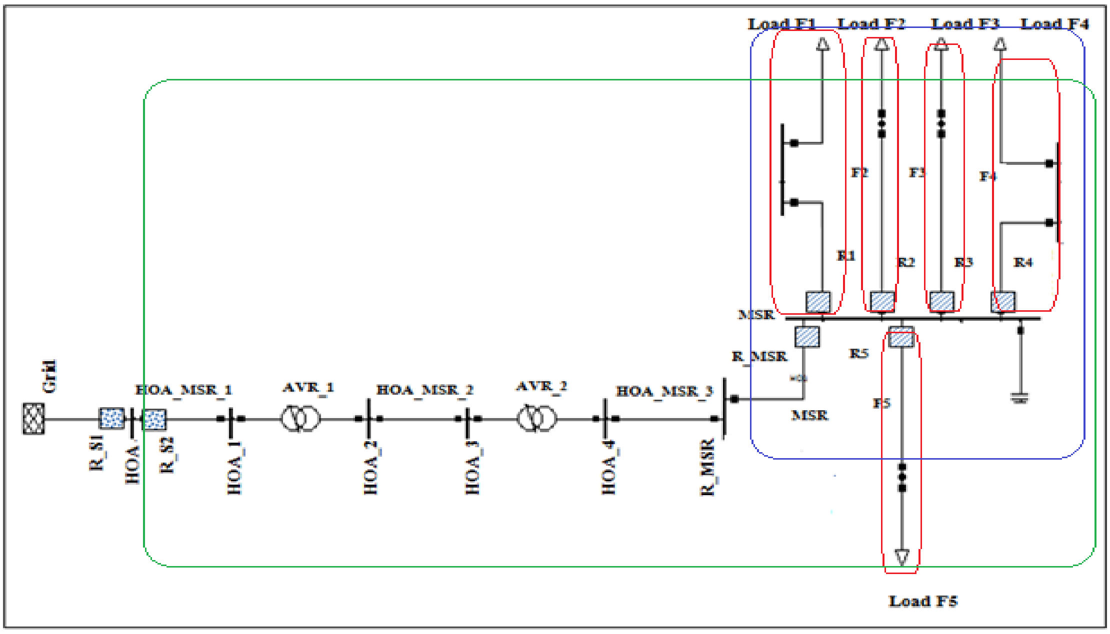


Figure 4.4 The Base Case system

Design of overcurrent protection of this base case begins with load flow and fault calculation (by using tools in DIgSILENT PowerFactory). The maximum and minimum values of fault current of each feeders are collected. Then, these values are used in the calculation of the pickup current of the reclosers; while the other parameters of the reclosers are set according a typical value obtained from [23]. This results in the parameters of the protective devices as shown in Table4.1

Table 4.1 Parameter of protective devices in the Base Case system

devices	Setting				
	Load current (Amp.)	**Pickup current (Amp.)**	**Time Dial**	**Time adder**	**characteristics**
Recloser_1	26	135	1	0	4C-101
Recloser_2	24	125	1	0	4C-101
Recloser_3	25	130	1	0	4C-101
Recloser_4	27	140	1	0	4C-101
Recloser_5	34	185	1	0	4C-101
Recloser_MSR	125	250	1	0	4C-101
Relay_S1	138	420	0.10	-	Extremely inverse
Relay_S2	138	350	0.05	-	Normally inverse

*__Relay_S1__: Overcurrent Relay1 at substation, Relay**_S2**: Overcurrent Relay2 at substation

To validate the coordination of the protection system, the fault are applied to various location of the system and the operating times of related protective devices, according to the zone of protection defined in Figure 4.5, are compared.

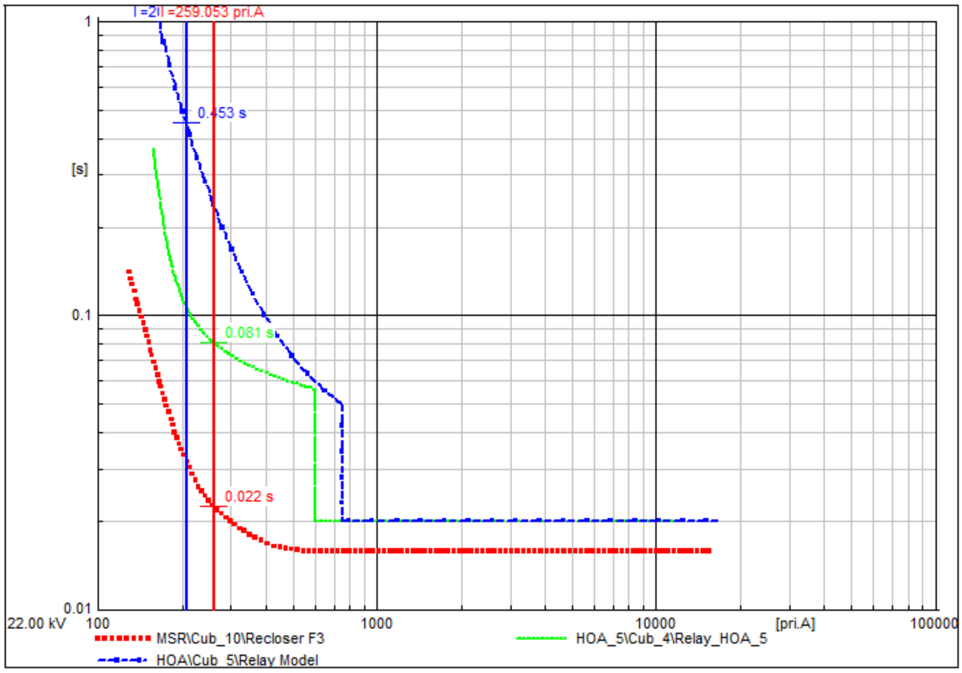


Figure 4.5 Characteristic curves of the protective devices show their operating times when there is a fault at F3 feeder

Figure 4.5 shows a sample of coordination among the protective devices when there is fault in the Feeder 3. It shows that the reclosers at Feeder 3 functions as the primary protection and operate at 0.022 s. Relay_HOA_5 functions as a backup protection and operates at 0.071 s. Finally, relay at the substation operates at 0.452s. This comparison shows a successful coordination. For other protective devices, the results are shown in Table 4.2.

Table 4.2 Operating time of protective devices of base case with IEC 60909 method

Fault location	Fault type	Main protection		Backup protection	
		Prot. Device	Opr. Time(s)	Prot. Device	Opr. Time(s)
HOA_MSR_1	SLG	Relay_S2	0.020	-	-
HOA_MSR_2	SLG	Relay_S2	0.125	-	-
HOA_MSR_3	SLG	Relay_S2	0.255	-	-
HOA_MSR_4	SLG	Relay_S2	0.382	-	-
F1	SLG	Recloser 1	0.023	Recloser_MSR Relay_S2	0.167 0.448
F2	SLG	Recloser 2	0.021	Recloser_MSR Relay_S2	0.164 0.442
F3	SLG	Recloser 3	0.022	Recloser_MSR Relay_S2	0.071 0.453
F4	SLG	Recloser 4	0.024	Recloser_MSR Relay_S2	0.156 0.420
F5	SLG	Recloser 5	0.026	Recloser_MSR Relay_HOA_5	0.171 0.459

*SLG: Single phase to ground fault

Table 4.2 summarizes the operating time of related protective devices for each fault location. The related protective devices are divided into main and backup protections. As seen in the table, there is no backup protection acting faster than main protection. Therefore, for this base case, all protective devices are working properly.

4.4 imulations of Grid-connected Mode

4.4.1 Scenario 1

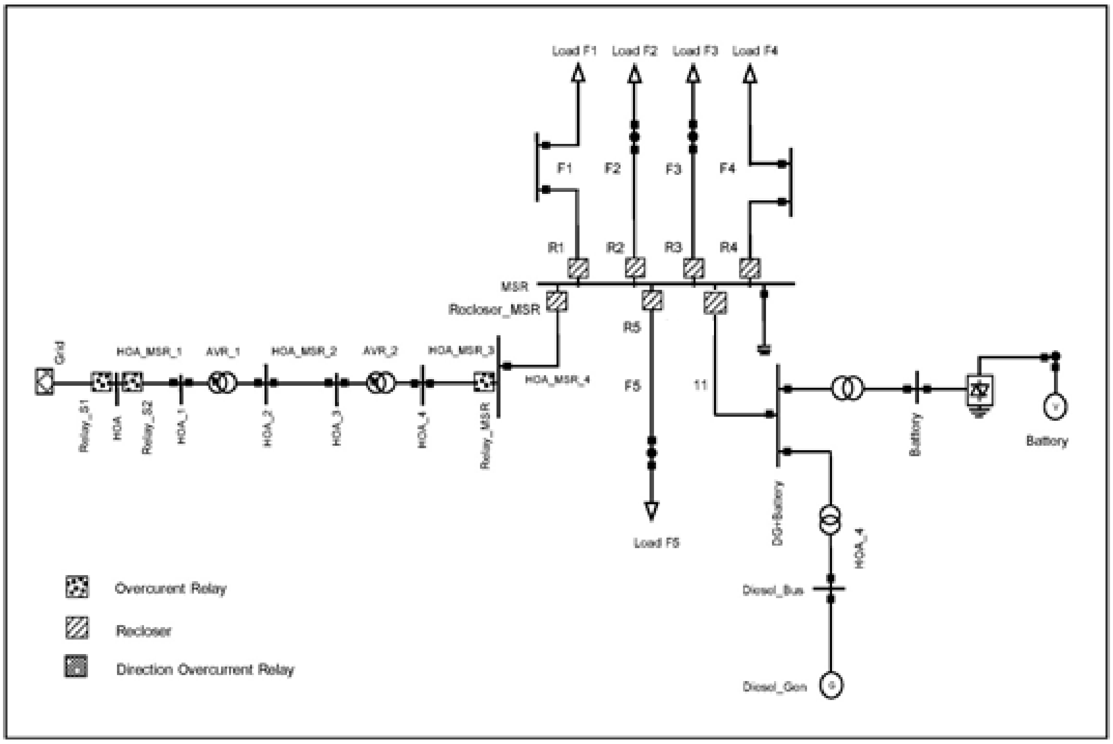


Figure 4.6 The scenario1 system

The scenario is consist: Grid Load 3.6 MW

Diesel Generator 4 MW

Consumers Load 9.6 MW

Battery 2 MW

In scenario1, a diesel Generator and an expansion circuit have been added to the base case scenario. The rescloser has been added at Feeder 11 and the relay has been added at bus HOA_MSR_5. These additions of protective devices are consistent to the operation plan of the PEA. The parameters of these protective devices have been set through the normal method used in the protection system design of a traditional distribution system.

That is a using of calculated minimum and maximum values of fault current determines a pickup current and an operating time. Then, the protection system in Scenario1 is evaluated to find blinding of protection and false tripping (according to Step 3 in Figure 4.1).

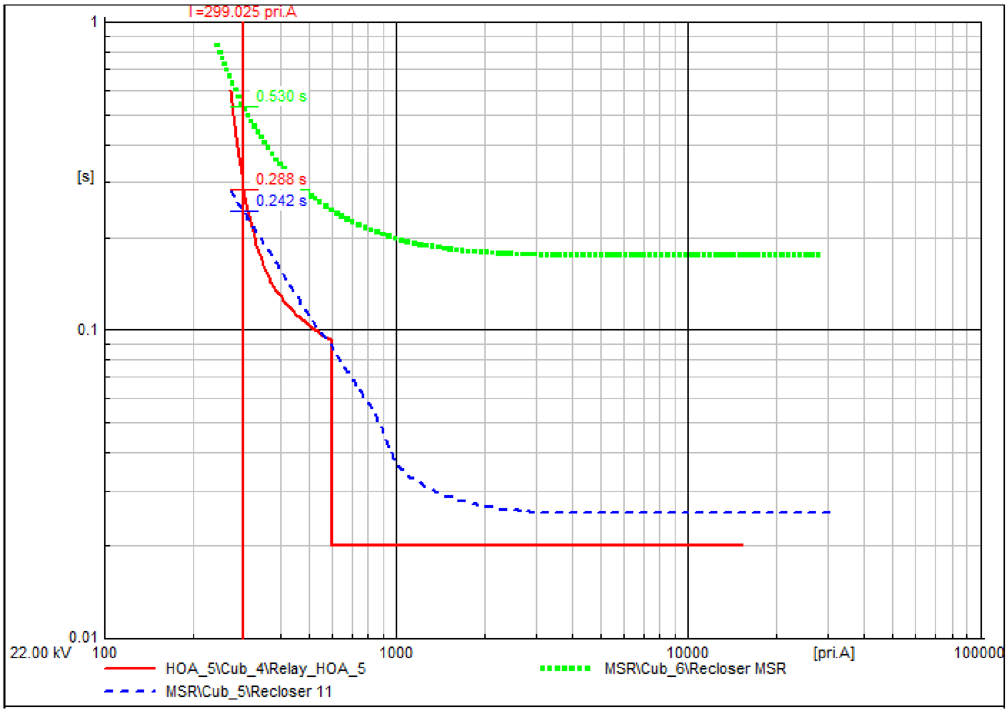


Figure 4.7 Characteristic curves of the protective devices show their operating times when there is a fault at HOA_MSR_2

Figure 4.7 shows characteristic curves of the protective devices to be operated when there is a fault at the feeder HOA_MSR_2. It is found that the recloser at Feeder 11 operates within 0.242s and this operation is faster than that of the relay in the substation and the Relay_HOA_5, which function as the primary protection.

This is because there is a fault current from the diesel generator which make the recloser operation fail. This mis-coordination may be considered as the false tripping; and, the correction according to guideline mentioned in chapter 3 is then applied.

After modifying "Time dial" and re-checking, the problem of false tripping is still detected. Therefore, "Time Adder" is modified and re-checking, still the problem cannot be solved. Further, the pickup current is modified; still problem is unsolved. Finally, modification of characteristic curve has been made; still the problem exists. The final decision is to modify a protection scheme rather than parameters of protective device.

The first attempt is on changing recloser at Feeder 11 into the overcurrent relay. After re-checking a mis-coodination, the false tripping still exists even though the parameters of relay have been modified to many combinations.

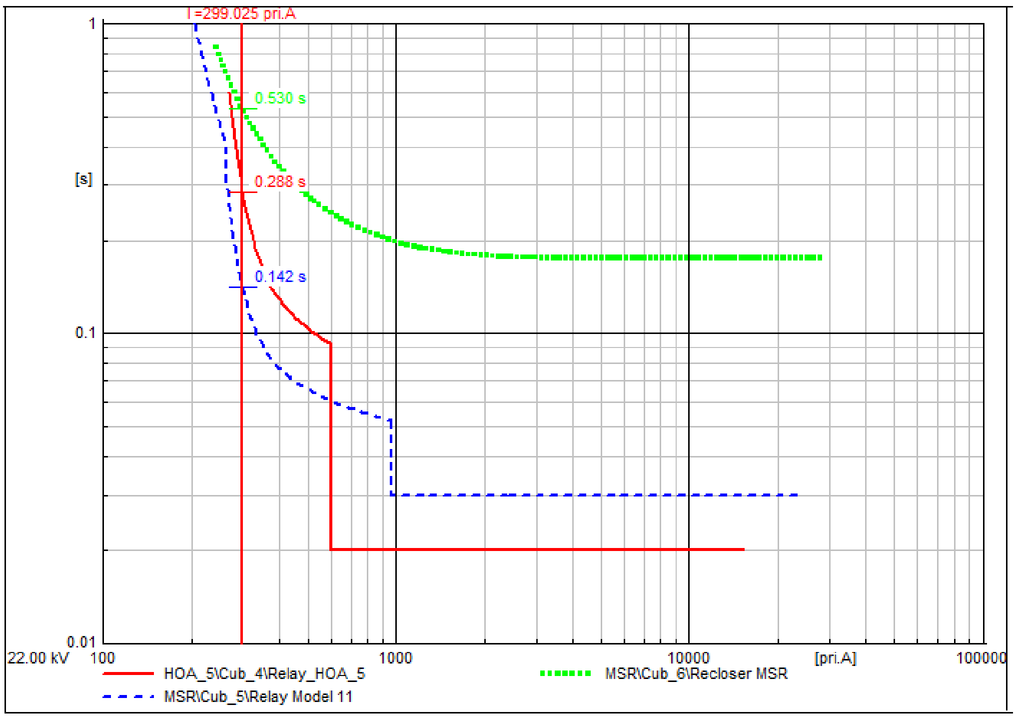


Figure 4.8 Characteristic curves of the protective devices show their operating times when there is a fault at HOA_MSR_2

Figure 4.8 shows that the Overcurrent Relay operates within 0.142s, which is faster than the Relay at the main protection. In addition to this zone of protection, it is found that other zones still face the problems of mis-coordination too. Table 4.3 shows the problems of mis-coordination between the Relay 11 and the Relay _HOA_5 when there are fault at feeders HOA_MSR_3 and HOA_MSR_4.

This is because there is possibly current flown through the overcurrent relay in bi-direction.

Table 4.3 Operating time of protective devices of scenario1 with IEC 60909 method

Fault location	Fault type	Main protection		Backup protection	
		Prot. Device	**Opr. Time(s)**	**Prot. Device**	**Opr. Time(s)**
HOA_MSR_1	SLG	Relay_S2	0.020	-	-
HOA_MSR_2	SLG	Relay_HOA_5	0.288	Recloser_MSR	0.530
				Relay 11	0.142
		Relay_S2	0.449	-	-
HOA_MSR_3	SLG	Relay_HOA_5	0.095	Recloser_MSR	0.552
				Relay 11	0.062
		Relay_S2	0.314	-	-
HOA_MSR_4	SLG	Recloser_MSR	0.073	Relay 11	0.055
		Relay_HOA_5	0.383	-	-

*Relay11: Overcurrent Relay 11

The next attempt at modifying protection scheme is to add a direction unit.

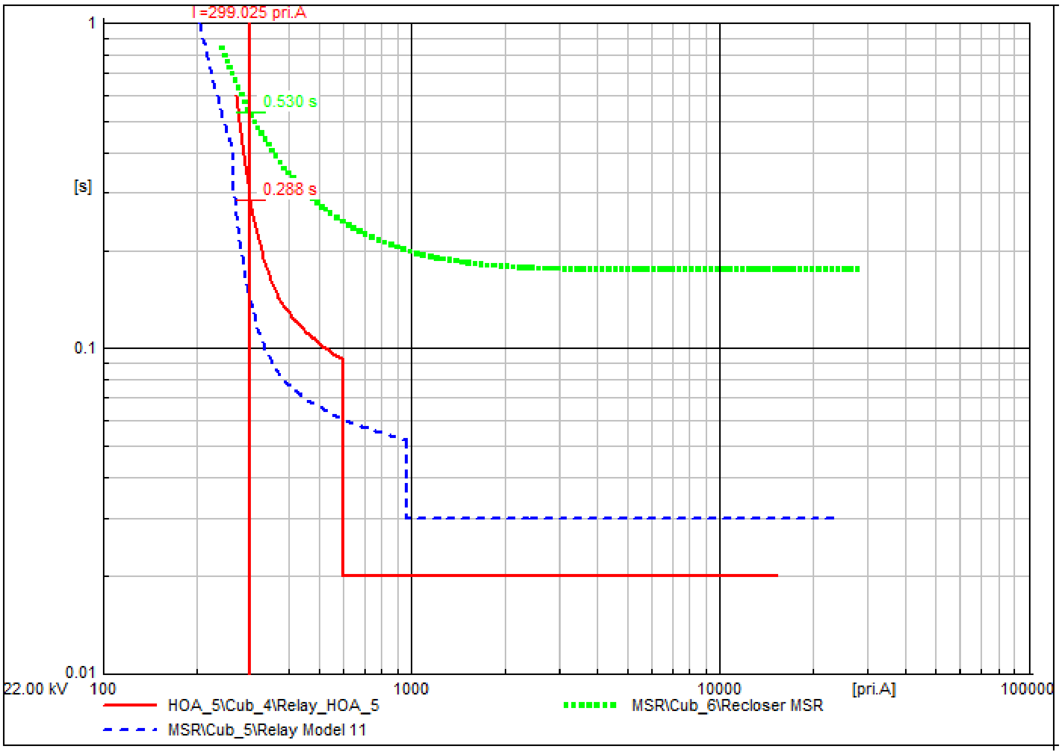


Figure 4.9 Characteristic curves of the protective devices show their operating times when there is a fault at HOA_MSR_2

Figure 4.9 shows that when there is fault in MSR_HOA_2 feeder, the direction overcurrent relay will not operate and no problem of false tripping is detected again. In addition, the protection system can operate correctly and there is no false tripping for other faults as well (see Table 4.4).

Table 4.4 Operating time of protective devices of scenario1 with IEC 60909 method

Fault location	Fault type	Main protection		Backup protection	
		Prot. Device	**Opr. Time(s)**	**Prot. Device**	**Opr. Time(s)**
HOA_MSR_1	SLG	Relay_S2	0.020	-	-
HOA_MSR_2	SLG	Relay_HOA_5	0.288	Recloser_MSR	0.530
		Relay_S2	0.449	-	-
HOA_MSR_3	SLG	Relay_HOA_5	0.095	Recloser_MSR	0.552
HOA_MSR_4	SLG	Recloser_MSR	0.221	-	-
		Relay_HOA_5	0.383	-	-
F1	SLG	Recloser 1	0.175	Recloser_MSR	0.771
F2	SLG	Recloser 2	0.016	Recloser_MSR	0.742
F3	SLG	Recloser 3	0.016	Recloser_MSR	0.802
F4	SLG	Recloser 4	0.160	Recloser_MSR	0.633
F5	SLG	Recloser 5	0.016	Recloser_MSR	0.833
11	SLG	Relay 11	0.197	Recloser_MSR	0.605
		Diesel	NA	-	-

*Recloser 1:R1, Recloser 2:R2

Table 4.4 summarizes the operating time of related protective devices for each fault location. The related protective devices are divided into main and backup protections. From the table, there is no backup protection acting faster than main protection. In this thesis, the study does not concern a DG-side protection; so its device and its operating time are shown as "NA" for the last row. However, if the DG-side protection is installed, it will definitely operate to stop a current flowing from the DG to the fault at Feeder 11. Therefore, for this scenario, all protective devices are working properly.

In conclusion, for the scenario1, the Recloser 11 is changed to the direction overcurrent relay (as shown in Figure 4.10). The final parameters of the protective devices after the correction process are given in the Table 4.5

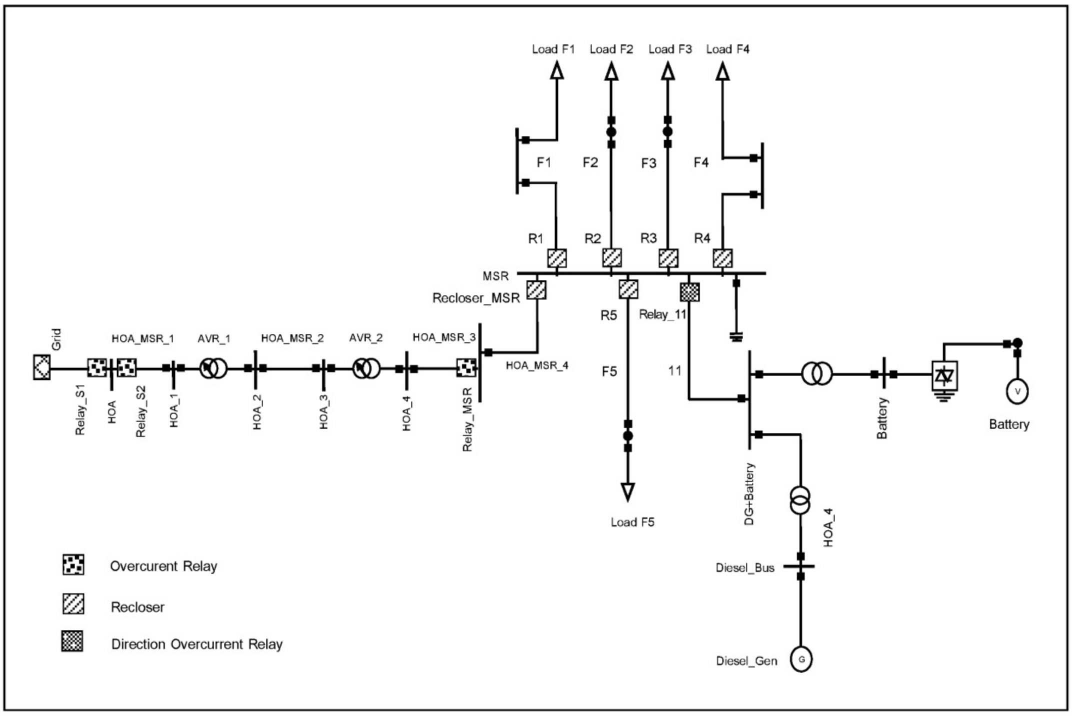


Figure 4.10 The scenario 1 system after modify protective devices

Table 4.5 Parameter of protective devices in the scenario1 system

devices	Setting				
	Load current (Amp.)	**Pickup current (Amp.)**	**Time Dial**	**Time adder**	**characteristics**
Recloser_1	48	135	1.55	0.15	4C-103
Recloser_2	44	125	1	0	4C-101
Recloser_3	46	130	1	0	4C-101
Recloser_4	50	350	1.70	0.10	4C-103
Recloser_5	63	185	1	0	4C-101
Recloser_MSR	146	240	1.80	0.15	4C-103
Relay_S1	156	600	0.10	-	Extremely inverse
Relay_S2	156	300	0.06	-	Normally inverse
Relay_HOA_5	146	246	0.10	-	IAC inverse
DOC Relay 11	117	240	0.05	-	IAC inverse

*DOC Relay 11: Direction Overcurrent relay at feeder 11

4.4.2. Scenario 2

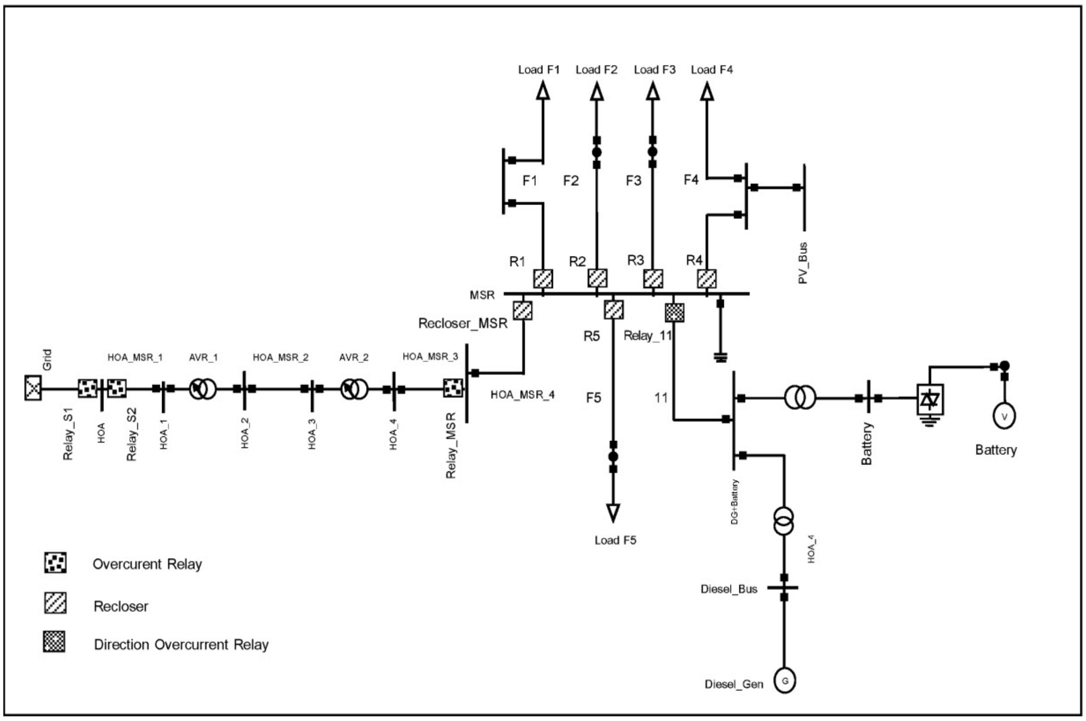


Figure 4.11 The scenario2 system

The scenario is consist: Grid Load 0.36 MW
Diesel Generator 4 MW
Battery 2 MW
PV 4 MW
Consumers Load 9.6 MW

In scenario 2, the scenario 1 system will be modified according to the changes above mentioned. For the existing protective devices, their parameters are adopted from the previous section. Then, the mis-coordination is evaluated.

If a mis-coordination of protection system is found, the solutions as mentioned in Chapter 3 will be implemented. After successfully solving the problem in the scenario 2, the mis-coordination of protection system of scenario 1 will be rechecked. This is to guarantee that the current parameters of protective devices could be work properly to the protection system of scenario 1.

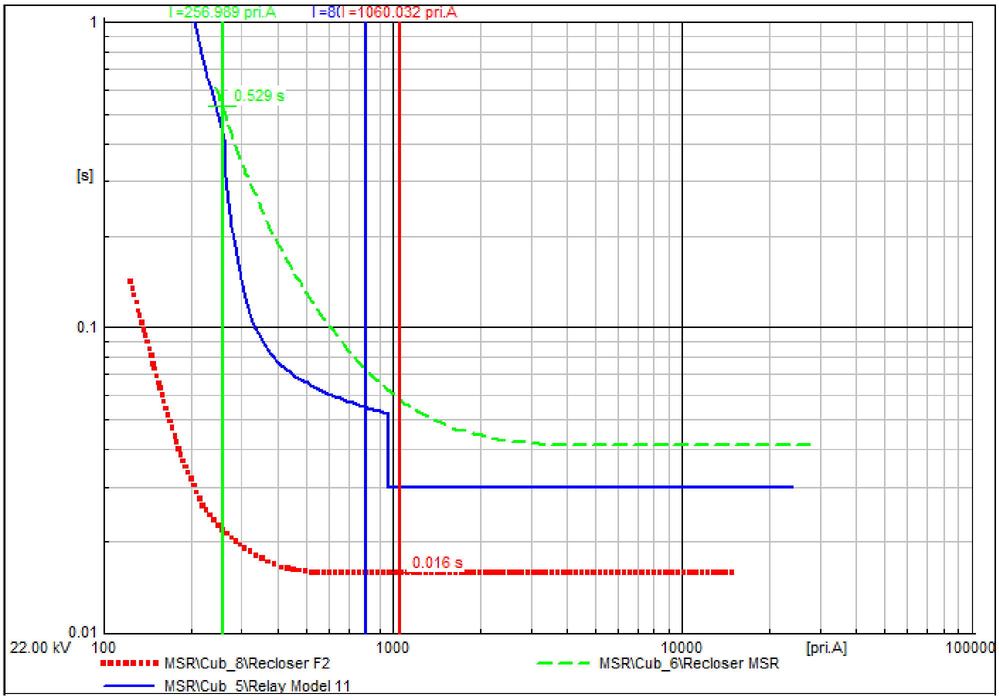


Figure 4.12 Characteristic curves of the protective devices show their operating times when there is a fault at F2 feeder

Figure 4.12 shows a sample of coordination of the overcurrent protection during a fault at F2 feeder. The graph shows that the recloser at F2 feeder, as a primary protection, operates faster than the Recloser_ MSR (as a backup protection). Moreover, the figure also shows that the overcurrent relay does not operate. This result shows the correct operation of the protection for the fault at bus 2. For other faults, the results are summarized in Table 4.6. These results show that no problem of coordination is detected.

Table 4.6 Operating time of protective devices of scenario2 with IEC 60909 method

Fault location	**Fault type**	**Main protection**		**Backup protection**	
		Prot. Device	**Opr. Time(s)**	**Prot. Device**	**Opr. Time(s)**
HOA_MSR_1	SLG	Relay_S2	0.020	-	-
HOA_MSR_2	SLG	Relay_HOA_5	0.288	Recloser_MSR	0.530
		Relay_S2	0.449	-	-
HOA_MSR_3	SLG	Relay_HOA_5	0.095	Recloser_MSR	0.552
HOA_MSR_4	SLG	Recloser_MSR	0.221	-	-
		Relay_HOA_5	0.383	-	-
F1	SLG	Recloser 1	0.175	Recloser_MSR	0.771
F2	SLG	Recloser 2	0.016	Recloser_MSR	0.742
F3	SLG	Recloser 3	0.016	Recloser_MSR	0.802
F4	SLG	Recloser 4	0.160	Recloser_MSR	0.633
		PV	NA		
F5	SLG	Recloser 5	0.016	Recloser_MSR	0.833
11	SLG	Relay 11	0.197	Recloser_MSR	0.605
		Diesel	NA	-	-

Table 4.6 summarizes the operating time of related protective devices for each fault location. The related protective devices are divided into main and backup protections. From the table, there is no backup protection acting faster than main protection. Again, this study does not concern the DG-side protection; so its device and its operating time are shown as “NA” for the last row. Therefore, for this scenario, all protective devices are working properly.

The final parameters of the protective devices after the correction process are given in the Table 4.7

Table 4.7 Parameter of protective devices in the scenario2 system

devices	Setting				
	Load current (Amp.)	**Pickup current (Amp.)**	**Time Dial**	**Time adder**	**characteristics**
Recloser_1	48	135	1.55	0.15	4C-103
Recloser_2	44	125	1	0	4C-101
Recloser_3	46	130	1	0	4C-101
Recloser_4	50	350	1.70	0.10	4C-103
Recloser_5	63	185	1	0	4C-101
Recloser_MSR	146	240	1.80	0.15	4C-103
Relay_S1	156	600	0.10	-	Extremely inverse
Relay_S2	156	300	0.06	-	Normally inverse
Relay_HOA_5	146	245	0.1	-	IAC inverse
DOC Relay 11	138	240	0.05	-	IAC inverse

4.4.3 Scenario 3

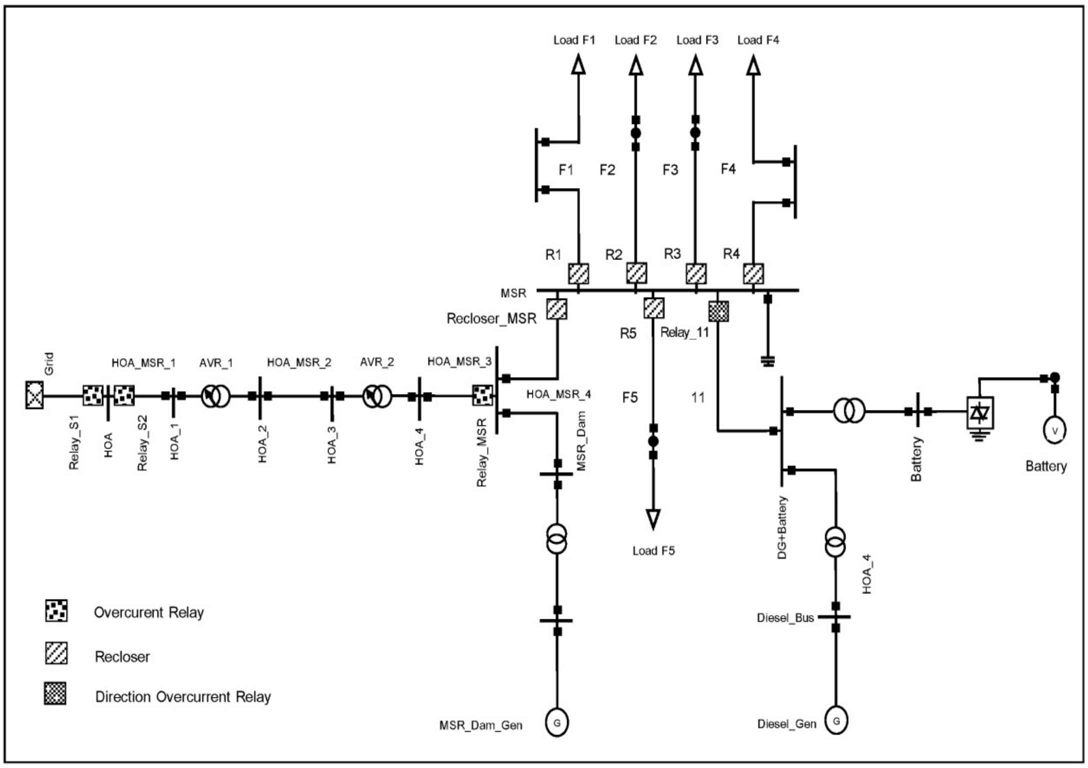


Figure 4.13 The scenario3 system

The scenario is consist: Grid Load 0.36 MW
Diesel Generator 4 MW
PV 4 MW
Battery 2 MW
Consumers Load 9.6 MW

In scenario 3, the scenario 2 system will be modified according to the changes above mentioned. For the existing protective devices, their parameters are adopted from the previous section. Then, the mis-coordination is evaluated. If a mis-coordination of protection system is found, the solutions as mentioned in Chapter 3 will be implemented. After successfully solving the problem in the scenario 3, the mis-coordination of protection system for the previous scenarios will be rechecked.

This is to guarantee that the current parameters of protective devices could be work properly to the protection system of the previous scenarios.

In this scenario, there is an addition of recloser at HOA_5 bus. This recloser is to improve reliability when there is a fault at MSR_Dam feeder. The load at Dam will be out of service for the fault if no recloser is added at HOA_5 bus.

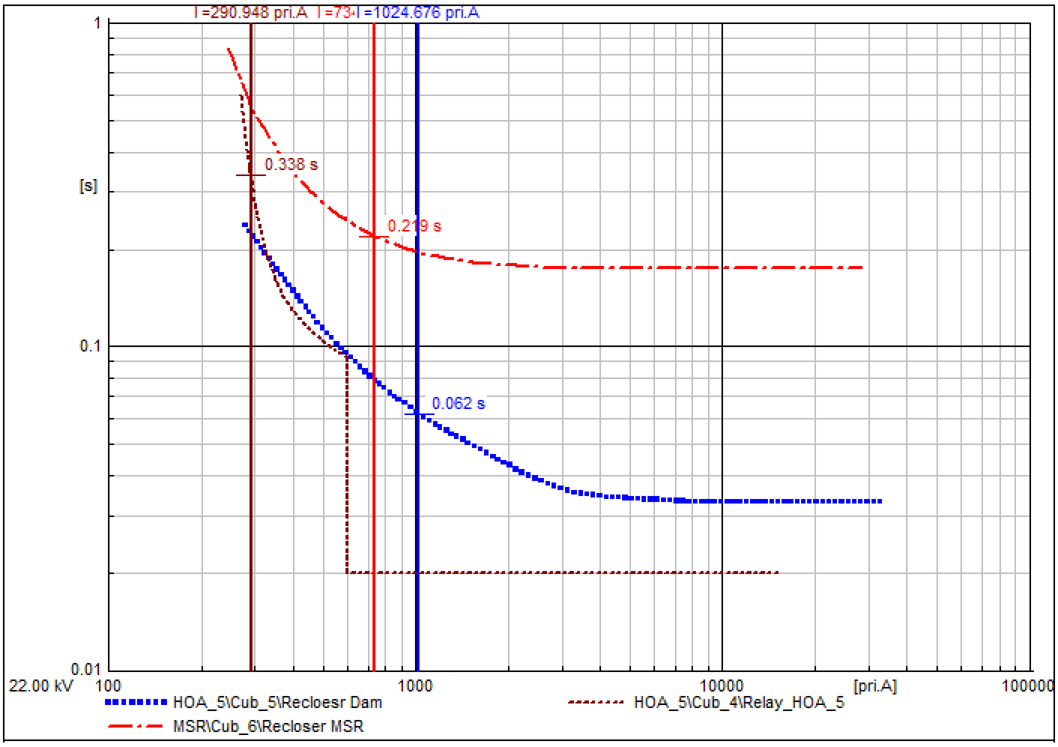


Figure 4.14 Characteristic curves of the protective devices show their operating times when there is a fault at MSR_Dam

Figure 4.12 shows that, when a fault occurred at MSR_Dam feeder, the operating times of Recloser_Dam, Relay_HOA_5, and Recloser_MSR will be 0.062s, 0.338s, and 0.219s, respectively. Recloser_Dam operates faster than the other protective devices; and it allows operations in other part of the system can normally distribute electricity.

In addition, when other zones have fault, the protective devices can coordinate accurately too as in Table 4.8

Table 4.8 Operating time of protective devices of scenario3 with IEC 60909 method

Fault location	**Fault type**	**Main protection**		**Backup protection**	
		Prot. Device	**Opr. Time(s)**	**Prot. Device**	**Opr. Time(s)**
HOA_MSR_1	SLG	Relay_S2	0.02	-	-
HOA_MSR_2	SLG	Relay_HOA_5	0.187	Recloser_MSR	0.739
		Relay_S2	0.459	-	-
HOA_MSR_3	SLG	Relay_HOA_5	0.002	Recloser_MSR	0.264
HOA_MSR_4	SLG	Recloser_MSR	0.211	-	-
		Relay_HOA_5	0.429	-	-
MSR_Dam	SLG	Recloser_Dam	0.062	Recloser_MSR	0.219
				Relay_HOA_5	0.338
		Dam	NA	-	-
F1	SLG	Recloser 1	0.174	Recloser_MSR	0.336
F2	SLG	Recloser 2	0.016	Recloser_MSR	0.329
F3	SLG	Recloser 3	0.016	Recloser_MSR	0.342
F4	SLG	Recloser 4	0.151	Recloser_MSR	0.305
F5	SLG	Recloser 5	0.016	Recloser_MSR	0.349
11	SLG	Relay 11	0.069	Recloser_MSR	0.300
				Relay_HOA_5	0.594
		Diesel	NA	-	-

Table 4.8 summarizes the operating time of related protective devices for each fault location. The related protective devices are divided into main and backup protections. From the table, there is no backup protection acting faster than main protection. Again, this study does not concern the DG-side protection; so its device and its operating time are shown as "NA" for the 9th row and the last row. Therefore, for this scenario, all protective devices are working properly.

The final parameters of the protective devices after the correction process are given in the Table 4.9

Table 4.9 Parameter of protective devices in the scenario3 system

devices	Setting				
	Load current (Amp.)	**Pickup current (Amp.)**	**Time Dial**	**Time adder**	**characteristics**
Recloser_1	48	135	1.55	0.15	4C-103
Recloser_2	44	125	1	0	4C-101
Recloser_3	46	130	1	0	4C-101
Recloser_4	50	350	1.70	0.10	4C-103
Recloser_5	63	185	1	0	4C-101
Recloser_Dam	23	270	0.3	0.03	4C-105
Recloser_MSR	146	240	1.80	0.15	4C-103
Relay_S1	156	600	0.10	-	Extremely inverse
Relay_S2	156	300	0.06	-	Normally inverse
Relay_HOA_5	146	246	0.10	-	IAC inverse
DOC Relay 11	116	240	0.05	-	IAC inverse

4.4.4. Scenario 4

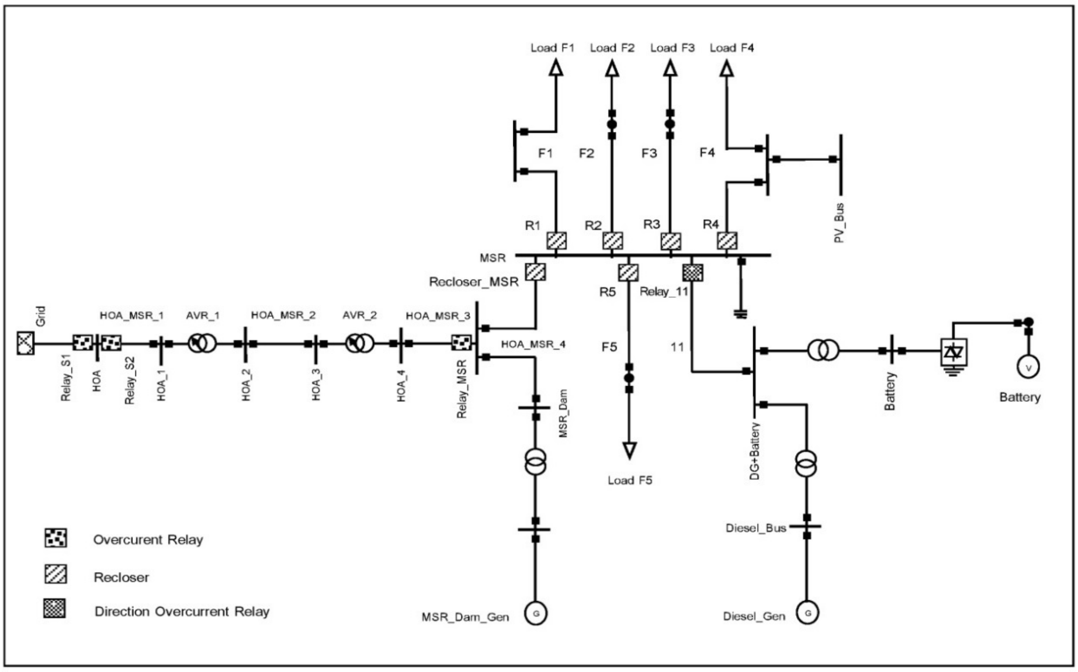


Figure 4.15 The scenario4 system

The scenario is consist: Grid Load 0.1 MW

Diesel Generator 4 MW

PV 4 MW

Battery 1MW

Dam 0.5 MW

Consumers Load 9.6 MW

In scenario 4, the scenario 3 system will be modified according to the changes above mentioned. For the existing protective devices, their parameters are adopted from the previous section. Then, the mis-coordination is evaluated. If a mis-coordination of protection system is found, the solutions as mentioned in Chapter 3 will be implemented. After successfully solving the problem in the scenario 4, the mis-coordination of protection system for the previous scenarios will be rechecked.

This is to guarantee that the current parameters of protective devices could be work properly to the protection system of the previous scenarios.

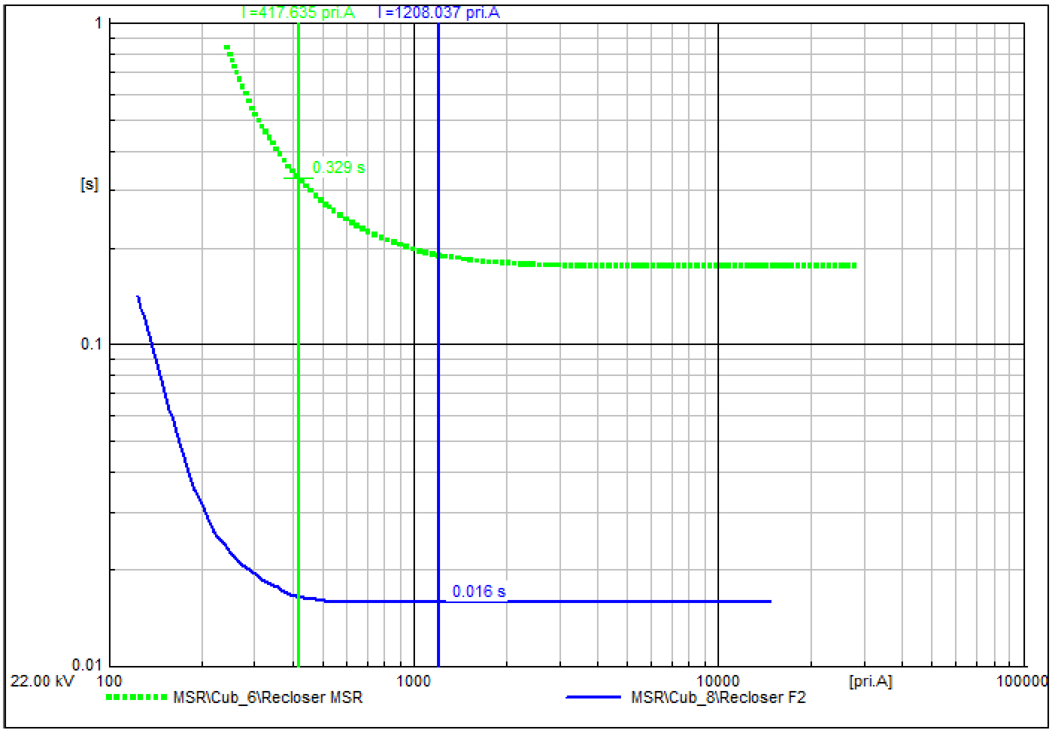


Figure 4.16 Characteristic curves of the protective devices show their operating times when there is a fault at F2 feeder

Figure 4.16 displays a sample of coordination among the overcurrent protective devices during the fault at F2 feeder. The graph shows that the recloser at F2 feeder, as the main protection, operates in 0.016s and the Recloser_MSR, as the backup protection, operates in 0.326s. For other faults, results are displayed in Table 4.10.

Table 4.10 Operating time of protective devices of scenario4 with IEC 60909 method

Fault location	Fault type	Main protection		Backup protection	
		Prot. Device	Opr. Time(s)	Prot. Device	Opr. Time(s)
HOA_MSR_1	SLG	Relay_S2	0.020	-	-
HOA_MSR_2	SLG	Relay_HOA_5	0.187	Recloser_MSR	0.739
		Relay_S2	0.459		
HOA_MSR_3	SLG	Relay_HOA_5	0.020	Recloser_MSR	0.264
HOA_MSR_4	SLG	Recloser_MSR	0.211	-	-
		Relay_HOA_5	0.429	-	-
MSR_Dam	SLG	Recloser_Dam	0.062	Recloser_MSR	0.211
				Relay_HOA_5	0.338
		Dam	NA	-	-
F1	SLG	Recloser 1	0.174	Recloser_MSR	0.336
F2	SLG	Recloser 2	0.016	Recloser_MSR	0.329
F3	SLG	Recloser 3	0.016	Recloser_MSR	0.342
F4	SLG	Recloser 4	0.151	Recloser_MSR	0.305
F5	SLG	Recloser 5	0.016	Recloser_MSR	0.349
11	SLG	Relay 11	0.069	Recloser_MSR	0.300
		Diesel	NA	-	-

Table 4.10 summarizes the operating time of related protective devices for each fault location. The related protective devices are divided into main and backup protections. From the table, there is no backup protection acting faster than main protection. Again, this study does not concern the DG-side protection; so its device and its operating time are shown as "NA" for the 11th row and the last row. Therefore, for this scenario, all protective devices are working properly.

The final parameters of the protective devices after the correction process are given in the Table 4.11

Table 4.11 Parameter of protective devices in the scenario4 system

devices	Setting				
	Load current (Amp.)	**Pickup current (Amp.)**	**Time Dial**	**Time adder**	**characteristics**
Recloser_1	48	135	1.55	0.15	4C-103
Recloser_2	44	125	1	0	4C-101
Recloser_3	46	130	1	0	4C-101
Recloser_4	50	350	1.70	0.10	4C-103
Recloser_5	63	185	1	0	4C-101
Recloser_Dam	30	270	0.3	0.03	4C-105
Recloser_MSR	146	240	1.80	0.15	4C-103
Relay_S1	156	600	0.10	-	Extremely inverse
Relay_S2	156	300	0.06	-	Normally inverse
Relay_HOA_5	146	246	0.10	-	IAC inverse
DOC Relay 11	127	240	0.05	-	IAC inverse

4.4.5. Scenario 5

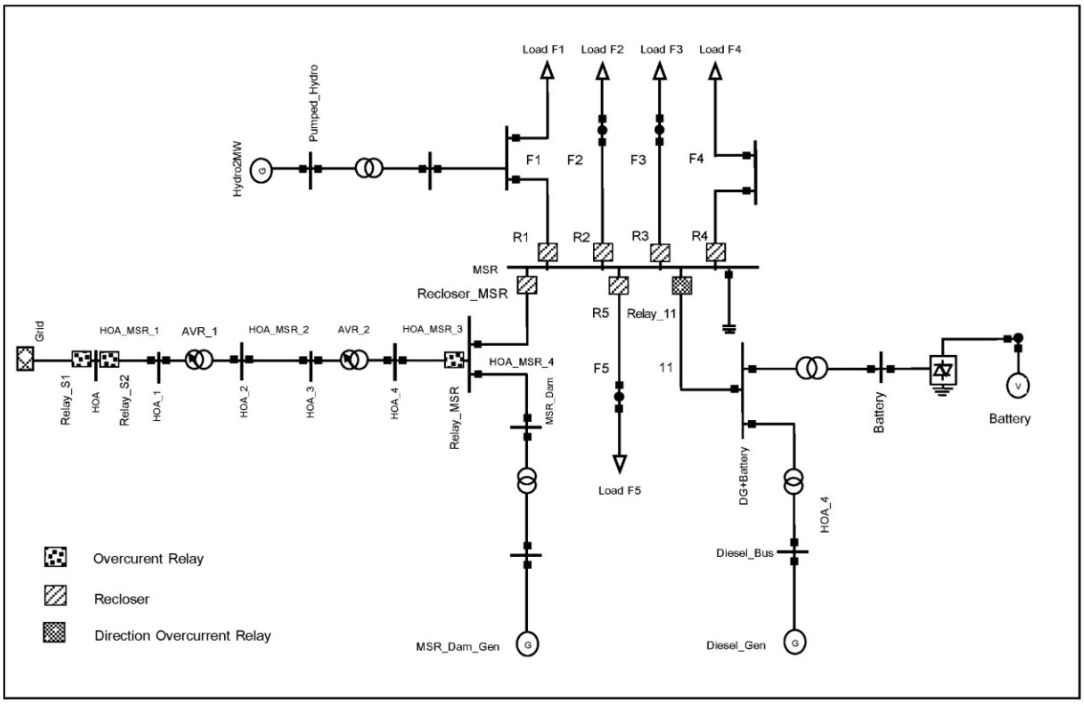


Figure 4.17 The scenario5 system

The scenario is consist: Grid Load 1.1 MW
Diesel Generator 4 MW
Pump Hydro 2 MW
Battery 2 MW
Dam 0.5 MW
Consumers Load 9.6 MW

In scenario 5, the scenario 4 system will be modified according to the changes above mentioned. For the existing protective devices, their parameters are adopted from the previous section. Then, the mis-coordination is evaluated. If a mis-coordination of protection system is found, the solutions as mentioned in Chapter 3 will be implemented.

After successfully solving the problem in the scenario 4, the mis-coordination of protection system for the previous scenarios will be rechecked. This is to guarantee that the current parameters of protective devices could be work properly to the protection system of the previous scenarios.

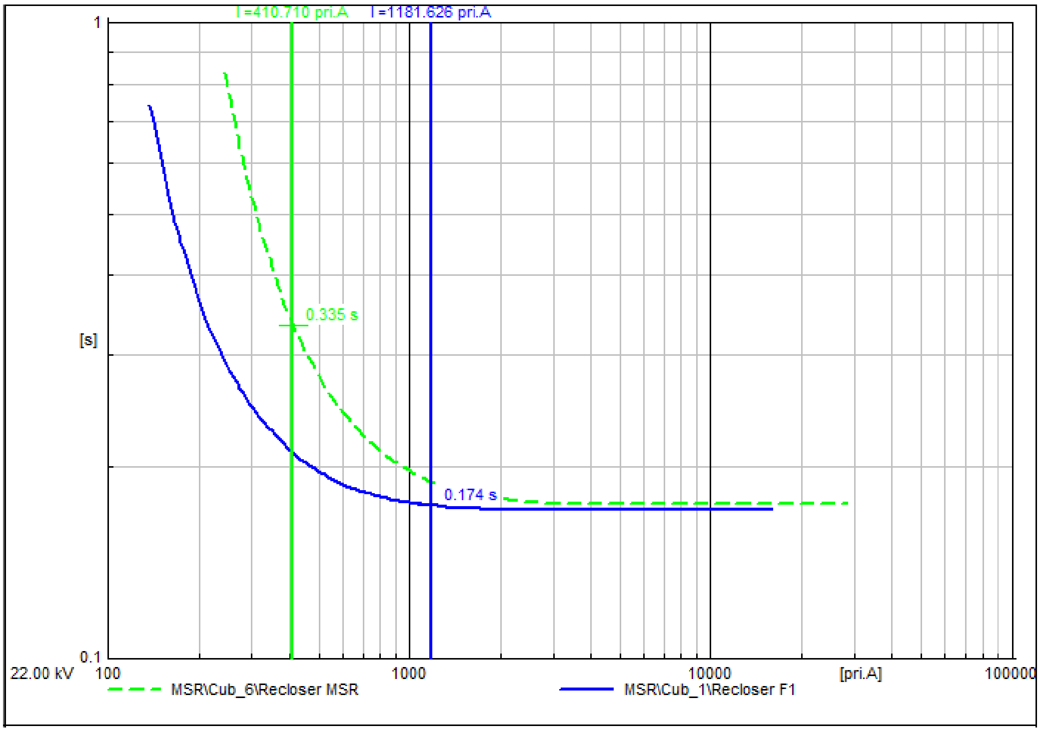


Figure 4.18 Characteristic curves of the protective devices show their operating times when there is a fault at F1 feeder

Figure 4.18 shows a sample of successfully coordination among the overcurrent protective devices during the fault at F1 feeder. The graph shows that the recloser at F1 feeder, as the main protection, operates in 0.171s and the Recloser _MSR, as the backup protection, operates in 0.335s. For other faults, the operating times are summarized in Table 4.12.

Table 4.12 Operating time of protective devices of scenario5 with IEC 60909 method

Fault location	Fault type	Main protection		Backup protection	
		Prot. Device	**Opr. Time(s)**	**Prot. Device**	**Opr. Time(s)**
HOA_MSR_1	SLG	Relay_S2	0.020	-	-
HOA_MSR_2	SLG	Relay_HOA_5	0.150	Recloser_MSR	0.532
		Relay_S2	0.478	-	-
HOA_MSR_3	SLG	Relay_HOA_5	0.020	Recloser_MSR	0.230
HOA_MSR_4	SLG	Recloser_MSR	0.192	Recloser 1	0.238
		Relay_HOA_5	0.438	-	-
MSR_Dam	SLG	Recloser_Dam	0.055	Recloser_MSR	0.198
				Relay_HOA_5	0.350
		Dam	NA	-	-
F1	SLG	Recloser 1	0.174	Recloser_MSR	0.335
		Hydro	NA	-	-
F2	SLG	Recloser 2	0.016	Recloser 1	0.239
				Recloser_MSR	0.388
F3	SLG	Recloser 3	0.016	Recloser_MSR	0.356
				Recloser 1	0.246
F4	SLG	Recloser 4	0.139	Recloser_MSR	0.307
				Recloser 1	0.227

Table 4.12 Operating time of protective devices of scenario5 with IEC 60909 method (cont.)

Fault location	Fault type	Main protection		Backup protection	
		Prot. Device	**Opr. Time(s)**	**Prot. Device**	**Opr. Time(s)**
F5	SLG	Recloser 5	0.016	Recloser_MSR	0.367
				Recloser 1	0.249
11	SLG	Relay 11	0.055	Recloser_MSR	0.302
				Recloser 1	0.225
		Diesel	NA	-	-

Table 4.8 summarizes the operating time of related protective devices for each fault location. The related protective devices are divided into main and backup protections. From the table, there is no backup protection acting faster than main protection. Again, this study does not concern the DG-side protection; so its device and its operating time are shown as “NA” for the 9^{th}, 11^{th} and 22^{th} rows. Therefore, for this scenario, all protective devices are working properly.

The final parameters of the protective devices after the correction process are given in the Table 4.13

Table 4.13 Parameter of protective devices in the scenario5 system

devices	Setting				
	Load current (Amp.)	**Pickup current (Amp.)**	**Time Dial**	**Time adder**	**characteristics**
Recloser_1	48	135	1.55	0.15	4C-103
Recloser_2	44	125	1	0	4C-101
Recloser_3	46	130	1	0	4C-101
Recloser_4	50	350	1.70	0.10	4C-103
Recloser_5	63	185	1	0	4C-101
Recloser_Dam	25	270	0.30	0.03	4C-105
Recloser_MSR	146	240	1.80	0.15	4C-103
Relay_S1	156	600	0.10	-	Extremely inverse
Relay_S2	156	300	0.06	-	Normally inverse
Relay_HOA_5	146	246	0.10	-	IAC inverse
DOC Relay 11	117	240	0.05	-	IAC inverse

4.4.6. Scenario 6

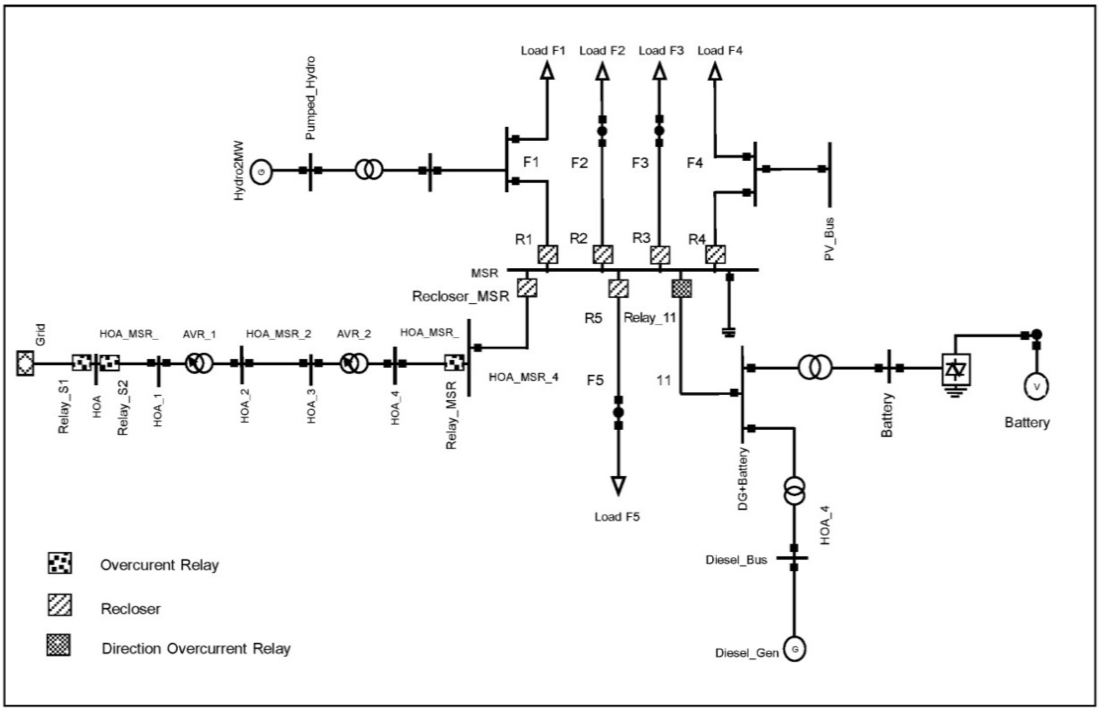


Figure 4.19 The scenario6 system

The scenario is consist: Grid Load 0.6 MW
Diesel Generator 4 MW
Pump Hydro 2 MW
Battery 0 MW
PV 3 MW
Consumers Load 9.6 MW

In scenario 6, the scenario 5 system will be modified according to the changes above mentioned. For the existing protective devices, their parameters are adopted from the previous section. Then, the mis-coordination is evaluated. If a mis-coordination of protection system is found, the solutions as mentioned in Chapter 3 will be implemented. After successfully solving the problem in the scenario 6, the mis-coordination of protection system for the previous scenarios will be rechecked.

This is to guarantee that the current parameters of protective devices could be work properly to the protection system of the previous scenarios.

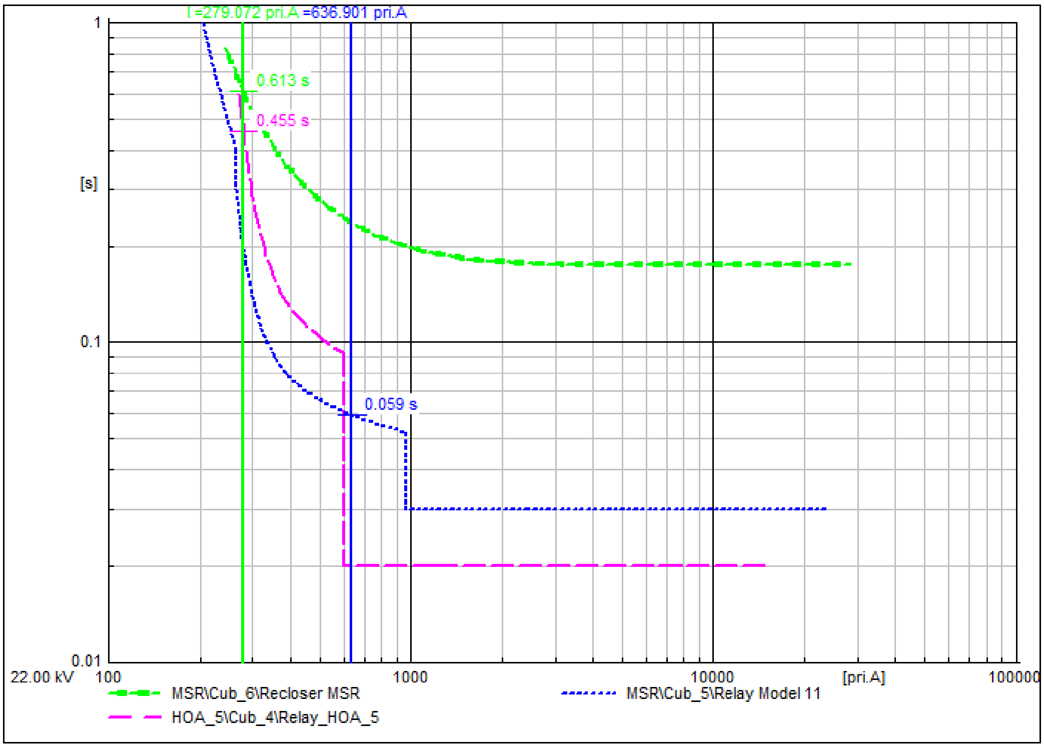


Figure 4.20 Characteristic curves of the protective devices show their operating times when there is a fault at Feeder 11

Figure 4.20 shows a sample of successfully coordination among the overcurrent protective devices during fault at feeder 11. The graph shows that the recloser at Feeder 11, as the main protection operates, in 0.059s. Recloser _MSR and Recloser1 operate as the backup protection, which operates in 0.613s and 0.224s, respectively. For other faults, the operating times are summarized in Table 4.14.

Table 4.14 Operating time of protective devices of scenario6 with IEC 60909 method

Fault location	Fault type	Main protection		Backup protection	
		Prot. Device	**Opr. Time(s)**	**Prot. Device**	**Opr. Time(s)**
HOA_MSR_1	SLG	Relay_S2	0.020	-	-
HOA_MSR_2	SLG	Relay_HOA_5	0.176	Recloser_MSR	0.433
		Relay_S2	0.471	-	-
HOA_MSR_4	SLG	Recloser_MSR	0.192	Recloser 1	0.237
		Relay_HOA_5	0.388		
F1	SLG	Recloser 1	0.175	Recloser_MSR	0.375
		Hydro	NA	-	-
F2	SLG	Recloser 2	0.016	Recloser_MSR	0.789
				Recloser 1	0.237
F3	SLG	Recloser 3	0.016	Recloser 1	0.243
F4	SLG	Recloser 4	0.144	Recloser_MSR	0.641
				Recloser 1	0.226
		PV	NA	-	-
F5	SLG	Recloser 5	0.016	Recloser 1	0.246
11	SLG	Relay 11	0.059	Recloser_MSR	0.613
				Recloser 1	0.224
		Diesel	NA	-	-

Table 4.14 summarizes the operating time of related protective devices for each fault location. The related protective devices are divided into main and backup protections. From the table, there is no backup protection acting faster than main protection. Again, this study does not concern the DG-side protection; so its device and its operating time are shown as “NA” for the 7^{th}, 13^{th} and 17^{th} rows. Therefore, for this scenario, all protective devices are working properly.

The final parameters of the protective devices after the correction process are given in the Table 4.15

Table 4.15 Parameter of protective devices in the scenario6 system

devices	Setting				
	Load current (Amp.)	**Pickup current (Amp.)**	**Time Dial**	**Time adder**	**characteristics**
Recloser_1	48	135	1.55	0.15	4C-103
Recloser_2	44	125	1	0	4C-101
Recloser_3	46	130	1	0	4C-101
Recloser_4	50	350	1.70	0.10	4C-103
Recloser_5	63	185	1	0	4C-101
Recloser_MSR	146	240	1.80	0.15	4C-103
Relay_S1	156	600	0.10	-	Extremely inverse
Relay_S2	156	300	0.06	-	Normally inverse
Relay_HOA_5	146	246	0.10	-	IAC inverse
DOC Relay 11	131	240	0.05	-	IAC inverse

4.4.7 Scenario 7

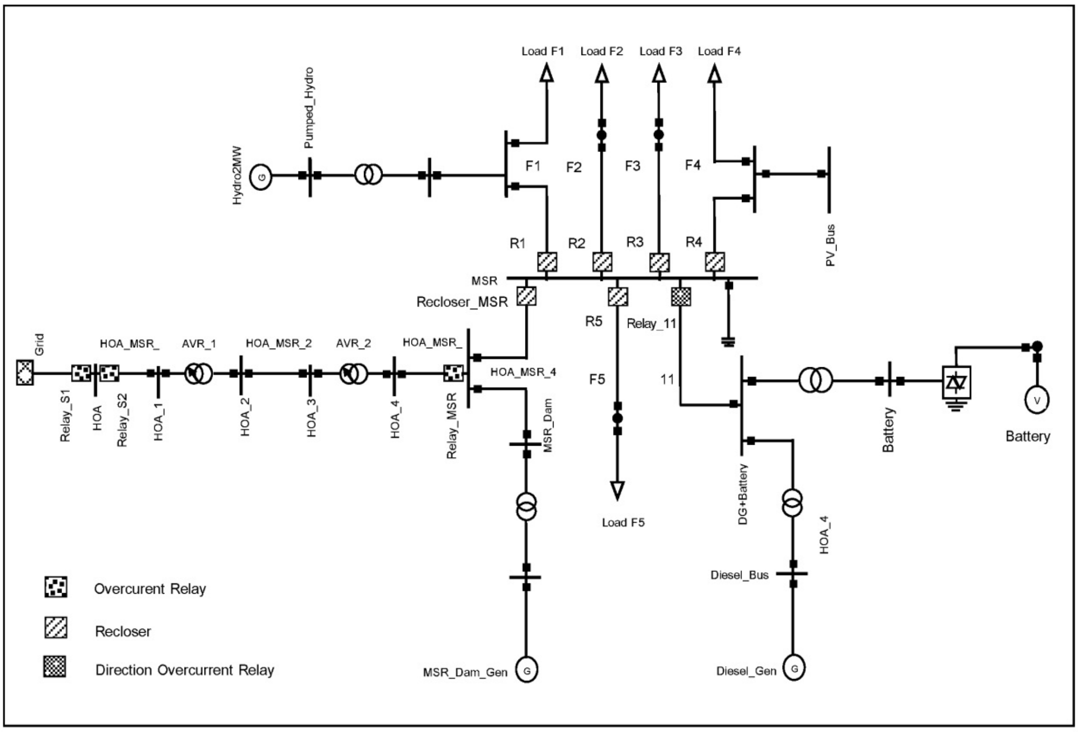


Figure 4.21 The scenario7 system

The scenario is consist: Grid Load 0.1 MW
Diesel Generator 4 MW
Pump Hydro 2 MW
Battery 2 MW
Dam 0.5 MW
PV 4 MW
Consumers Load 9.6 MW

In scenario 7, the scenario 6 system will be modified according to the changes above mentioned. For the existing protective devices, their parameters are adopted from the previous section. Then, the mis-coordination is evaluated.

If a mis-coordination of protection system is found, the solutions as mentioned in Chapter 3 will be implemented. After successfully solving the problem in the scenario 7, the mis-coordination of protection system for the previous scenarios will be rechecked. This is to guarantee that the current parameters of protective devices could be work properly to the protection system of the previous scenarios.

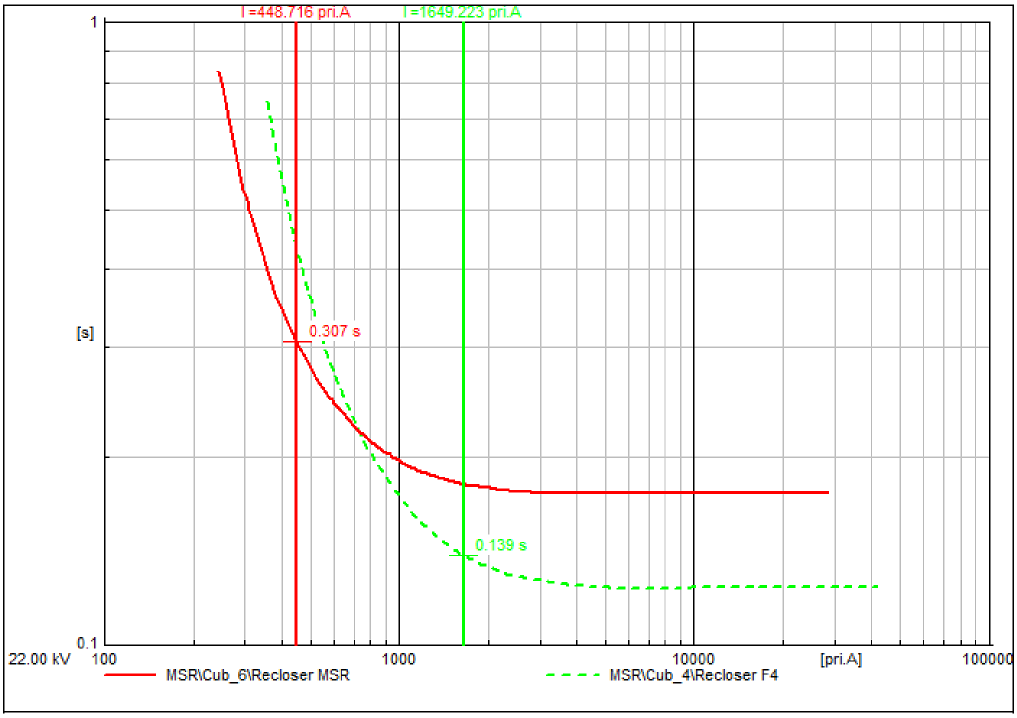


Figure 4.22 Characteristic curves of the protective devices show their operating times when there is a fault at F4 feeder

Figure 4.22 displays a sample of coordination among the overcurrent protective devices during the fault at F4 feeder. The graph shows that the recloser at F4 feeder, as the main protection, operates in 0.139s and the Recloser_MSR, as the backup protection, operates in 0.227s. For other faults, the operating times are summarized in Table 4.16.

Table 4.16 Operating time of protective devices of scenario7 with IEC 60909 method

Fault location	Fault type	Main protection		Backup protection	
		Prot. Device	Opr. Time(s)	Prot. Device	Opr. Time(s)
HOA_MSR_1	SLG	Relay_S2	0.020	-	-
HOA_MSR_2	SLG	Relay_HOA_5	0.150	Recloser_MSR	0.532
		Relay_S2	0.478	-	-
HOA_MSR_3	SLG	Relay_HOA_5	0.020	Recloser_MSR	0.230
HOA_MSR_4	SLG	Recloser_MSR	0.192	Recloser 1	0.238
		Relay_HOA_5	0.438	-	-
F1	SLG	Recloser 1	0.174	Recloser_MSR	0.335
		Hydro	NA	-	-
F2	SLG	Recloser 2	0.016	Recloser_MSR	0.338
				Recloser 1	0.229
F3	SLG	Recloser 3	0.016	Recloser_MSR	0.246
				Recloser 1	0.356
F4	SLG	Recloser 4	0.139	Recloser_MSR	0.227
		PV	NA	-	-
F5	SLG	Recloser 5	0.016	Recloser_MSR	0.367
				Recloser 1	0.249

Table 4.16 Operating time of protective devices of scenario7 with IEC 60909 method (cont.)

Fault location	Fault type	Main protection		Backup protection	
		Prot. Device	**Opr. Time(s)**	**Prot. Device**	**Opr. Time(s)**
11	SLG	Relay 11	0.055	Recloser_MSR	0.302
				Recloser 1	0.225
		Diesel	NA	-	-
MSR_Dam	SLG	Recloser _Dam	0.055	Recloser_MSR	0.198
				Relay_HOA_5	0.350
		Dam	NA	-	-

Table 4.16 summarizes the operating time of related protective devices for each fault location. The related protective devices are divided into main and backup protections. From the table, there is no backup protection acting faster than main protection. Again, this study does not concern the DG-side protection; so its device and its operating time are shown as "NA" for the 8^{th}, 14^{th}, 19^{th} and 22^{th} rows. Therefore, for this scenario, all protective devices are working properly.

The final parameters of the protective devices after the correction process are given in the Table 4.17

Table 4.17 Parameter of protective devices in the scenario7 system

devices	Setting				
	Load current (Amp.)	**Pickup current (Amp.)**	**Time Dial**	**Time adder**	**characteristics**
Recloser_1	48	135	1.55	0.15	4C-103
Recloser_2	44	125	1	0	4C-101
Recloser_3	46	130	1	0	4C-101
Recloser_4	50	350	1.70	0.10	4C-103
Recloser_5	63	185	1	0	4C-101
Recloser_Dam	28	270	0.30	0.03	4C-105
Recloser_MSR	146	240	1.80	0.15	4C-103
Relay_S1	156	600	0.10	NA	Extremely inverse
Relay_S2	156	300	0.06	NA	Normally inverse
DOC Relay 11	121	240	0.05	-	IAC inverse

Table 4.18 Protective devices coordination stages

devices	Feeder1	Feeder2	Feeder3	Feeder4	Feeder5	MSR busbar	HOA_5 busbar	Feeder11	Dam busbar
Stage1	R	R	R	R	R	R	-	-	-
Stage2	R	R	R	R	R	R	OC	R	R
Stage3	R	R	R	R	R	R	OC	OC	R
Stage4	R	R	R	R	R	R	OC	DOC	R

*R: Recloser, OC: Overcurrent Relay, DOC: Direction Overcurrent Relay

4.5 Evaluate Results for Islanding Mode Scenarios

The final protection design of the 7th scenario from the previous section will be applied throughout every scenario of islanding mode. Then, the problems of blinding and false tripping will be investigated to evaluate a capability of the protection system for islanding mode. Hence, in this section, the protection system will not be modified after the problems detected. The reason that there is no protection modification is because the correction of protection for islanding mode is very complex task and need further research. For example, it needs a study about re-defining a zone of protection as no grid for reference.

4.5.1 Scenario 8

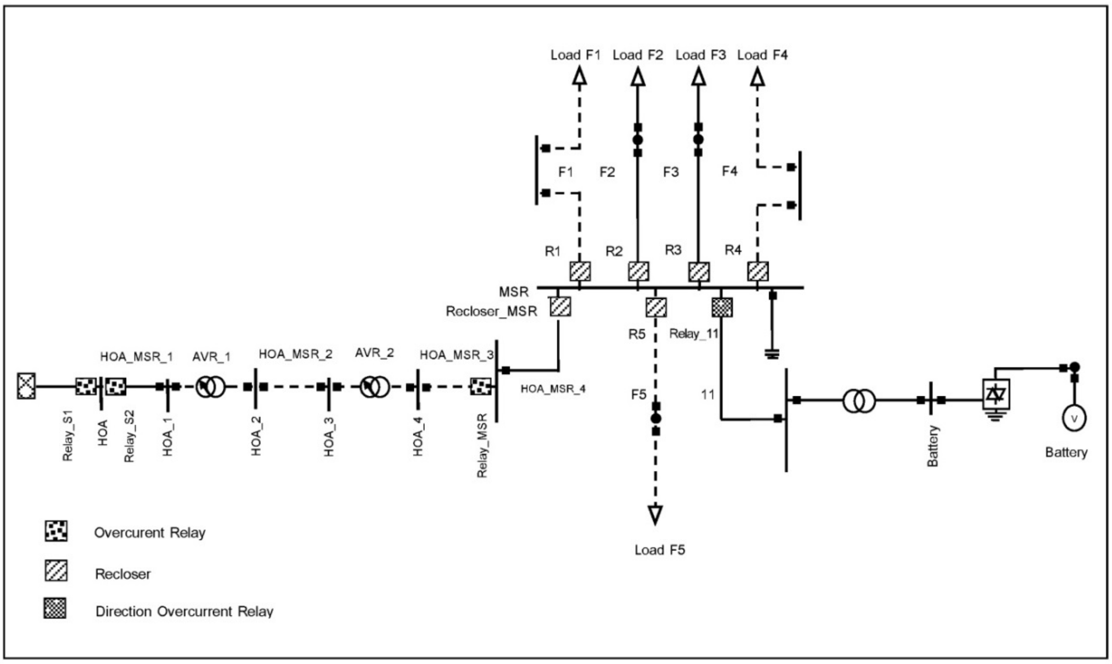


Figure 4.23 The scenario8 system

The scenario is consist: Battery 2.7 MW

Consumer Load 2.7 MW

This scenario is happen when there is a fault occurred at HOA_MSR Feeder. Then, the right part of system from HOA_5 bus will be disconnected from the main grid. In addition, all DGs and low priority loads are consequently disconnected.

The system has to temporally operate in the Islanding mode with 3MW battery (as the only power source) and F2 and F3 loads (as the high priority loads) [1].

Then, the problems of Blinding and False Tripping of protections will be investigated by the same method as in the case of grid connected mode scenarios. The results show that there are no problems detected when the fault currents are calculated by using the Electromechanical Transients method.

However, the conclusion cannot be reached when IEC60909 method for fault calculation is used. As can be seen in Table 4.19, the main protection or backup protections do not operate as no current flowing when fault occurred. One of the reasons is that no model of DC battery is enrolled in IEC60909 method.

Table 4.19 Operating time of protective devices of scenario8 with IEC 60909 method

Fault location	Fault type	Main protection		Backup protection	
		Prot. Device	Opr. Time(s)	Prot. Device	Opr. Time(s)
F2	SLG	Recloser 2	NA	-	-
F3	SLG	Recloser 2	NA	-	-
11	SLG	Diesel	NA	-	-

Table 4.20 Parameter of protective devices in the scenario8 system

devices	Setting				
	Load current (Amp.)	Pickup current (Amp.)	Time Dial	Time adder	characteristics
Recloser_2	36	125	1	0	4C-101
Recloser_3	36	130	1	0	4C-101
DOC Relay 11	108	240	0.05	NA	IAC inverse

4.5.2 Scenario 9

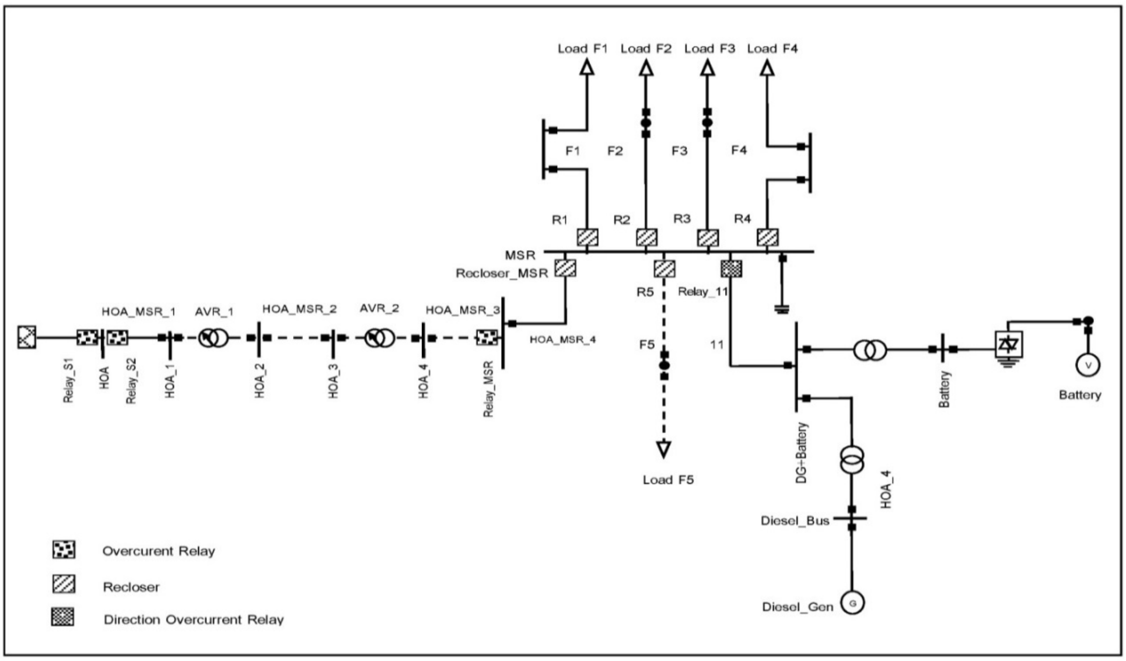


Figure 4.24 The scenario9 system

The scenario is consists: Diesel Generator 4 MW
Battery 2.3 MW
Consumer Load 6.3 MW

This scenario is happen when there is a fault occurred at HOA_MSR feeder. Then, the right part of system from HOA_5 bus will be disconnected from the main grid. The system has to temporally operate in the Islanding mode with 2.3 MW battery and the Diesel Generator. And, the high priority customer loads in this scenario will be the loads F1, F2 and F3.

In this scenario, the simulations show that there are no problems of blinding of protection and false tripping when using either IEC 60909 method or Electromechanical Transients method for fault calculation.

Table 4.21 Operating time of protective devices of scenario9 with IEC 60909 method

Fault location	Fault type	Main protection		Backup protection	
		Prot. Device	**Opr. Time(s)**	**Prot. Device**	**Opr. Time(s)**
F1	SLG	Recloser 1	0.180	-	-
F2	SLG	Recloser 2	0.016	-	-
F3	SLG	Recloser 3	0.016	-	-
F4	SLG	Recloser 3	0.194	-	-
11	SLG	Diesel	NA	-	-
HOA_MSR_4	SLG	Recloser_MSR	0.212	-	-

Table 4.21 summarizes the operating time of related protective devices for each fault location. Again, this study does not concern the DG-side protection; so its device and its operating time are shown as "NA" for the 5th row. Therefore, for this scenario, all protective devices are working properly.

Table 4.22 Parameter of protective devices in the scenario9 system

devices	Setting				
	Load current (Amp.)	**Pickup current (Amp.)**	**Time Dial**	**Time adder**	**characteristics**
Recloser_1	48	135	1.55	0.15	4C-103
Recloser_2	44	125	1	0	4C-101
Recloser_3	46	130	1	0	4C-101
Recloser_4	50	140	1.70	0.10	4C-103
DOC Relay 11	194	240	0.05	-	IAC inverse

4.5.3 Scenario 10

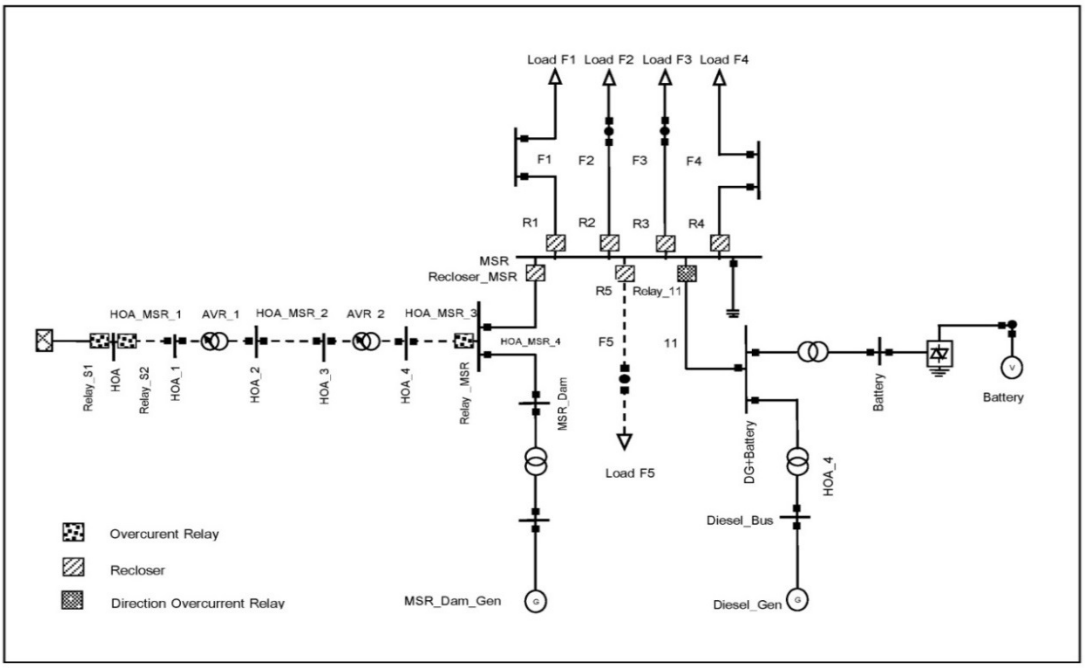


Figure 4.25 The scenario10 system

The scenario is consists: Diesel Generator 4 MW
Battery 2.7 MW
Dam 0.5 MW
Consumer Load 7.2 MW

In this scenario, the simulation shows that the overcurrent protection system can accurately operate except when there is fault at Feeder 11. The protective device does not operate because the value of the fault current is less than the pickup current of Relay 11. In figure 4.26, it causes the problem of the blinding of protection.

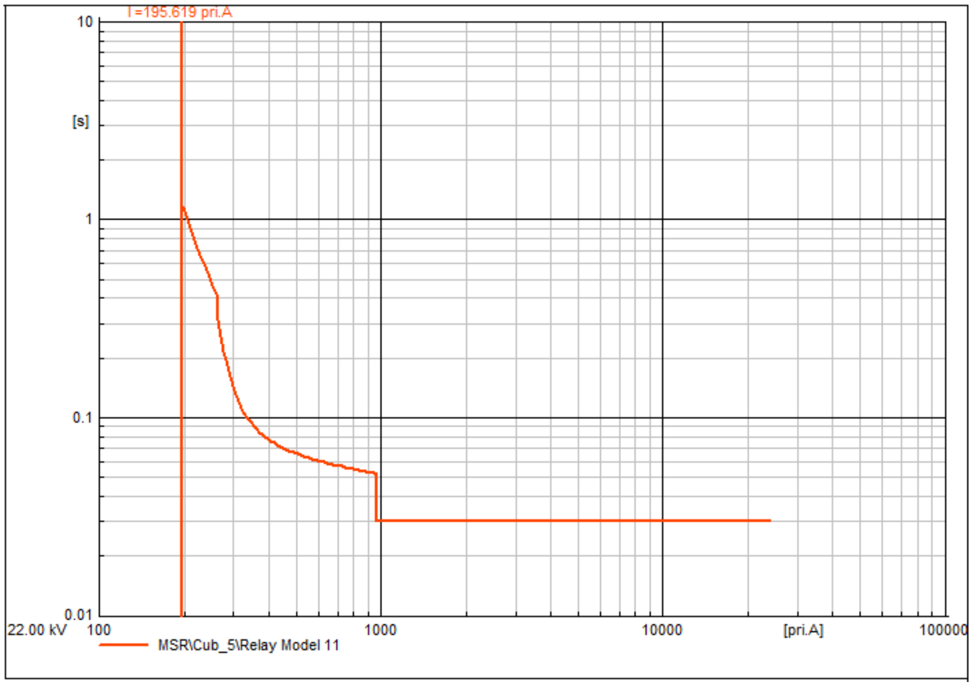


Figure 4.26 Characteristic curves of the protective devices show their operating times when there is a fault at Feeder11

In the Figure 4.26, it shows that when fault occurs at Feeder 11 the values of the fault current through the Relay_11 are just 195 A which is less than the value of the pickup current (which is Relay 11).The relay_11 thus does not operate.

Table 4.23 Operating time of protective devices of scenario10 with IEC 60909 method

Fault location	**Fault type**	**Main protection**		**Backup protection**	
		Prot. Device	**Opr. Time(s)**	**Prot. Device**	**Opr. Time(s)**
F1	SLG	Recloser 1	0.176	-	-
F2	SLG	Recloser 2	0.016	-	-
F3	SLG	Recloser 3	0.016	-	-
F4	SLG	Recloser 4	0.169	-	-
HOA_MSR_4	SLG	Recloser_MSR	0.212	-	-
MSR_Dam	SLG	Recloser_Dam	0.079	Recloser_MSR	0.220
		Dam	NA	-	-
11	SLG	Relay 11	Not operate	-	-
		Diesel	NA	-	-

Table 4.23 summarizes the operating time of related protective devices for each fault location. The related protective devices are divided into main and backup protections. From the table, there is no backup protection acting faster than main protection. Again, this study does not concern the DG-side protection; so its device and its operating time are shown as “NA” for the 7th and 9th rows. Therefore, for this scenario, all protective devices are working properly except the 8th row shows that when there is fault in Feeder 11. The Relay11 will not operate.

Table 4.24 Parameter of protective devices in the scenario10 system

devices	Setting				
	Load current (Amp.)	**Pickup current (Amp.)**	**Time Dial**	**Time adder**	**Characteristics**
Recloser_1	48	135	1.55	0.15	4C-103
Recloser_2	44	125	1	0	4C-101
Recloser_3	46	130	1	0	4C-101
Recloser_4	50	140	1.7	0.10	4C-103
Recloser_Dam	21	270	0.30	0.03	4C-105
Recloser_MSR	21	240	1.80	0.15	4C-103
DOC relay	186	240	0.05	NA	IAC inverse

4.5.4 Scenario 11

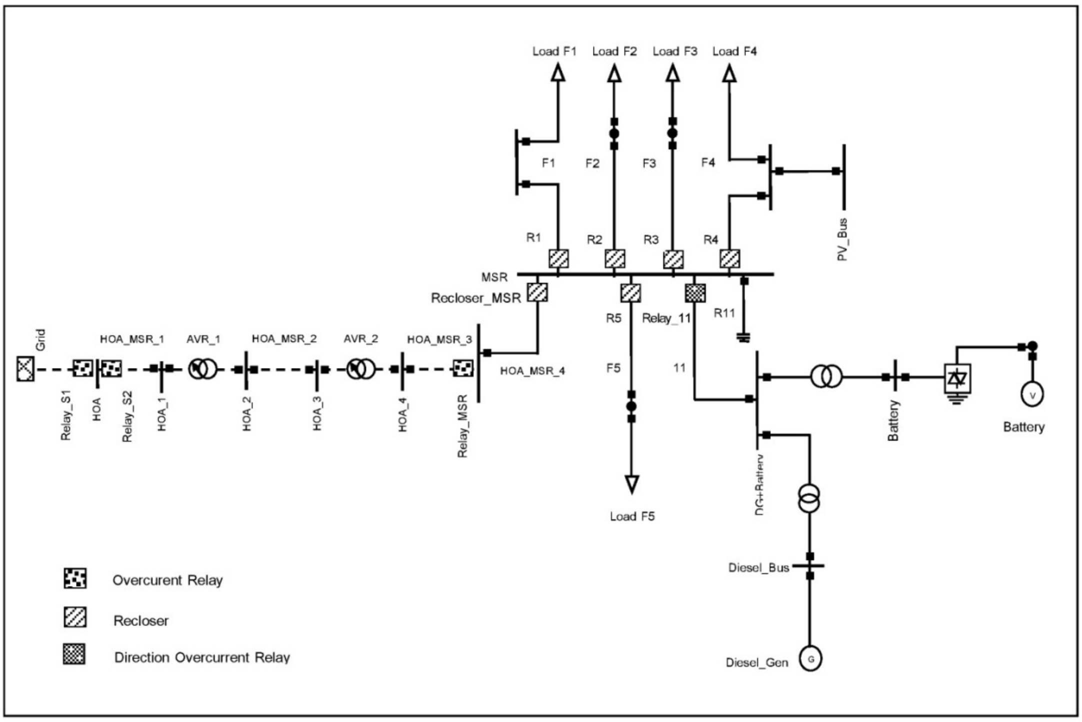


Figure 4.27 The scenario11 system

The scenario is consists: Diesel Generator 4 MW

Battery 1.6 MW

PV 4 MW

Consumer Load 9.6 MW

In this scenario, the simulation shows that the protection system can accurately operate except when there is fault at Feeder11. There is no current flowing when using IEC60909 for fault calculation.

However, when applying the Electromechanical Transients method, it shows that there is a fault current presented but very low. This value is less than the pickup setting of relay at Feeder 11. Therefore, the problem of the blinding of protection is detected for this scenario.

Table 4.25 Operating time of protective devices of scenario11 with IEC 60909 method

Fault location	Fault type	Main protection		Backup protection	
		Prot. Device	**Opr. Time(s)**	**Prot. Device**	**Opr. Time(s)**
Feeder 1	SLG	Recloser 1	0.180	-	-
Feeder 2	SLG	Recloser 2	0.016	-	-
Feeder 3	SLG	Recloser 3	0.016	-	-
Feeder 4	SLG	Recloser 4 PV	0.194 NA	-	-
HOA_MSR_4	SLG	Recloser_MSR	0.212	-	-
Feeder 5	SLG	Recloser 5	0.016	-	-
Feeder 11	SLG	Relay 11	Not operate	-	-
		Diesel	NA	-	-

Table 4.25 summarizes the operating time of related protective devices for each fault location. The related protective devices are divided into main and backup protections. From the table, there is no backup protection acting faster than main protection. Again, this study does not concern the DG-side protection; so its device and its operating time are shown as “NA” for the 5th and 9th rows. Therefore, for this scenario, all protective devices are working properly except the 8th row shows that when there is fault in Feeder 11. The Relay11 will not operate.

Table 4.26 Parameter of protective devices in the scenario11 system

devices	Setting				
	Load current (Amp.)	**Pickup current (Amp.)**	**Time Dial**	**Time adder**	**Characteristics**
Recloser_1	48	135	1.55	0.15	4C-103
Recloser_2	44	125	1	0	4C-101
Recloser_3	46	130	1	0	4C-101
Recloser_4	49	140	1.7	0.1	4C-103
Recloser_5	62	185	1	0	4C-101
DOC relay	168	240	0.05	NA	IAC inverse

4.5.5 Scenario 12

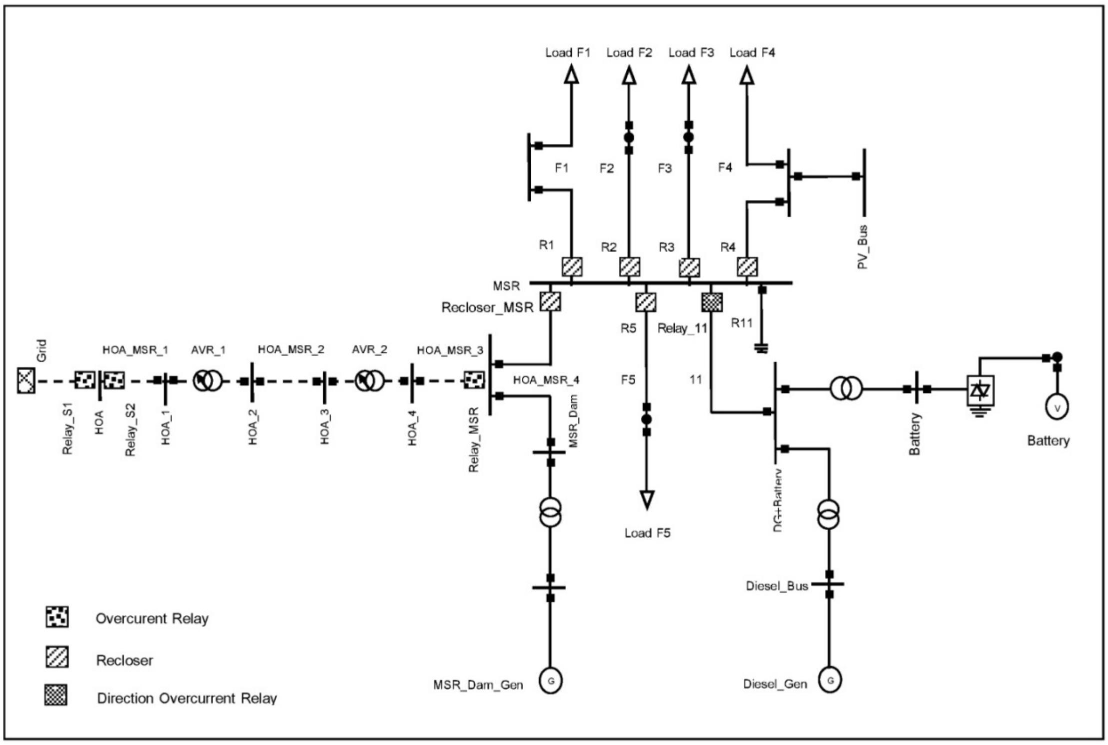


Figure 4.28 The scenario12 system

The scenario is consists: Diesel Generator 4 MW
Battery 1.2 MW
Dam 0.5 MW
PV 4 MW
Consumer Load 9.6 MW

In this scenario, the simulation shows that the overcurrent protection system can accurately operate except when there is fault at Feeder 11. The blinding of protection is detected when using either IEC 60909 methods or Electromechanical Transients method for fault calculation.

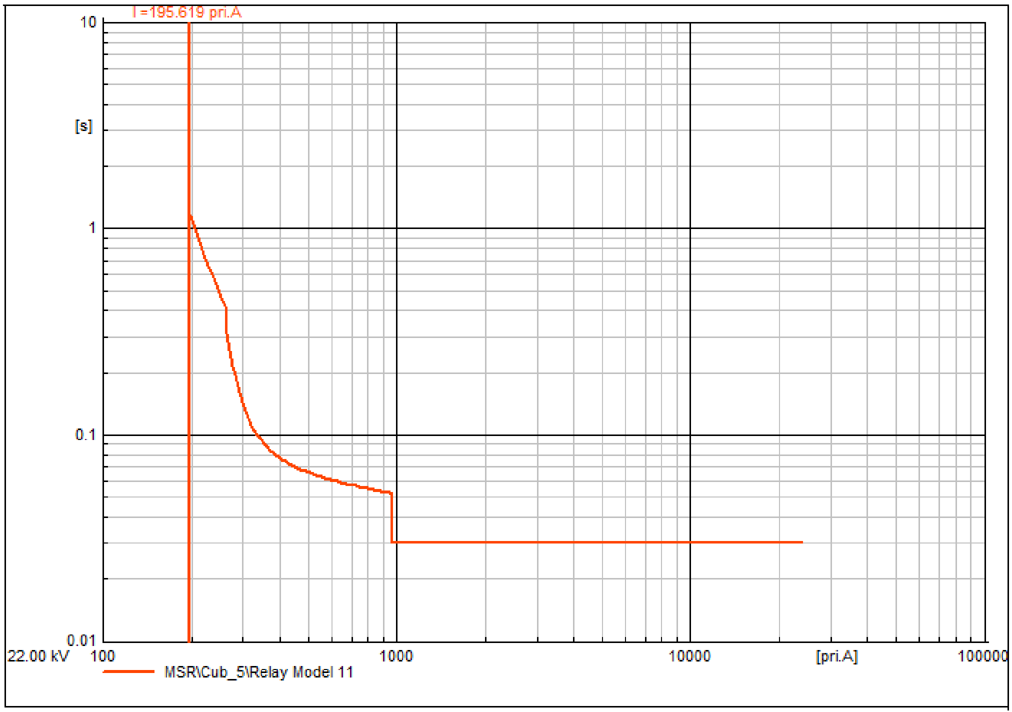


Figure 4.29 Characteristic curves of the protective devices show their operating times when there is a fault at feeder11

In the Figure 4.29, it shows that when s fault occurs at Feeder 11 the values of the fault current through the Relay_11 are just 195 A which fault current is less than the value of the existing pickup current. The Relay_11 thus does not operate.

Table 4.27 Operating time of protective devices of scenario12 with IEC 60909 method

Fault location	Fault type	Main protection		Backup protection	
		Prot. Device	Opr. Time(s)	Prot. Device	Opr. Time(s)
Feeder 1	SLG	Recloser 1	0.176	-	-
Feeder 2	SLG	Recloser 2	0.016	-	-
Feeder 3	SLG	Recloser 3	0.016	-	-
Feeder 4	SLG	Recloser 4	0.169	-	-
Feeder 5	SLG	Recloser 5	0.016	-	-
HOA_MSR_4	SLG	Recloser_MSR	0.213	-	-
MSR_Dam	SLG	Recloser_Dam	0.079	-	-
		Dam	NA	-	-
Feeder 11	SLG	Relay 11	Not operate	-	-
		Diesel	NA	-	-

Table 4.27 summarizes the operating time of related protective devices for each fault location. The related protective devices are divided into main and backup protections. From the table, there is no backup protection acting faster than main protection. Again, this study does not concern the DG-side protection; so its device and its operating time are shown as “NA” for the 8th and 10th rows. Therefore, for this scenario, all protective devices are working properly except the 9th row shows that when there is fault in Feeder 11. The Relay11 will not operate.

Table 4.28 Parameter of protective devices in the scenario12 system

devices	**Setting**				
	Load current (Amp.)	**Pickup current (Amp.)**	**Time Dial**	**Time adder**	**characteristics**
Recloser_1	48	135	1.55	0.15	4C-103
Recloser_2	44	125	1	0	4C-101
Recloser_3	46	130	1	0	4C-101
Recloser_4	54	140	1.7	0.10	4C-103
Recloser_5	63	185	1	0	4C-101
Recloser_Dam	22	270	0.3	0.03	4C-105
Recloser_MSR	22	240	1.80	0.15	4C-103
DOC Relay 11	148	240	0.05	-	IAC inverse

CHAPTER V
CONCLUSION

This thesis has studied the overcurrent protection design of distribution system for micro-grid operation. The proposed method is based on a detection and correction scheme. The method begins with a protection design of a fundamental scenario which is an essential part of a final system. Then the fundamental scenario will be modified scenario by scenario towards the expected final system. For each scenario, the coordination of protective devices will be checked; and, the mis-coordination will be corrected before moving to next scenario. The key features of this method are as follows.

- It could be applied to design a protection of an existing system as well as a new system
- It requires the analysis tools (i.e. power flow and fault calculation) which are normally available in a commercial power system simulator

However, there are some limitations as follows.

- It is a time-consuming process

In addition, this method has been applied to design the overcurrent protection of Mae Saraing system. The results of study have shown that:

- The original protection system of Mae Saraing system is not ready for micro-grid operation
- In order to make the protection system ready for micro-grid operation, the following modifications should be considered

(1) provide an additional overcurrent relay at HOA_5 bus
(2) provide an additional recloser at MSR_Dam bus
(3) provide an additional direction overcurrent relay at feeder 11

- The addition of above protective devices will make the protection ready to be properly operated as micro-grid for seven scenarios of grid connected mode and for two scenarios of islanding mode.

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