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Design and development of first MW-level microgrid in Thailand

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Abstract

This paper presents the design and development of a MW-level Microgrid project at Mae Sariang District Mae Hon Son province in northern of Thailand. The Microgrid project coverage area get power supply by a 110 km 22kV distribution line which also pass the forest area. Thus the power supply is not stable, and the power quality is not good, the weak power system has limited the local society development. To improve the power system in the mentioned area, the Microgrid project has decided to build which include four local resources: 1.2MW hydro-power plant, 4MWp solar PV, 5MW diesel generator and 3MW/1.5MWh battery energy storage system (BESS).Moreover, Power flow study, short circuit study, dynamic study and protection system design based on various combinations of RE systems are calculated using DIgSILENT PowerFactory software in achieving the most optimal design. The obtained solution shows that a hybrid combination of solar/ hydro/battery/diesel is cost effective, sustainable, social-economically and environmentally [1]. Additionally, the result shows that the Microgrid system could significantly increase the power system stability and reliability in the Microgrid coverage area. Moreover, after lost power supply from the main grid, by automatically black start function, the Microgrid system can supply power locally to the customer and can reduce the outage time from at least 20 minutes to within 1 minute.

Keywords: Microgrid, BESS

1. Introduction

Mae Sariang District is about 110 km away from HOT substation.A long(110 km) 22 kV distribution line which also pass through the forest area is the only link between the main grid and Mae Sariang District, to reduce the power loss of the long distribution line , a 4MWp solar farm and 1.2MW hydro-power plant are built to supply power locally, but there are still remain following main issues: The energy loss from long distribution line is about 19% or about 6.7 million kWh per year; the number of outage is more than 20 times per year caused by damaged equipment, maintenance, or weather related; during peak load, diesel generator has to run to support the voltage in the area; solar farm cannot connect to the grid in some cases caused by voltage sag, over voltage, or unbalance voltage; the operation in this area still depends on the local operator due to the reliability of controlled equipment in SCADA system which are sometime low battery or loss of communication. Therefore, when the outage occurs, it will take about 20 minutes to connect and disconnect equipment before diesel generator is able to supply to the load.Hence, the Provincial Electricity Authority (PEA) decided to build a smart microgrid by integrating PV generation, BESS, hydro-power plant and diesel generator to enhance the local power supply, the stability and resiliency of the power system.

Fig. 1 illustrates the power system single line diagram. It has 11 circuit breaks at substation for all

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feeders which is included incoming feeder from HOA08 and HOA09(22kV source) and 1BVB(future 115kV source) . The feeder from solar farm connect to the same bus with battery in order to use battery in many operations such as PV smoothing, peak shaving, energy management, etc. 15 load break switches installed in this project to provide the function of load shedding, load recovery and Fault Location, Isolation, and Service Restoration(FLISR).

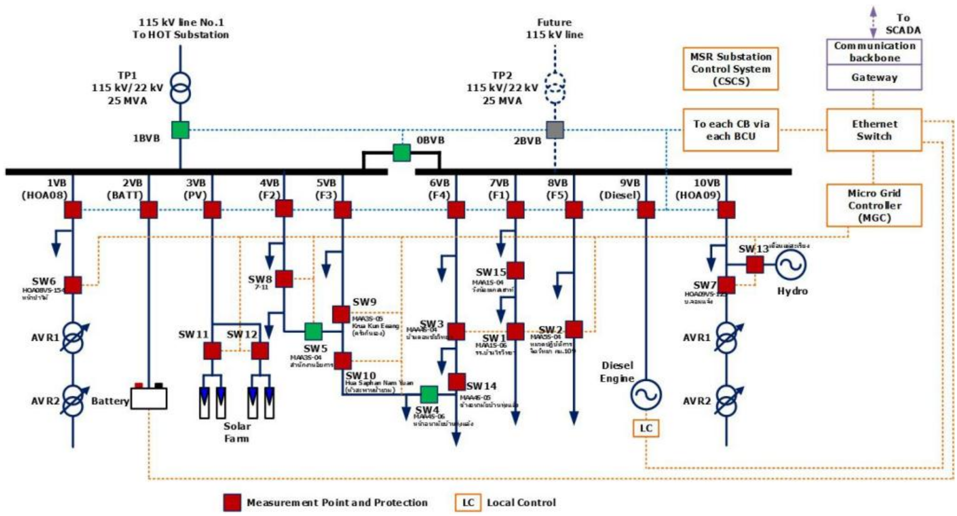


Fig. 1. Power system single line diagram

Fig. 2 has been shown the typical load profile of the microgrid coverage area, the most load is come from the residential electricity consumption, thus the peak load is happen at 6:30AM when people wake up and start to cooking and 6:30PM when people start to use lighting and air-conditioner. And during those peak time, PV already cannot generate power at that time , power supply is not enough, the system voltage will drop , without microgrid system, PEA has to start Diesel generator to maintain system voltage despite the cost of diesel oil is quite high, after microgrid system set up, it will use BESS to discharge during the peak time. The microgrid system also can be used for voltage and frequency dynamic regulation function when system has some disturbance .In case that there is some internal fault happen, the Fault Location, Isolation, and Service Restoration(FLISR) function will operate to locate ,isolate and restore the fault area automatically to reduce the outage duration. In addition, in case the distribution line is interrupted, the coverage area will be supplied by energy sources from battery, diesel generator, Solar farm, or hydro power plant to form as islanding area in order to increase the reliability of the system.

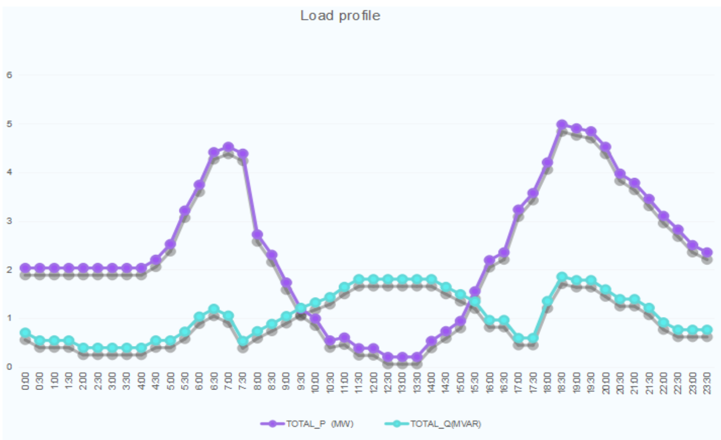


Fig. 2. Typical load profile of Microgrid coverage area

2. System Components

Microgrid control & protection system adopts the layered and distributed design, which is divided into local control level, coordinative control level and optimal control level. [2-4]

The topology as shown in Fig. 3:

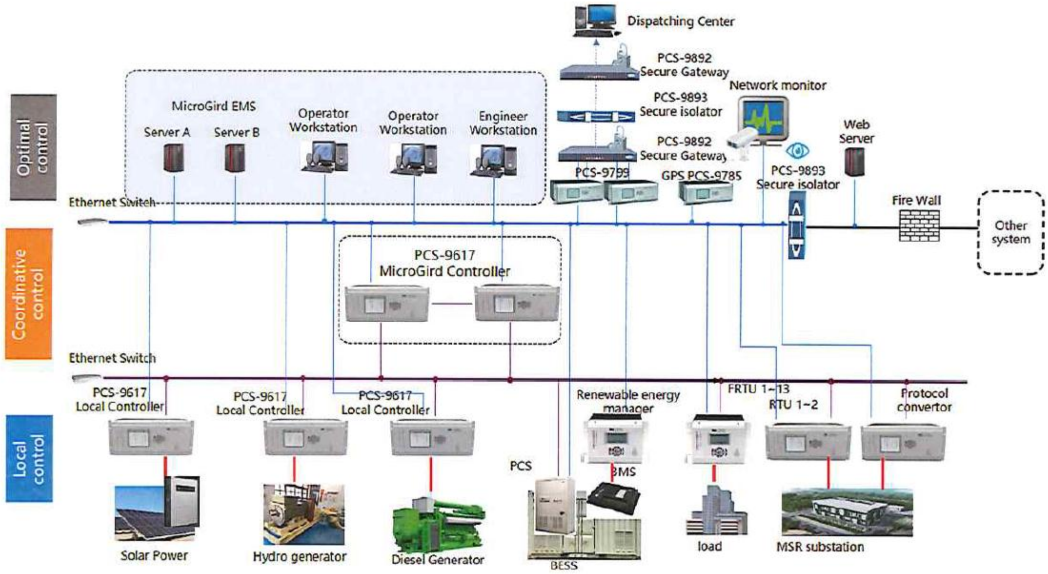


Fig. 3. Layered Microgrid control and protection system

2.1. Local control level

The Local control level includes DGs, PCS, local controller and protection IEDs. Our automated local control system with independent communication can provide fast response speed between equipment during minor disturbances or short-circuit faults, and stabilize power-supply by the self-regulation of converter or the fast action of protection equipment.

2.2. Coordinative control level

The coordinative control level includes the Microgrid controller, which acquires the information of DGs, energy storage, diesel generators and important load via the control communication network. When Microgrid operates in the islanded mode and large disturbance occurs (such as non-scheduled grid outage, large-capacity DG trip, etc.), the Microgrid controller coordinates the operating modes of energy storage and diesel generator as well as the output power of DGs to maintain the voltage and frequency within the allowable ranges and guarantee the stable and safe operation of Microgrid system.

2.3. Optimal control level

The optimal control level includes the Microgrid EMS and depends on the data supplied by SCADA system, dispatching & schedule system, load forecast system, etc. It realizes the functions of data analysis, energy prediction, load management, optimal operation, economic dispatching for the specified applications to maximize the comprehensive utilization rate of the DGs within Microgrid.

3. System Modeling

According to the problems, DIgSILENT PowerFactory software is used to show ability of the MGDP in any case or scenario studies defined by PEA, the power system study result has also been used for function design and relay setting calculation.

3.1. System modelling

The system modelling as shown in Fig. 4:

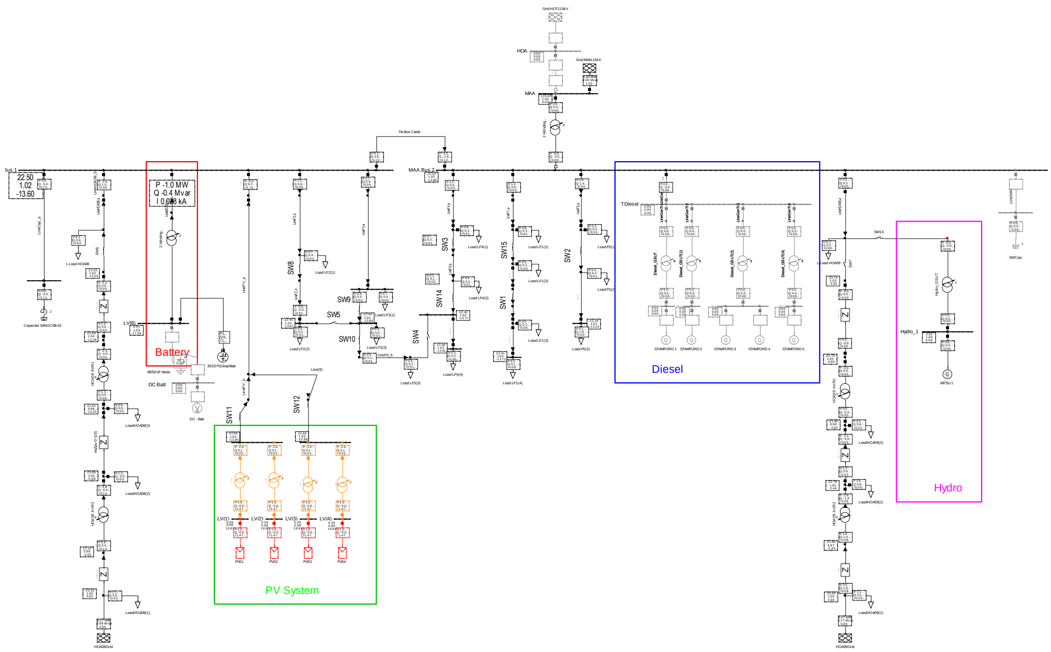


Fig. 4. The all power system modelling in DIgSILENT PowerFactory software

3.2. Cases definition

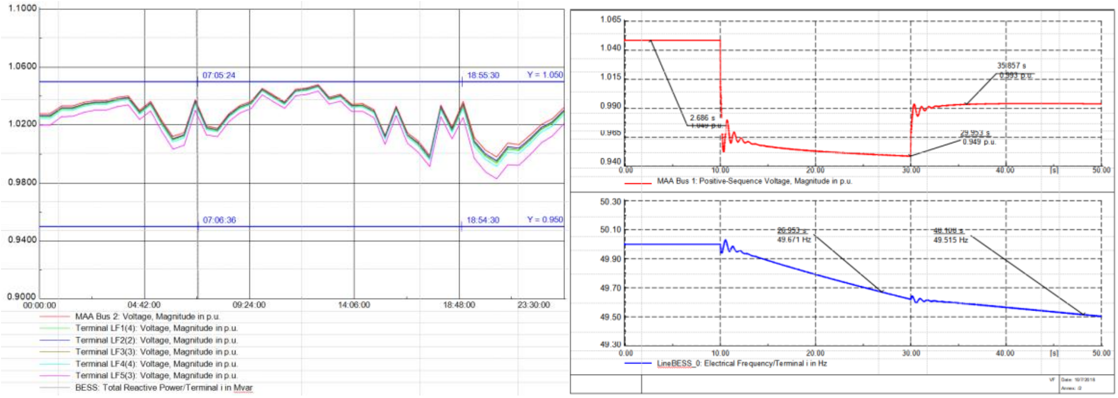
All the case definition as shown in Table 1.

Table 1.Case definition

Case No.	Grid-connected			Islanding	PV	BESS	Diesel	Hydro
	115kV	HOA08	HOA09					
1081	0	1	0	0	1	1	1	1
1082	0	1	0	0	1	1	0	0
1083	0	1	0	0	0	0	1	0
1091	0	0	1	0	1	1	1	1
1092	0	0	1	0	1	1	0	0
1093	0	0	1	0	0	0	1	0
1151	1	0	0	0	1	1	1	1
1152	1	0	0	0	1	1	0	0
1153	1	0	0	0	0	0	1	0
0001	0	0	0	1	1	1	1	1
0002	0	0	0	1	1	1	0	0
0003	0	0	0	1	0	0	1	0

Remark: Status 1: Connected Status 0: Disconnected

For example, Case No. 1081: The power system connect to 22kV system at HOA08 together with BESS, PV power plant, Diesel generators, and Hydro power plant. The simulation result of case 1081 has been shown on Fig. 5., Fig. 6. and Fig. 7..



(a) (b)

Fig.5. Case 1081: (a)Voltage profile and (b) Active power profile

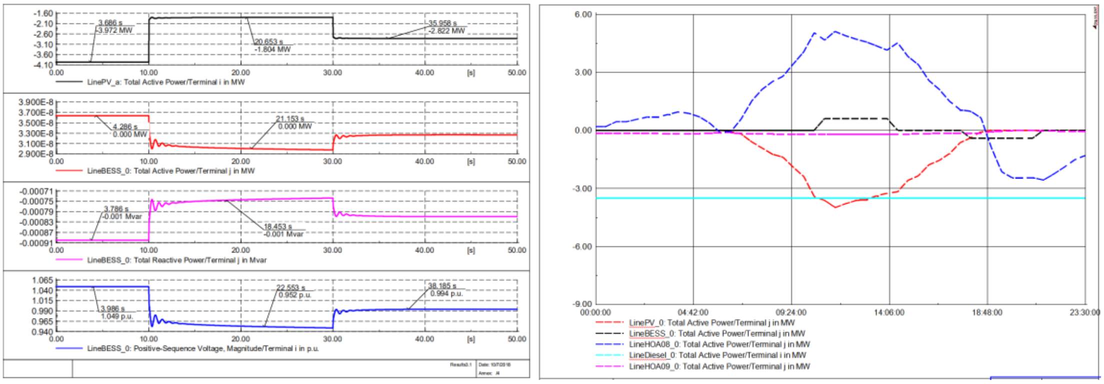


Fig. 6. Dynamic study of case 1081without BESS

In this case without BESS, voltage and frequency deviation may not comply with PEA regulation.

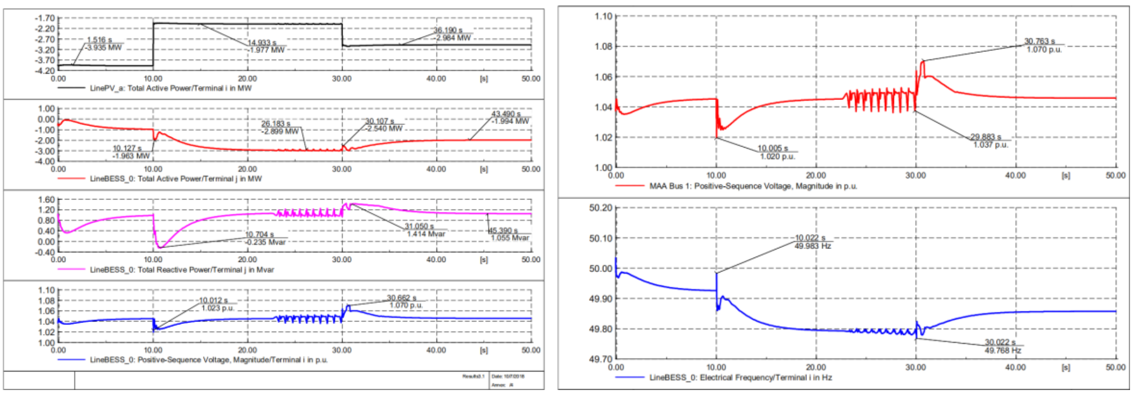


Fig. 7. Dynamic study of case 1081 with BESS

In this case with BESS, the BESS discharge/charge active power (-1.96 or -2.54 MW) and reactive power (-0.24 or 1.41 Mvar) to regulate the voltage and frequency, can comply with the PEA regulation without any outage.

4. System Function Design

The design follows the connection standard IEEE 1547[5]. The Microgrid system is designed to operate in both grid connecting and islanding mode [6] and more detail can be explained as following:

4.1. Scenario definition

Scenario 1 Before islanding

Scenario 1A grid connecting with 115kV incoming; Scenario 1B grid connecting with both HOA08 and HOA09 with tie breaker 0BVB open; Scenario 1C grid connecting with HOA08 with tie breaker 0BVB close; Scenario 1D grid connecting with HOA09 with tie breaker 0BVB close

Scenario 2 Preventive islanding if a supply interruption is planned, or an outage is expected

Intentional switching from grid connecting to islanding

Scenario 3 Automated islanding in case of unplanned grid failure

This project not have scenario 3

Scenario 4 Black start recovery to re-supply loads after grid failure

Automatic black start

Scenario 5 Maintaining the islanding

Islanding status control

Secnario 6 Reconnection to the main grid

Automatic connect back to grid

4.2. System operation mode for only have 22kV incoming:

The system will have 4 operation mode: Grid connecting open loop operation mode 1 (Scenario 1B, 0BVB open), grid connecting close loop opearation mode 2 (Scenario 1D,0BVB close), grid connecting close loop opearation mode 3 (Scenario 1C, 0BVB close), island operation mode 4 (Scenario 5, 0BVB close).

4.3. System operation mode for 115kV incoming:

After Mae Sariang substation 115kV incoming finished construction, the bus tie breaker will work as normally close, 1VB 10VB will work as both feeder and back up power source in case 115kV power source has been lost, then PCC point will have three which are 115kV incoming, HOA08 and HOA09.

4.4. System operation mode switching for 22kV incoming only

The operation mode switching as shown in Fig. 8.

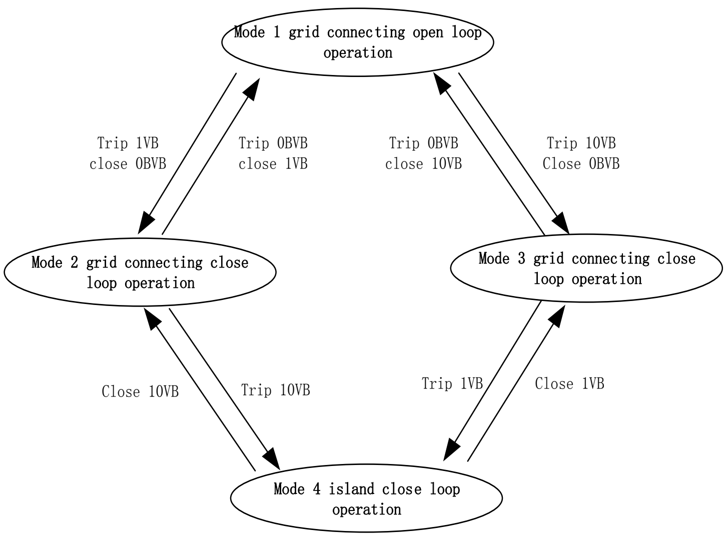


Fig. 8. System operation mode switching

Below Incoming 1 indicate for HOA08, Incoming 2 indicate for HOA09

The operation mode switching:

Logic 1: When system work in mode 1, incoming 1 lost power, bus I lost voltage, trip 1VB, PV and BESS will stop asthmatically, close 0BVB, bus I lost power short time, go to mode 2; Switching from Scenario 1B to 1D

Logic 2: When system work in mode 1, Incoming 2 lost power, bus II lost voltage, trip 10VB, close 0BVB, but II lost power short time, go to mode 3; Switching from Scenario 1B to 1C

Logic 3: When system work in mode 2: Incoming 2 supply to load, after that the voltage of incoming 1 has been recovered, it will trip 0BVB, then PV BESS stop automatically, bus I close 1VB, bus I lost power short time. Switching from 1D to 1B.

Logic 4: When system work in mode 3: incoming 1 supply to load, after that the voltage of incoming 2 has been recovered, it will trip 0VBV, the diesel engine will stop, close 10VB, but II lost power for short time, Switching from 1C to 1B

Logic 5: In case both incoming lost power, bus I and bus II both lost voltage, it will trip 1VB and 10VB, close 0BVB, go to black start mode, Scenario 4.

4.5. Function of mode 1

The function are: 1, Peak Shaving and Valley Filling, 2, Stabilize Fluctuation,3, frequency regulation, 4, voltage regulation

4.5.1. Peak shaving and valley filling

Because of its fast response and its superior peaking performance of the large-scale battery energy storage system, in the electricity trough as the load store electrical energy, in the peak period as the power to release energy, thereby reducing the peak valley load difference, improve the economy and safety of power grid operation. This function can be set as “Local” or “Remote” mode. In remote mode, according to the power plan curve transmitted by the main station (EMS), the energy storage charge and discharge power are controlled. In local mode, the stored charge and discharge power are controlled in accordance with the planned curve value set by this controller. The local planning curve can be formulated according to the peak and valley price. [7-8]

4.5.2. Stabilize fluctuation

Photovoltaic output is affected by light intensity and has fluctuation characteristics. Especially in the grid connected state, it is always in the MPPT control mode, and the change of light intensity has a great influence on the PV output. The fast charging and discharging characteristics of the energy storage battery can be used to stabilize the fluctuation of PV output. The fluctuation control is divided into first order filtering control method and average filter control method according to the algorithm.

4.5.3. Frequency regulation

The Microgrid controller will detect the frequency of power grid, it will based on the offset of the frequency, and calculate the power output of BESS P_{bess} according to the Droop characteristic equation and SOC of BESS, and send the power control command to BESS.

4.5.4. Voltage regulation

Voltage regulation use the controller to detect the voltage of power grid, according to the offset of the voltage, and calculate the reactive power output of BESS Q_{bess} according to the Droop characteristic equation , and send the reactive power control command to BESS.

4.6. Black start

Microgrid controller detect the open position of 1VB and 10VB, MGCC trip SW6 and SW7, limit the load within 3MW via load shedding which the trip matrix is provided in the setting, the above process will finish in 1 minute.

And then start the BESS via VSG mode, after the system voltage has been set up, then start the diesel generator via parallel mode, after diesel generator start finish , BESS switch to PQ mode， diesel generator check the voltage and frequency fluctuation and switching to main source mode. Then it will automatic connect the load which has been shedding by black start.

4.7. Load recovery

In Microgrid controller will have the setting for control prohibit, when manually open or close the LBS, and not allow Microgrid controller to automatically open and close the LBS, need control in the Microgrid EMS to prohibit the control for LBS. Local switch at the LBS panel should be one of the input of prohibit the control for LBS

When FLISR function isolate the fault via trip the LBS will automatically prohibit automatic control for Microgrid controller, when the fault recover by operator, need cancel the prohibit control command in the HMI.

Load recovery time will be set in the Microgrid controller, after the time (since it has been shedding) finish the load will not recover to ensure the safety consideration. The maximum setting of this time will be consider as 10 minutes.

4.8. Intentional grid connecting to island (Scenario 2)

The control center or Microgrid EMS issues the island instruction. Then the MGCC receives the island instruction. It will start the diesel generator via parallel mode first to be ready for island mode. it will limited the tie line power to ensure that the tie line active power and reactive power is restricted in the allowable range via control the diesel generator and BESS, In case BESS and diesel power output is lower than the load, need shed some load and send trip command for the LBS and send mode switching commands to switch the diesel generator to island mode. [9-10]

4.9. Island to grid connecting

In case the island is from the intentional island command, it will not automatically connect back the grid even the voltage of grid side is normal. In case the island is not from the intentional island command, after the Microgrid controller detect the voltage of power grid side has recovered, it will control the voltage and frequency of diesel generator, the voltage and frequency of Microgrid side to synchronize close the LBS to connect back the power grid. After connect back to grid, change the diesel generator back to parallel mode.

5. Conclusions

The key issue for access for big scale distributed renewable energy is the voltage stability and power quality issue due to the unstable of the power generation of distributed renewable energy such as PV or wind farm. Microgrid is a locally controllable power system composed of distributed generation (Wind/Solar/Diesel, etc), energy storage and load, which can be connected to bulk power system and islanding operation and it is also an autonomous system to realize control, protection and management by itself, further more it is an efficient way to make full use of distributed generation. This paper introduces the background of Thailand first MW level smart Microgrid project at Mae Sariang, Chiang Mai Thailand. A typical topology and function design for Microgrid project at rural area also has been proposed in this paper which is possible to use in other similar Microgrid project. DIgSILENT PowerFactory is used to simulate the power system study of the area for the purpose of function design and relay setting calculation. Finally, the microgrid system can increase reliability and stability, reduce SAIDI and SAIFI and reduce greenhouse gas emission. Consequently, Mae Sariang district becomes green community.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

A, C conducted the research; B analyzed the data; A, C wrote the paper; all authors had approved the final version.

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References

[1] Tirapong K, Patompong B, Titti B. PEA Microgrid design for coexistence with local community and environment: Case study at Khun Pae village Thailand. *IEEE Innovative Smart Grid Technologies-Asia (ISGT-Asia)*, 2017; (1-5).

[2] Suttichai P . Microgrid controller: Control and operation- Thailand IEEE,Session 3.2 13 Sep 2018.

[3] Haobin Z, Guangfu X, Xianwen Z, Qunbing Y, Jun C, Xu L. Microgrid coordinated control system with VSG-CIRED Workshop - Ljubljana, 7-8 June 2018.

[4] NR Electric Co., Ltd. PCS-9617MG Microgrid controller, 2017.

[5] IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, IEEE std 1547-2003-2014.

[6] Li FS, Li RS, Zhou FQ. *Microgrid Technology and Engineering Application*, Academic Press, 2016.

[7] Moghimi M, Leskarac D, Panchal C, Lu J, Stegen S. Energy management system for peak shaving in an experimental microgrid employing MILP optimization. *International Journal of Engineering and Innovative Technology (IJEIT)*, January 2018.

[8] Estefanía P, Jon A, José IG, Iñigo Martínez de A, Edorta I. AC and DC technology in Microgrids: A review. *Renewable and Sustainable Energy Reviews*, Mar, 2015; 43: 726- 749.

[9] Loh PC, Ding L. Chai Y, and Blaabjerg F. Autonomous operation of hybrid microgrid with AC and DC subgrids. *IEEE Trans. Power Electron.*, May 2013; 28(5): 2214-2223.

[10] Cho C, Jeon JH, Kim JY et al. Active synchronizing control of a microgrid. *IEEE Trans. Power Electronics*. 2011; 26(12): 3707-3719.