ระบบบริหารจัดการพลังงานของการผลิตกำลังไฟฟ้าแบบผสมพร้อมกับตัวกักเก็บพลังงานแบตเตอรี่เพื่อการประยุกต์ใช้กับโครงข่ายไฟฟ้าอัจฉริยะในจังหวัดแม่ฮ่องสอน

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Energy Management System of Hybrid Power Generation with Battery Energy Storage for Application to Smart Grid in Mae Hong Son

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Electrical Engineering
Department of Electrical Engineering
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Field of Study	Electrical Engineering
Thesis Advisor	Professor David Banjerdpongchai

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ณพสิทธิ์ พิพิธพัฒนาปราปต์ : ระบบบริหารจัดการพลังงานของการผลิตกำลังไฟฟ้าแบบผสมพร้อมกับตัวกักเก็บพลังงานแบตเตอรี่เพื่อการประยุกต์ใช้กับโครงข่ายไฟฟ้าอัจฉริยะในจังหวัดแม่ฮ่องสอน (Energy Management System of Hybrid Power Generation with Battery Energy Storage for Application to Smart Grid in Mae Hong Son) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ศ. ดร. เดวิด บรรเจิดพงศ์ชัย, 76 หน้า.

วิทยานิพนธ์ฉบับนี้นำเสนอกลยุทธการจัดสรรกำลังไฟฟ้าสำหรับจังหวัดแม่ฮ่องสอน ซึ่งจะแบ่งเป็นสองโหมดคือ โหมดเหตุการณ์ปกติ และโหมดแยกโดด โดยนำเสนอแนวทางการบริหารจัดการพลังงานไฟฟ้าผสมผสานกับแหล่งกำเนิดพลังงานไฟฟ้าจากแหล่งพลังงานทดแทนในจังหวัดแม่ฮ่องสอน ในโหมดปกติได้ออกแบบแบบจำลองระบบไฟฟ้าและส่วนประกอบต่างๆ ของระบบไฟฟ้าในจังหวัดแม่ฮ่องสอนแบบเชิงเส้นเพื่อแก้ปัญหาโดยใช้กระบวนการหาค่าเหมาะที่สุดโดยใช้โปรแกรมเชิงเส้น สำหรับฤดูแล้งและฤดูฝนโดยสร้างสมการจุดประสงค์แบบหลายเป้าประสงค์ เพื่อให้ค่าการบริหารจัดการพลังงานรวมต่ำสุด และค่าปลดปล่อยคาร์บอนไดออกไซด์รวมต่ำสุด ในการทดลองได้ใส่ระบบบริหารตัวกักเก็บพลังงานแบบแบตเตอรี่ที่อยู่ในแผนการพัฒนาโครงการระบบโครงข่ายไฟฟ้าอัจฉริยะของจังหวัดแม่ฮ่องสอนเข้ามาด้วย ผลลัพธ์ที่ได้เปรียบเทียบกับข้อมูลการส่งจ่ายกำลังไฟฟ้าประจำปี พ.ศ. 2557 ของการไฟฟ้าส่วนภูมิภาคจังหวัดแม่ฮ่องสอน ในโหมดแยกโดด วิทยานิพนธ์นี้ได้ศึกษาความเป็นไปได้ของการเกิดความผิดพร่องในระบบไฟฟ้าของจังหวัดแม่ฮ่องสอน โดยเน้นไปที่ระบบจัดสรรไฟฟ้าที่อาจนำไปสู่สภาพโดดเดี่ยวของระบบไฟฟ้า การศึกษานี้อยู่บนพื้นฐานของแบบจำลองระบบไฟฟ้าแบบผสม ตัวกักเก็บพลังงานแบตเตอรี่ หลักการอนุรักษ์พลังงาน และหลักการสำคัญระบบไฟฟ้ากำลัง ผลลัพธ์จากการทดลองแสดงให้เห็นถึงแนวทางการจัดสรรกำลังไฟฟ้าของแม่ฮ่องสอนในสถานการณ์เมื่อเกิดความผิดพร่องในระบบไฟฟ้าจากกระบวนการหาค่าเหมาะที่สุด

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สาขาวิชา วิศวกรรมไฟฟ้า ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

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NOPPASIT PIPHITPATTANAPRAPT: Energy Management System of Hybrid Power Generation with Battery Energy Storage for Application to Smart Grid in Mae Hong Son. ADVISOR: PROF. DAVID BANJERDPONGCHAI, 76 pp.

This research proposes a dispatch strategy to Mae Hong Son (MHS) power system which is classified in 2 modes of operation: the normal mode and islanding mode. In this research, we design dispatch strategy of energy management system (EMS) using various renewable sources within MHS. In normal mode operation, we model the power system components in linear model and formulate EMS as linear program to solve for the optimal dispatch. Multi-objective function approach aims to minimize Total Operational Cost (TOC) and Total CO_2 Emission (TCOE). In addition, we add Battery Energy Storage (BES) to the power generation and compare the results of operation to that of existing system as of 2014. In islanding mode, we go through various possibilities such as fault at day/night time, with/without BES. We formulate the dispatch strategy after fault subjected to constraints on hybrid power generation, battery state of charge, and power balance principle along with the power system condition. The results show the dispatch profiles of MHS power system based on the optimal operation.

Department:	Electrical Engineering	Student's Signature	....
Field of Study:	Electrical Engineering	Advisor's Signature	....
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Chapter 1

Introduction

1.1.Motivation and significant of the research problems.

MHS is located in the remote mountain area in the north-western Thailand. It had just connected to grid with 115 kV line in the April of 2014 after under construction for almost 10 years. Few years ago, MHS had faced the worst electrical power reliability and quality in Thailand [1]. Meanwhile, MHS has potential renewable energy resources, for example: mini-hydro and PV power plant. In 2013, we worked on the optimal operation of the MHS Energy Management System (EMS) without 115 kV grid connect to zone 2 that is the main residential, government, and core business area of MHS. The 115kV transmission line was still under construction and the main power that supply MHS was coming from 22kV transmission line that contain huge loss [2]. Fig. 1 shows the single line diagram of MHS.

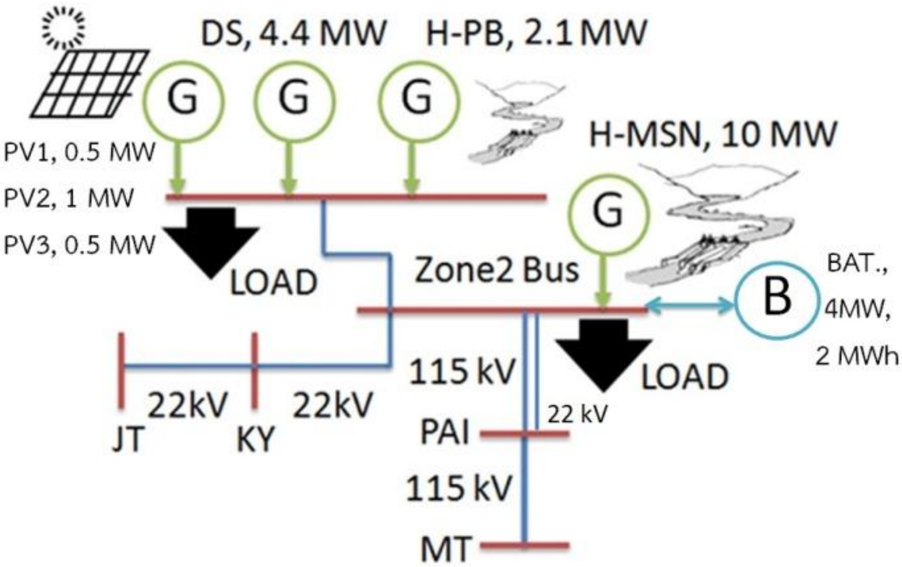

Fig. 1 Single line diagram of MHS zone 2 in MHS smart grid project.

In 2007, Mulugetta *et al.* proposed the green future (GF) as one of power sector scenarios for Thailand [3]. GF scenario offers an optimistic route for energy security by installing additional proportion of renewable energy that goes along well with environmental friendly concept. At present, Thailand energy profile bases on natural gas more than 70 percent at the end of 2013. Their work showed that GF shall provide more benefit to the country in long run. In 2013, Palma-Behnke *et al.* presented a renewable-based microgrid energy management system together with water demand management and demand response that was practical to remote area community energy management system [4]. In 2005, Shahirinia *et al.* presented hybrid power generation system involving an effective fuel consumption and CO_2 emission [5]. The performance of hybrid distribution generation depended strongly on power management strategies between multi-sources. The performance of hybrid distribution generation depended on dispatch strategies between various sources of generation. Maximizing efficiency and security of power system, energy storage took part in the first role. Poonpun et al. studied the cost analysis of various grid-connected energy storages in terms of cost added to the normal energy price [6]. This helped EMS to operate while concerning real cost of power system with battery in the operation.

By the end of 2014, we have worked on multi-objective dispatch strategy between economical approach and environmental approach where the power system already connected to 115kV from the north with additional PV with Time Of Used system (TOU). The results show that with renewable based system minimum of total operating cost (TOC) and the minimum of total CO_2 emission (TOCE) can be in the same dispatch profile [7]. Smart grid road map of Thailand is moving ever closer to the day of commissioning of MHS pilot project to the day MHS have a better electrical quality.

Our research investigates EMS that will offer the solution to minimize the operating cost based on energy cost including fuel cost at normal mode operation with battery as we cast as a linear objective function and subjected to linear constraints associated with hybrid power generation in various seasons. To let MHS operate as microgrid, islanding operation need to be study as an emergency plan; we study on the strategies of energy management of MHS in this case too.

1.2.Overview of energy management system

“Energy management system (EMS) is the process of monitoring, controlling and conserving energy in a building, organization, or distribution system”, [8]. EMS can be divided in 2 types; these are single unit EMS and whole system EMS.

Single unit EMS is related to building or structure energy management system with the main purpose to maximize the efficiency and productivity of staffs that work in that place by the control of comfort level and, at the same time, minimize the energy cost. Single unit EMS is designed to monitor and control of heating, ventilation, and air-conditioning system that is approximate 60% energy consumption in the building. In 2014, real time monitoring energy consumption in domestic application is the currently application in EMS while some provide general energy saving tips that not focusing on any specific electrical appliances. Finding the set point of the EMS’ components, weighted multi-objective optimization is purposed with these weighted indexes: decreased cost of energy, decrease greenhouse gas emission.

Whole system EMS can be divided into 2 types of EMS—customer owned EMS and electrical utilities owned systems. Microgrid EMS can be classified as the customer owned EMS; for manage this type of EMS, couple ideas are proposed--centralized energy management system (CEMS) and distributed energy management system (DEMS). The operator in CEMS can take full control in range of operation of every component in their owned power system but the disadvantage of CEMS is the lack of flexibility to modify the system components with related to many parties. However in the DEMS, it provides more flexibility to the components’ owner; the different agents only have to communicate with central microgrid operator. The big disadvantage for the DEMS is that DEMS might not be reach optimal operation of the microgrid because the lack of strongly cooperation between all of the components. Electrical utilities system energy management is about the big picture of the national power system: the distribution management, energy efficiency, time of use, demand response, spinning reserve.

The completion in energy management system is not only management of supply side but the system has to do load management too. The operation is classified in 3 states—routine (normal mode), emergency and restorative. Load management is a useful tool to meet the objective in the normal and restorative operation but not the emergency state [9]. In Fig. 2 Daily load curve in summer [10]Fig. 2, we can notice that the majority sections of load consumption are industrial, commercial and residential section. Two ways to control load demand are real time electrical energy pricing which operator can do rate design by using cost curves as shown in Fig. 3 and load control by using equipment.

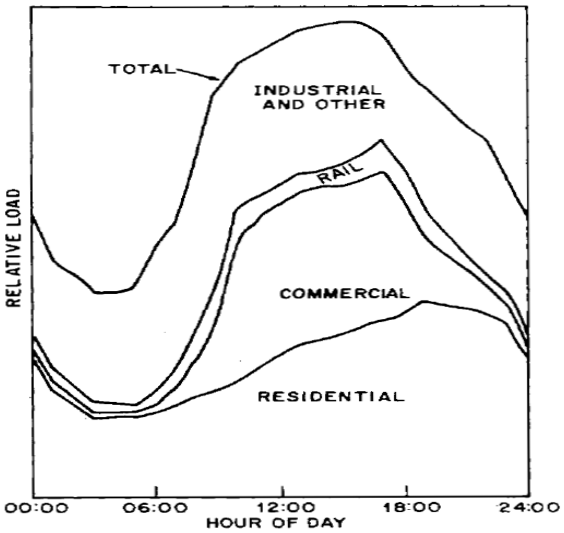

Fig. 2 Daily load curve in summer [10]

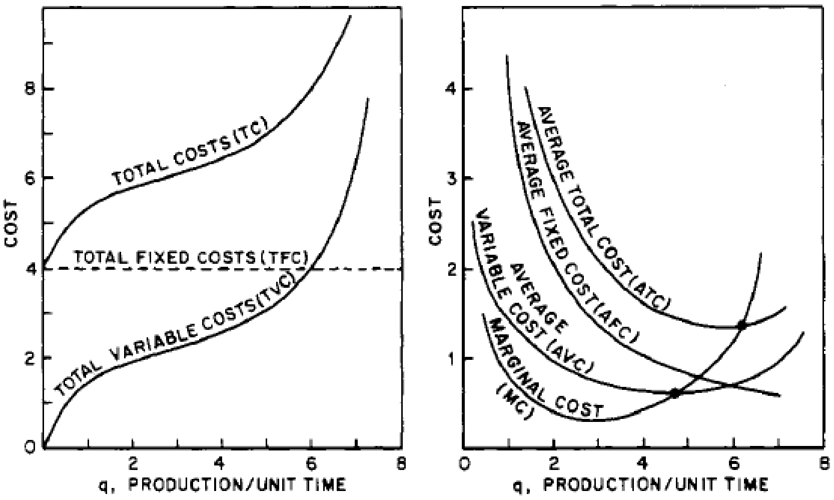

Fig. 3 Cost curves for a typical firm total costs (left); average and marginal cost (right).

EMS in many research have shown the results of operating cost reduction even though they applied to different area, have different components, and calculated by difference algorithm. Every EMS share same similarity in 3 mains parts [11]. Those are forecasting module for load and PV, energy storage module, and optimization module which bases on the model of power system or application. Temperature and radiation are the inputs of PV forecast module but for other renewable forecast are depend on the application. Load forecast modules mostly based on historical data only few developed their own algorithm. In 2014, Kanchev *et al.* proposed multi-objective EMS apply to the urban microgrid in which the load forecast module which based on Supervisory Control And Data Acquisition (SCADA) using the algorithm to adjust the parameters of optimization module by comparing the 1 day-ahead and 1 hour-ahead load forecast data [12].

The biggest section of energy storage in the world is hydro storage; because of its lowest cost of operation compared to other types of storage [6] but its' slow ramp rate, high installation cost, and the difficulty on how to find the building area are the disadvantages hydro storage. Another promising storage is battery storage for using in emergency situation, helping power system to do load management, and smooth fluctuation of renewable source.

The optimization module is the most important part of the EMS. The frequency algorithms that had been use in EMS were linear programming which based on the linear constraints and genetic algorithm. Genetic algorithm can deal with more complicated power system model but the disadvantage was that it takes more calculation time. Many research are focusing on improve the efficiency of algorithm by design more specific power system models or to acquired multi-objective approach of dispatch the mostly suitable to their application.

In our study, we introduce the multi-objective approach apply to MHS area with battery storage system in 30 minute time step. The forecasting module applies for only PV forecast. The energy storage system bases on the actual plan of battery implementation of MHS smart grid pilot project 2014 in which we study on how to manage battery in the most efficiency way in the normal mode and islanding mode of operation. The last part is optimization module. The linear program with uncertainty in load that applies to the MHS power system is proposed with multi-objective cost function bases on the existing feeder data of MHS in 2014.

1.3.Thesis Objective

1. Propose optimal dispatch strategy for hybrid power system with battery energy storage of Mae Hong Son (MHS). Dispatch Strategies proposes corresponding to normal mode and islanding mode of Operation.

1.4. Thesis Scope

1. Load and renewable profile based on 2014 MHS feeder data; the results will be classified as dry season and rainy season.
2. Power system of MHS is reference on the latest smart grid model by 2014.
3. Dispatch on economical operation and environmental operation and multi-objective operation.
4. Time step of the operation is 30 minute corresponding to the feeder data for normal mode of operation and 1 minute time step during islanding operation..
5. EMS is based on spec output of the power system components in MW and MWh while not consider of voltage.

1.5.Expected Results

1. Optimal dispatch strategy and adjustable dispatch program that provides set point for MHS power system with battery.
2. Dispatch profile in the case studies consists of
   1. Normal mode of MHS’ dry season.
   2. Normal mode of MHS’ rainy season.
   3. Islanding mode of MHS’ dry season.

1.6.Research Procedures

1. Review literatures related to EMS and Battery Storage System.
2. Survey MHS to investigate characteristic of hybrid power generation and transmission line in MHS.
3. Develop linear program for compute optimal dispatch in dry season and rainy season in normal mode of operation.
4. Compare the result in 3) to the existing dispatch profile of MHS in 2014.
5. Develop linear program for compute optimal dispatch in dry season and rainy season in islanding mode of operation.
6. Summarize the results, analysis, and discussion.
7. Complete thesis writing and have oral defense examination.

1.7.Thesis Outlines

In Chapter 1, the introduction of energy management research of Mae Hong Son is presented. Next, chapter 2 presents problem formulation of this research consists of the concept idea and how we execute the problem that are dispatch strategy and the parameter in the operation that we will get in detailed on the numerical results in Chapter 3 and Chapter 4 which is focusing on each mode of operation, then we will explain how we construct the linear program for dispatch energy and objective function of the energy management of Mae Hong Son. In chapter 3 and 4, those are the normal mode and islanding mode of operation for Mae Hong Son respectively in which we design the operation for define the set point of operation of each components in Mae Hog Son. In this 2 chapters, there will be describe the detail, concept, and technique of calculation of each operation and also the result analysis and discussion. Next chapter is conclusion and future work. This chapter will summary on what we have done and what is the useful results we get for whole research period during 2013-2015.

Chapter 2

MHS energy management framework

2.1.Power generation model

PV Array Model [13]

PV output of time step *t* can be forecast by using $T_C(t)$ the temperature at the beginning of time step *t* in degree Celsius and $G_T(t)$ the radiation. The PV output is given by

$$P_{PV}(t) = \frac{G_T(t)}{G_{ref}}(P_{Rated} + \mu(T_C(t) - T_{ref})) \,, \tag{1}$$

where $P_{PV}(t)$ is the power output generated by PV array, μ is temperature constant, P_{Rated} is rated power, G_{ref} is radiation reference and T_{ref} is the reference temperature of the PV. In the smart grid case study, PV1, PV2 and PV3 are calculated as one PV power plant calls **PV output model**.

For PV Power plant as the power output is limit by the environment which are radiation and surrounding temperature so the boundary limit of this power plant is depend on itself but not more than 500 kW as this is the limit of it capacity. The power generates by PV is as follows

$$0 \leq P_{PV}(t) \leq U_{PV} \,. \tag{2}$$

$$\text{Thus, } 0 \leq x_{PV}(t) \leq P_{PV}(t) \,, \tag{3}$$

where U_{PV} is the maximum power that PV power plant can generator whatever how much power PV can be generate from solar power, and $x_{PV}(t)$ is the actual power output that PV power plant transmit to the MHS power system. The two constraints above call **PV boundary constraints.** This $x_{PV}(t)$ is the optimization variable. In practical, the power output of the whole PV array never reach the maximum limit of the power plant but the highest peak was around 450 kW. In the smart grid plan of MHS by 2014, there will be additional PV farm for 1 MW and PV rooftop in MHS city for 500 kW.

Mini-Hydro Power Plant Model and Daily Water Storage

Mini-hydro power plant is one of the main power supplies of MHS. Its generation is related to water level of the reservoir. The amount of water in MHS is strongly associated with season of the year. The water flow rate can be controlled by flow rate valve of each mini-hydro dam to generate electrical power. Even though the model of mini-hydro is complicated, we can manipulate control valve to adjust the output power of mini-hydro. Therefore, we model it as the function of month for simplicity calls **Water storage constraint**.

$$\sum_t x_{H,i}(t) = \; T \cdot \overline{x_{H,\iota,m}} \, , \tag{4}$$

where $\overline{x_{H,\iota,m}}$ is an average power generation of the ith mini-hydro of the mth month in a unit of kW; $x_{H,i}(t)$ is the power output of mini-hydro and T is the number of the time step. $x_{H,i}(t)$ is the optimization variable. In practical, the turbine generator of mini hydro have a small ramp rate of 5-10 minutes from start to the maximum output rate. Ramp rate of mini hydro is defined as

$$\left| x_{H,i}(t) - x_{H,i}(t-1) \right| \leq R_{H,i} U_{H,i} \, , \tag{5}$$

where $U_{H,i}$ is the capacity of mini hydro and $R_{H,i}$ is the ramp rate in percent per time step calls **Water ramp rate constraint**.

There are two mini-hydro power plants in MHS pilot smart grid study project area. We note that MHS mini-hydro dams are too small to operate as pump storage which is the main type of hydro storage so we try to manage power generation during the day to share load balance helping us cut load at peak period. Thus, let us define

Mini-Hydro power plants have the limit of power production due to their limit power output of the hydro generator and level of water of the dam. The Mae San Ngar consists of 4 generators which all can be sum up to 10 MW in power capacity generation. While the Pabong mini-hydro power plant have only 800 kW power production capacity while it has plan to upgrade to 2.1 MW in soon future. Constraints below calls **Hydro boundary constraint.**

$$0 \leq x_{H,i}(t) \leq U_{H,i}. \tag{6}$$

In MHS, there will be 2mini- hydro power plant at Pabong and Mae Sa Ngar as we call $x_{H,1}$, and $x_{H,2}$ respectively.

Diesel Generator Model

We consider diesel generator as a linear static component and neglect dynamic behavior due to a large sampling time. In MHS diesel power plant, there are 2 diesel generators with 1,000 kW capacity and 3 diesel generators with 800 kW capacity. They are modeled as

$$0 \leq x_D(t) \leq U_D, \tag{7}$$

where $x_D(t)$ is the power output of diesel generator and U_D is the maximum output of the power plant. $x_D(t)$ is the optimization variable. Constraint above calls **Diesel boundary constraint.**

We consider diesel generator ramp rate which is for too fast compare to the time step of normal mode operation that can be 1 time step to the maximum capacity. However, in case of transient state during fault the ramp rate of diesel generator can be observed by the 1 minute time step. The ramp rate constraints is written as follows

$$|x_D(t) - x_D(t-1)| \leq R_D U_D \, , \tag{8}$$

where R_D is the ramp rate in percent per time step. The ramp rate of diesel generator is quite fast compare to other type of generators, its ramp rate is approximately around 5 minute to the maximum capacity so in case of 1 minute time step; $R_D = 20\%$. The constraints above call **Diesel ramp rate constraint.**

We has given start-up cost and running cost to be simpler by combining in terms of average fuel cost per unit of power output, FC_D and the operating and maintenance cost is given as a function of unit output, O_D. The cost of diesel generation per unit output for whole optimization period F_D is as follows as calls **Diesel cost function**.

$$F_D = \sum_t x_D(t)(FC_D + C_D). \tag{9}$$

There is only one diesel power plant in MHS at capacity of 4,400 kW at Pabong power plant.

2.2.Power system of MHS

Transmission and Distribution Model [7]

Selling and buying electrical power are associated with energy authorized organization. For MHS, we buy energy from 3 main transmission lines: two circuits of 22 kV and one parallel transmission line of 115 kV. The price rate of buying electrical energy depends on level of voltage, Time of Used (TOU), peak charge. Selling price of specific type of electrical energy to grid depends on contract between electrical supplier and the electrical authority. In our study, we assume that MHS is the microgrid and do not have any special contract and use a standard rate which depends on voltage level pricing for buying energy and selling energy. We calculate the energy cost when buying and selling without any adder while concerning transmission loss from the buying substation to the city area and distribution loss in the load area. The transmission function; F_T is given as follows.

$$F_T = F_{TP} + F_{TOP} + x_{GP,115}PC_{115} + x_{GP,22}PC_{22} \ , \qquad (10)$$

where

$$\begin{aligned} F_{TP} = {} & \textstyle\sum_{t_p}(x_{Gi,115}(t_p)C_{p,115} - x_{Go,115}(t_p)C_{p,115}L_{T,115} \\ & + x_{Gi,22}(t_p)C_{p,22} - x_{Go,22}(t_p)C_{p,22}L_{T,22}) \ , \end{aligned} \qquad (11)$$

$$\begin{aligned} F_{TOP} = {} & \textstyle\sum_{t_{op}}(x_{Gi,115}(t_{op})C_{op,115} - x_{Go,115}(t_{op})C_{op,115}\, L_{T,115}) + \\ & (x_{Gi,22}(t_{op})C_{op,22} - x_{Go,22}(t_{op})C_{op,22}L_{T,22} \ , \end{aligned} \qquad (12)$$

$$Trans.Loss = x_{Go,115}(t)L_{T,115} + x_{Go,22}(t)L_{T,22} \ . \qquad (13)$$

$x_{Gi,115}(t)$, $x_{Gi,22}(t)$, $x_{Go,115}(t)$, and $x_{Go,22}(t)$ are grid-in power flow and grid-out power flow corresponding to MHS grid where 115 kV transmission line is the line connect between MHS and Mae Thang (MT) and 22 kV transmission line is the line connect between MHS and Jom Thong (JT) as shown in Fig. 1. The $C_{p,115}$, $C_{p,22}$, $C_{op,115}$ and $C_{op,22}$ are cost of energy unit (kWh) at peak and off peak. $L_{T,115}$, and $L_{T,22}$ are transmission loss proportion in which and be calculate the transmission loss of selling energy to Chiang Mai by using $Trans.Loss$ equation. Peak power cost which is in proportional to the monthly peak cost. In additional, TOU considers peak time from 9. am. to 10 pm. (t_p) and the rest are off peak (t_{op}) period. $x_{GP,115}$, and $x_{GP,22}$ are power peak of transmission. PC_{115}, and PC_{22} are peak cost per kW the transmission line. To calculate the peak of tie flow, we add the peak constraint as follows

$$x_{Gi,i}(t_p) - x_{GP,i} \leq 0, \qquad (14)$$

where i^{th} is the transmission line index which have 22 kV transmission line and 115 kV transmission line. However, peak power of tie flow or transmission line is still be under the limit of the equipment that can be describe as follows

$$0 \leq x_{GP,i} \leq U_{T,i}. \qquad (15)$$

Thus, $0 \leq x_{Gi,i}(t) \leq U_{T,i}$, (16)

and, $0 \leq x_{Go,i}(t) \leq U_{T,i}$. (17)

$x_{GP,i}$, $x_{Gi,i}(t)$ and $x_{Go,i}(t)$ are all the optimization variables. We call these constraints as **Transmission line boundary constraints.**

Model of Battery Energy Storage

Battery energy storage (BES) is one of the most important components in smart grid application. BES can be used in various applications such as peak load reduction, renewable energy storage in off peak period, customer feeder load management, power smoothing of PV array, frequency regulation, black start and others. Energy in BES can be observed by a state of charge of battery. We call equation below as **Battery model.** We define $x_s(t)$ as a state of charge of battery at time step *t* as follows

$$x_s(t+1) - x_s(t) - x_{sc}(t)\eta_C\eta_i + \frac{x_{sd}(t)}{\eta_d\eta_i} = 0 \, , \qquad (18)$$

where $x_{sc}(t)$ is the electricity allocated for charging BES at time step t, and $x_{sd}(t)$ is electricity output discharged to the grid from BES. $x_s(t)$ is the state of charge of battery that is the one who is store and discharge the energy working as the energy tank and the level of the energy in this tank have to limit by some criterion. For example, we have to spare some energy for using in emergency case and also maximize the lifetime of battery or the energy inside have to be enough to help system cut off the peak load. The state of charge has to limit in some certain value calls **Battery state of charge boundary** as follows

$$S^{min} \leq x_s(t) \leq S^{max} , \quad (19)$$

where S^{min} and S^{max} is the level limit of the state of charge of battery. In this research, we using state of charge to be 50%-90% or the battery storage level will be in between 1000 kWh to 1800 kWh. 1000 kWh is the number came from the fact that this number of energy can maintain the whole power system for at least 5 minute (we will show the evident in chapter 4) that is standard time for startup diesel generation and hydro power plant and 1800 kWh as the maximum of state of charge is for maximize the life time of battery for being last longer. η_c, η_d and η_i are charge efficiency, discharge efficiency, and inverter efficiency respectively. The efficiency of battery is related to the efficiency of inverter, charge and discharge efficiency. The calculation is made by the flow of energy from power system though inverter to battery and energy from the battery though inverter to the power system. The efficiency of BES is defined as

$$\eta = \eta_i{}^2 \eta_c \eta_d , \quad (20)$$

We can limit charge power and discharge power of battery by adding boundary constraints on x_{sc} and x_{sd}. These boundary criterions depend on the inverter device of battery storage in which is adjustable and we can set them to most suitable to the dispatch objective. We calls **Battery charge and discharge boundary.**

$$0 \leq x_{sc}(t) \leq d_{sc} , \quad (21)$$
$$0 \leq x_{sd}(t) \leq d_{sd} , \quad (22)$$

where d_{sc} and d_{sd} are the charge power limit and discharge power limit of the battery. In this research, as we assume that the default smart grid plan of implementation of battery in MHS is 4 MW inverter so with time step 30 minute it can charge to full capacity from zero. $x_{sd}(t)$, $x_{sc}(t)$, and $x_s(t)$ are the optimization variable.

Additional parameter for battery is that we can set $x_s(t)$ for the initial and final as follows

$$x_s(t_i) = SOC_i \,, \tag{23}$$

where SOC_i is the state of charge at t_i time step.

Power Balance Constraint and Loss (PBC)

Power balance is a basic and necessary constraint of the power system. Load, generation and loss must be balanced at all times as follows.

$$x_{H,1}(t) + \ x_{H,2}(t) + x_{PV}(t) + x_D(t) + x_{Gi,115}(t) + x_{Gi,22}(t) - \\ x_{Go,115}(t) - x_{Go,22}(t) - x_{sc}(t) + x_{sd}(t) = P_L(t)(1 + L_D) \tag{24}$$

where $P_L(t)$ is load demand and L_D is distribution loss included where $0 \le L_D \le 5\%$ and distribution loss describes as follows

$$Dist. Loss = \ \sum_t P_L(t) L_D \,. \tag{25}$$

In this research, the load forecast is using the MHS feeder data in 2014 as in [14]. The load in the raw data is load in which mixed with loss already.

Load and feeder description

Load in this study is calculated from the summation of feeder data of MHS in 2014.

$$P_L(t) = F_1(t) + F_2(t) + F_3(t) + F_4(t) + F_6(t) + G_3(t) + F_7(t) \\ + F_8(t) \tag{26}$$

where F is state from feeder power flow. $F_1(t)$ is the 22 kV transmission line connect MHS to the south to Khum Yuam substation then go to Mae Thang substation. This line contains huge loss due to its over length. $F_2(t)$, $F_4(t)$, $F_7(t)$, and $F_8(t)$ are the distribution feeder within MHS. $F_3(t)$ is the 22kV line from Pang Ma Pa to MHS this is the line from the north in which some interval it hangs on the same electrical post with 115 kV transmission line. When severe fault occurs it is likely to have failure together. $F_6(t)$ is the Pabong power plant feeder. In $F_6(t)$, there is distribution load too. G_3 is the summation of output of diesel power plant, mini-hydro power plant, and PV power plant at Pabong. TP1 and TP2 are the tie flow from Chiang mai in by north of 115 kV transmission line. $F_9(t)$ is the Mae Sa Ngar mini-hydro power plant output. Fig. 4 shows feeder diagram of MHS.

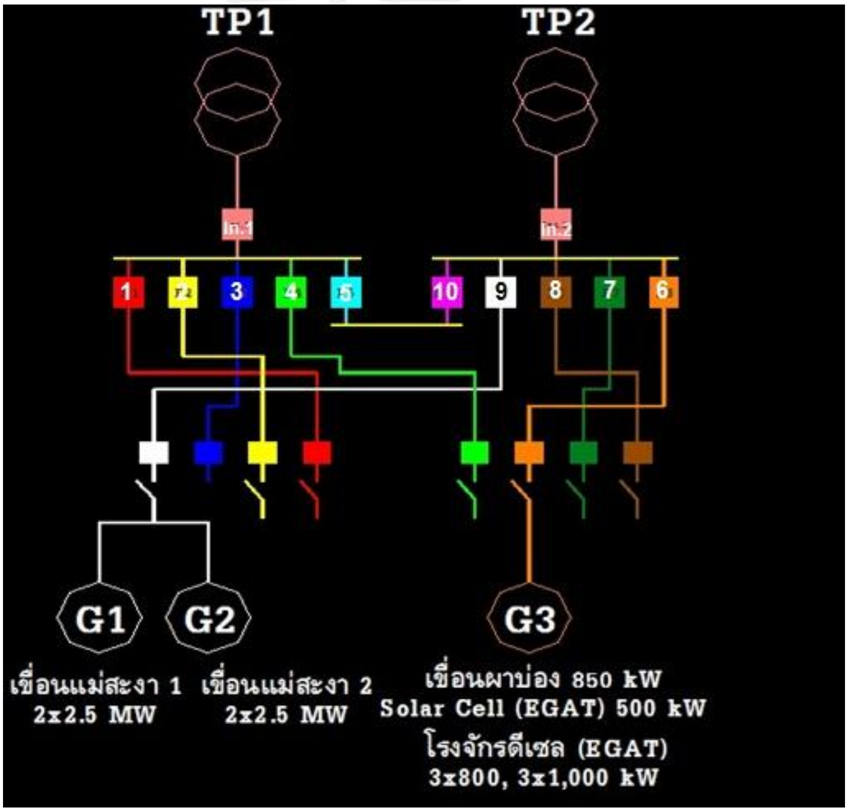

Fig. 4 Feeder diagram of MHS with hybrid generation by the end of 2014. [15]

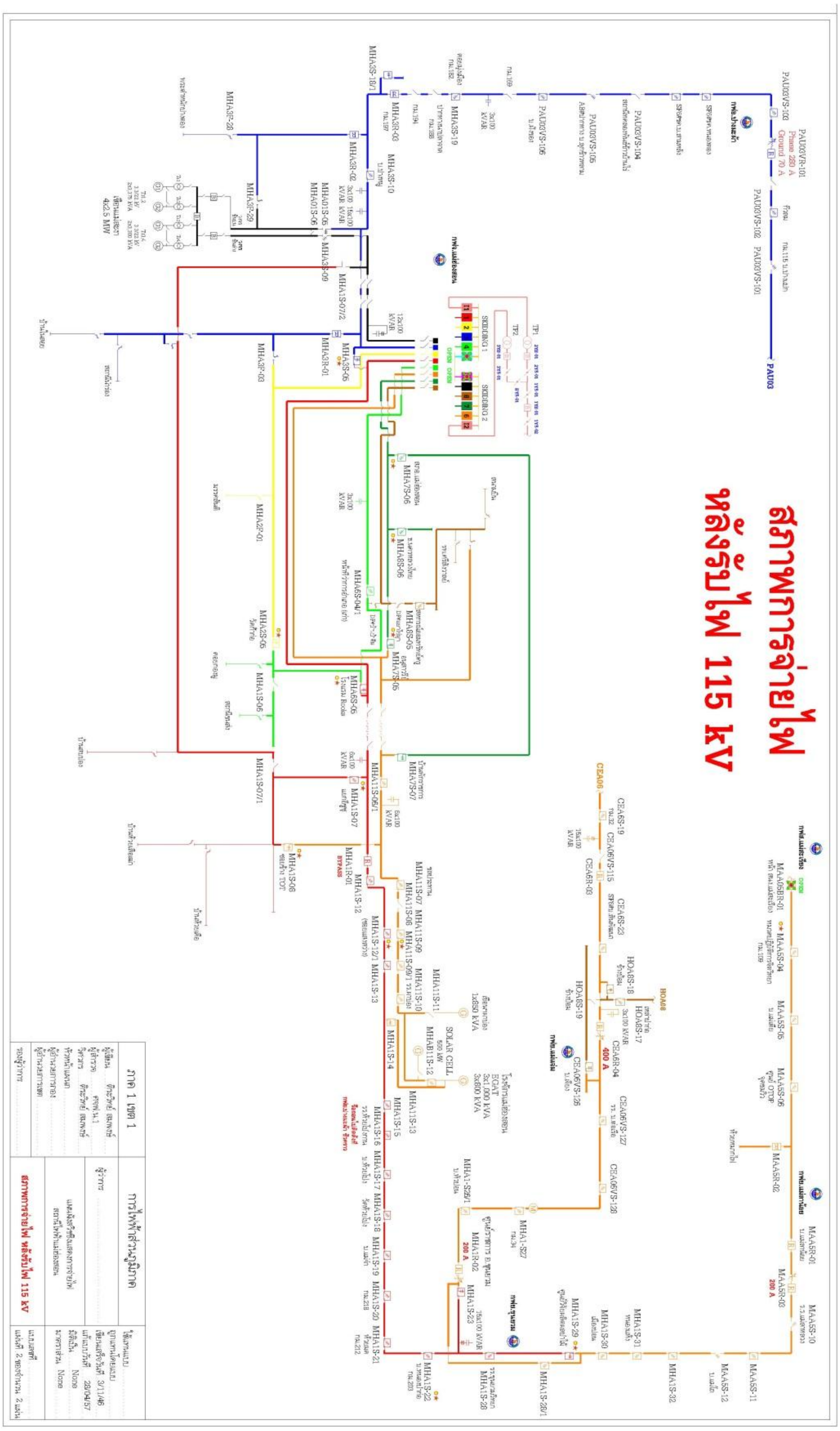

Fig. 5 MHS single line diagram by 2014

2.3. Multi-objective function

Economic Dispatch

The objective function of Total Operating Cost (TOC) is stated as follows

$$\begin{aligned} TOC = {} & \textstyle\sum_t (x_{H,1}(t)C_H + x_{H,2}(t)C_H + x_{PV}(t)C_{PV} + x_D(t)(FC_D + \\ & C_D) + x_{sc}(t)C_B) + \textstyle\sum_{t_p} \Big((x_{Gi,115}(t_p) - x_{Go,115}(t_p)L_{T,115})C_{p,115} + \\ & (x_{Gi,22}(t_p) - x_{Go,22}(t_p)L_{T,22})C_{p,22} \Big) + \textstyle\sum_{t_{op}} ((x_{Gi,115}(t_{op}) - \\ & x_{Go,115}(t_{op})L_{T,115})C_{op,115} + (x_{Gi,22}(t_{op}) - \\ & x_{Go,22}(t_{op})L_{T,22})C_{op,22}) + x_{GP,115}PC_{115} + x_{GP,22}PC_{22} , \end{aligned} \qquad (27)$$

where C_H, C_{PV}, C_D and C_B are the operating cost and maintenance cost of mini-hydro power plant, PV power plant, diesel power plant, and battery per kWh. The battery cost is given in terms of Total Battery Charge Cost per unit (TB) in dry season and rainy season respectively as follows

$$TB_D = (C_{op} + C_B)/\eta , \qquad (28)$$

$$TB_R = (C_H + C_B)/\eta , \qquad (29)$$

where TB_D is the total battery charge cost for dry season in which the renewable energy is lacking so the charging cost of battery is depend on power supply from grid from tie flow of 115 kV from Chiang Mai and the other parameter is the battery operation cost. TB_R is the total battery charge cost in rainy season where renewable energy is abundance. The charge cost comes from the cost of operation of mini-hydro and adds with the cost of operation of battery.

Environmental Dispatch

The objective function of environmental dispatch is to minimize the total CO2 emission (TCOE) from the power generation stated as follows

$$TCOE = \sum_t x_D(t)EF_D + EF_{Gi}\sum_t(x_{Gi,115}(t) + x_{Gi,22}(t)) \text{ ,} \quad (30)$$

where EF_D and EF_{Gi} are the CO_2 emission factor of diesel generator and average kg of CO2 per kWh of generation from grid network from average nationwide grid network of Thailand.

Multi-Objective Dispatch

Define the multi-objective dispatch function as follows.

$$F = (1-\alpha)\frac{TOC}{TOC_{\min}} + \alpha\frac{TCOE}{TCOE_{\min}} \quad (31)$$

where α is a weighting parameter having value between 0 and 1. The multi-objective function is valid when the minimum of TOC and TCOE is not zero. If α = 0, the problem becomes economic dispatch. On the other hand, when α = 1, it turns out to be environmental dispatch.

In case of $TCOE_{min} = 0$ the equation is not valid but this infer as the profile of system got plenty of renewable source. We will set tie flow into the MHS area to be zero or to cut off the main CO_2 source that inject to MHS and then we run economic dispatch while $x_{Gi,i}(t) = 0$ is given to acquire both zero CO_2 and economical result.

2.4. Conclusion

Our model consisted of mini-hydro power plant, PV, Diesel generator, transmission line, battery energy storage, and power balance constraints of power system. In this research, we neglect the voltage condition.

Our objective function consists of 3 concept: economic dispatch, environmental dispatch and multi-objective dispatch which weight concerns both TOC and TCOE.

Our generation models are based on cost of operation. In normal operation, we can neglect some dynamic behavior of hybrid power generation such as ramp rate of mini-hydro and diesel generator since its ramp rate is around 5 minute however in islanding operation in which we use 1 minute time step the ramp rate of components is observed.

Chapter 3
Normal mode of operation

3.1.Problem statement

MHS' existing power system in 2014 contains various types of components: 500 kW PV power plant at Pabong, 850 kW Hydro power plant at Pabong, 10 MW Hydro power plant at Mae Sa Nga, 4.4 MW diesel power plant at Pabong, 115 kV transmission line from Chiang Mai, and 22 kV transmission line from Chiang Mai. To enhance the capacity of renewable energy production due to the abundance sources of renewable energy, additional 1.5 mW PV is planned to be built and also Hydro power plant at Pabong is planned to be upgraded to 2.1 MW for increase the power production during rainy season which cover around 6 month a year. Moreover, 2 MW battery storage is under studying for being use for cut peak and also help to maintain system when fault occur.

The objective of study of energy management in normal mode is as follows.

- Minimize the total operating cost (TOC) in Baht that concerns of power generation cost, battery usage cost, peak demand charge.
- Minimize the total CO_2 emission in kilogram.

The dispatch of normal mode will be set up in 2 difference season that are dry season and rainy season which each has the different characteristic of load and renewable resource. In each season, there will be compare between the manual dispatch that is the actual dispatch profile of MHS [14], called 'Manual' case, to the economic dispatch that is set up by our energy management strategies with the existing resource of MHS, called 'Econ' case. Moreover, we will upgrade the simulated power system to be as MHS smart grid plan which has more PV farm, larger the capacity of Pabong mini-hydro generator, and the battery as we call them 'SG' cases.

As for better understanding about how battery is affect the power system. In SG cases we run various cases while varies the battery parameters to observe how battery perform.

Table 1 Power system configuration of MHS 2014 and SG

Existing Power system (2014)	Future Smart Grid Power system (SG)
• Transmission line 115 kV • Transmission line 22 kV • 10 MW Hydro Gen. @MSN • 850 kW Hydro Gen. @PB • 4.4 MW Diesel Gen. @PB • 500 kW PV Farm @PB	• Transmission line 115 kV • Transmission line 22 kV • 10 MW Hydro Gen. @MSN • 2.1 MW Hydro Gen. @PB • 4.4 MW Diesel Gen. @PB • 2 MW PV Farm @PB • 2 MWh Energy, 4 MW Power, Battery

3.2. Power dispatch strategy

Dispatch strategies will be separated describe in 2 modes of operation but both share the main concept of energy management system.

Dispatch strategy for normal mode of operation.

First of all, the energy dispatch shall satisfy the power balance constraints (PBC) and this is a must for every energy management system. For the normal mode of operation, we use 30 minute time step as we will not go through the dynamic system only seek for the set point of the big picture of the MHS power system so in this case PBC have to satisfy every 30 minute of time.

To acquire optimal set point, we have to describe the objective of the dispatch clearly whether it is economical or environment approach or we can balance between 2 of this approach to seek for the optimal one that most suitable for MHS criterion. In 2014, we reported that the Optimal Economic Operation of MHS power dispatch is identical to the result of Optimal Environmental Dispatch. It means the dispatch strategy that provides minimum

TOC also gives minimum *TCOE* [7]. The main reason is that the power system of MHS is renewable energy base. When we dispatch energy from renewable resources the energy cost and CO_2 emission will be reduced simultaneously.

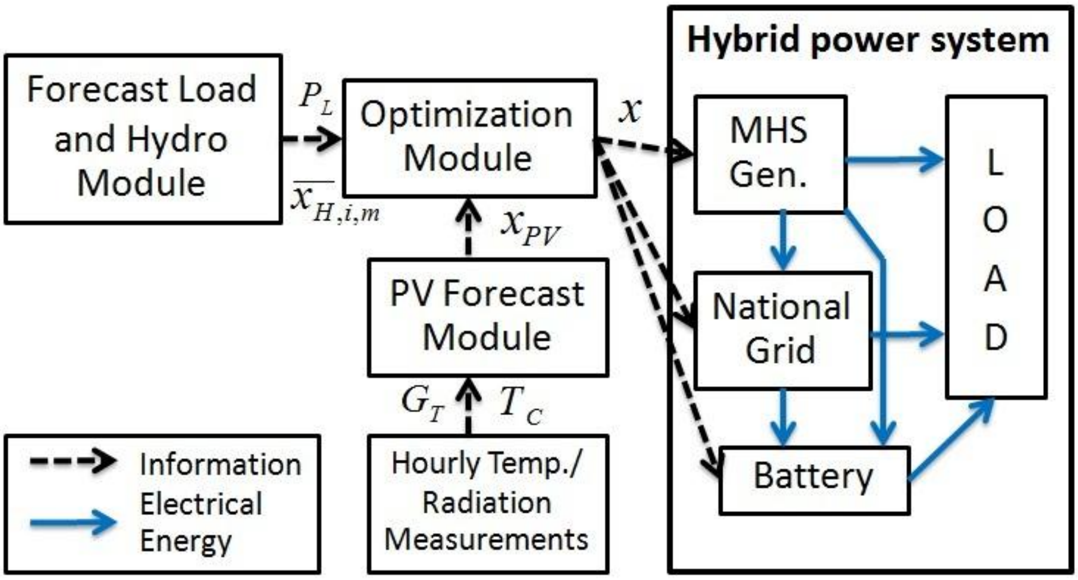

Fig. 6 Schematic diagram of normal mode dispatch strategy.

In this research, we assume that the load and renewable energy forecast are available and given to the control that is Economic Dispatch/ Environ mental Dispatch in Fig. 6. Hybrid power generation requires many parameters to expose its practical characteristic such as transmission/distribution loss, mini-hydro average output of each month, battery’s inverter efficiency, battery’s charge efficiency, battery’s discharge efficiency, operating cost of each generation, lower/upper bound, etc. We consider energy management as a linear programming optimization. We choose various seasonal parameters and vary BES size to observe their impacts on TOC and TCOE.

The power dispatch results are the set points for energy supplies. They will be sent to the hybrid power generation including power grid and mini-hydro power plant, PV power plant, diesel power plant, and BES.

Dispatch strategy for islanding mode of operation.

To study how the system will perform, we set the situation as we observe when the MHS power system which has planned to be normal operation but at the certain point of time it change itself to be islanding operation. Even though the MHS power system is perform islanding as the same but the cause of how it get to be an islanding state made it difference. As we roughly classify, there would be 2 cases; those are planned islanding and unplanned islanding. For planned islanding everything gradually increase and decease as plan. The other one is unplanned islanding. This is something that causes by fault it suddenly collapse the power system and MHS power system went black out.

As we have given the overview of MHS that is located in the mountain valley in the very north west of Thailand. The main problem is the frequently faults that occur along the long transmission line of MHS. Due to the fact that the System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDY) of MHS is rather high compare to other area in Thailand which is approximate in the single digit number as shown in Table below.

Table 2 SAIFI and SAIDI of MHS in before 2011.

Electricity Authority	2006		2007		2008		2009		2010		2011	
	SAIFI	SAIDI	SAIFI	SAIDI	SAIFI	SAIDI	SAIFI	SAIDI	SAIFI	SAIDI	SAIFI	SAIDI
PEA, Mae Hong Son	129.5	2553.2	134.4	2237.5	117.5	1583.8	89.4	1342.3	72.8	851.0	47.1	1143.9
PEA, Pai	87.2	3663.5	71.5	5080.3	83.2	4551.3	72.1	3958.7	24.6	1508.2	17.6	553.5
PEA, Khun Yuam	81.4	3445.4	78.3	2786.2	34.6	1570.5	35.5	1366.7	28.7	817.3	57.3	1837.0
PEA, Pang Ma Pa	90.3	5243.9	89.7	7057.0	103.5	5596.3	103.6	4781.0	42.6	2128.9	33.4	1233.1
PEA, Mae Sa Riang	39.4	2259.8	48.9	1731.6	23.7	1337.8	38.9	1673.3	10.7	404.8	22.2	856.2
PEA, Mae La Noi	43.9	2224.5	53.5	2008.8	31.0	1518.6	40.6	1801.0	17.6	597.9	28.3	1019.3
All Area	78.7	2796.8	82.6	2852.5	65.3	2195.8	59.8	2054.3	35.7	893.0	33.8	1033.7

According to Table 2, we focus this research of islanding operation on unplanned fault because this is the main problem of MHS. We let the planned normal operation with battery and random the fault time to observe how system will be performed in case of lacking of transmission line that will be 3 periods those are pre-fault period, during fault period, and post-fault period. In pre-fault, we dispatch as in normal operation and then in post fault we dispatch with the main object to provide as much as load energy while the power system is lacking of transmission line with the Virtual Power plant parameter to see how much load we have to shedding during the islanding mode. During fault period is the part that observe when fault occurs and what part battery will be in and how battery perform to help system to maintain. In this during fault period, we specific the smaller time step that is 1 minute time step to observe more dynamic of system those we can observe ramp rate of each power system components and how battery will perform better.

3.3. Linear program

Linear program is the main algorithm we use in this research as the tools to solve for the optimal set points of the energy dispatch. It is the tool helping us to find the objective and constraints oriented set points by sorting priority of the objective to find the minimum cost function while the set points have to satisfy the given constraints both equality and inequality. The linear program big advantage compare to some other optimization method such as genetic algorithm or quadratic algorithm is the easy to use and fast computation time but the tradeoff are both constraints and cost function have to be simplified or be written in linear term.

In this chapter, we will show how we construct the linear program using the given power system and hybrid power generation model and also with the cost function as mention in objective section.

The power dispatch is formulated as the following linear program.

$$\min \quad c'x \tag{32}$$

$$\text{subject to} \quad A_{eq}\, x = b_{eq} \tag{33}$$

$$A\, x \leq b \tag{34}$$

$$x_{min} \leq x \leq x_{max}. \tag{35}$$

c is the constant vector reflecting the cost per unit and x is the optimization variable that consists of $x_{H,1}(t)$, $x_{H,2}(t)$, $x_{PV}(t)$, $x_D(t)$, $x_{Gi,115}(t)$, $x_{Go,115}(t)$, $x_{Gi,22}(t)$, $x_{Go,22}(t)$, $x_{GP,115}$ $x_{GP,22}$, $x_{sc}(t)$, $x_{sd}(t)$, $x_s(t)$ where $t = 1,2,\ldots,t_{end}$

For example, if $t_{end} = 2$ that means the system consists of 2 step of time then

$$x = [\, x_{H,1}(1) \quad x_{H,1}(2) \quad x_{H,2}(1) \quad x_{H,2}(2) \quad \cdots \quad x_{Go,22}(1) \quad x_{G,22}(2) \quad x_{GP,115} \quad x_{GP,22} \quad x_{sc}(1) \quad x_{sc}(2) \quad \ldots \quad x_s(1) \quad x_s(2)]$$

The equality constraint where A_{eq} and b_{eq} are constructed by using PV array model, water storage constraint, battery model.

Note that **Hydro ramp rate constraint** is equivalent to

$$x_{H,i}(t) - x_{H,i}(t-1) \leq R_{H,i} U_{H,i}\ , \tag{36}$$

$$x_{H,i}(t-1) - x_{H,i}(t) \leq R_{H,i} U_{H,i}\ . \tag{37}$$

It goes the same way as diesel ramp rate. The inequality constraint where A and b are constructed by water ramp rate constraint, diesel ramp rate constraint.

Boundary limit is the bounding constraint of the optimization variable that contains PV boundary constraint, diesel boundary constraint, hydro boundary constraint, transmission line boundary constraints, battery state of charge boundary constraint, battery charge and discharge boundary constraint.

The formulation can be described as follows.

1. Objective function.

In dry season, the optimal dispatch objective function is described economic dispatch equation where in [7] the economic dispatch will provide the minimal TCOE.

In rainy season, the optimal dispatch objective function is described by economic dispatch equation with where we set diesel generator output and tie flow into MHS to be zero if the mini-hydro power greater than summation of load during and MHS distribution loss of the dispatch period before get into the optimization.

If $T \cdot \overline{x_{H,\imath,m}} \geq \sum_t P_L(t) + Dist.Loss$,
then, $x_{Gi,i}(t) = 0,\ x_D(t) = 0$.

It is recognized that supply of mini-hydro generation to the energy capability gives zero CO_2 emission. Only sources of CO_2 emission are diesel generator and import power into MHS power grid. Thus, we obtain optimal dispatch which returns zero TCOE and the lowest TOC as possible.

2. Input load and renewable source forecast data.

In this research, we use the load and RE generation profiles from the feeder data of MHS 2014 which are classified into 2 seasons, namely, dry season and rainy season. RE generation profiles consist of average mini-hydro generation and PV output which is recorded every 30 minutes. We assume that forecast RE data is available.

3. Using the typical parameters' value for in MHS power system components.

We use 30 minutes of sampling time so there are 48 samples per day. For one day, $t_{end} =$ 48. Using all the data parameters we will get the dispatch profile of operation. To propose the technique we use in our operation, in dry season, we notice that the RE is the base supply of power generation. Moreover, the top two largest weight parameters are diesel generator and tie flow or power from grid that put into MHS for both in TOC and TCOE. The operation in economic approach gives the optimal operation in MHS for dry season and offers minimum TCOE as we can individually run economic dispatch and also get the lowest TCOE.

In rainy season where the mini-hydro generation output supply is over demand, the multi-objective approach as mentioned in [7] is not applicable because $TCOE_{min}$ equals to zero. To acquire the optimal operation, the objective function will use the economic dispatch in which excludes the diesel generator and the tie flow into area of MHS.

3.4.Numerical results

We simulate various cases of optimal dispatch strategy in normal mode of dry season. The simulation consists of 6 consecutive days in normal mode without fault or disturbance of MHS power system. We compare the optimal dispatch to the power dispatch profile with manual operation in dry season of 2014 which has shown in Fig. 7 as a base case from manual operation.

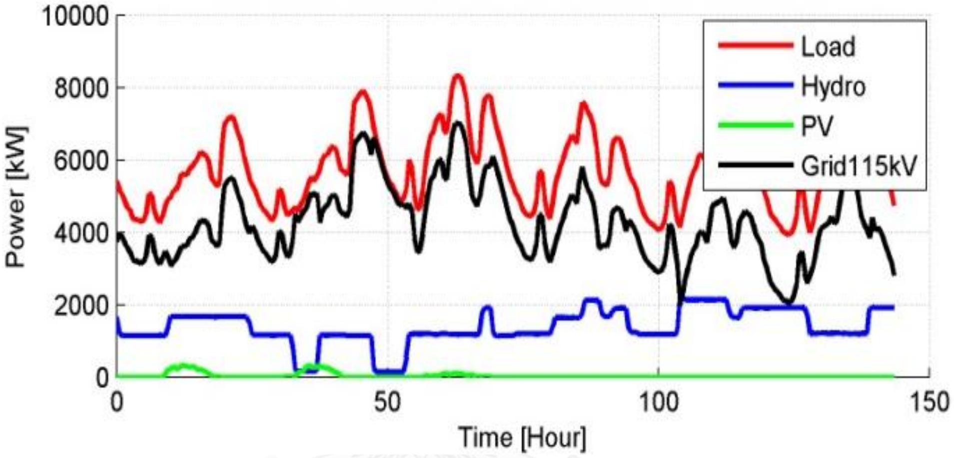

Fig. 7 Power dispatch profile with manual operation in dry season.

In Fig. 8, we simulate optimal economic dispatch with the existing MHS resources to perform the optimal operation, that TOC will be reduced as we can notice in

Table 4 in ‘Econ’ column. In all figures, ‘Load’ states for P_L, ‘Hydro’ state for sum of $x_{H,1}$ and $x_{H,2}$ which are mini-hydro PB and MSN, ‘PV’ states for x_{PV} or PV output and ‘Grid115’ states for tie flow of 115 kV or $x_{Gi,115}$ and $x_{Go,115}$ where the positive represent tie flow into MHS and negative value states for tie flow selling out of MHS. In this normal mode in dry season, the tie flow from 22 kV transmission line profile is equal to zero due to the cost that is higher than 115 kV as the result that the dispatch is not choose to transmit energy through this line.

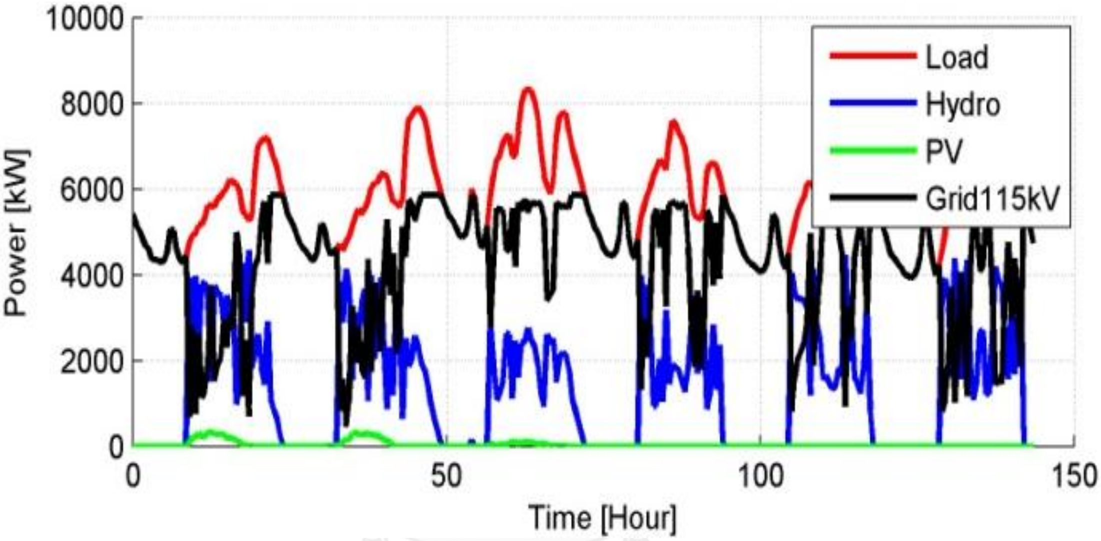

Fig. 8 Economic dispatch profile with optimal economic operation in dry season.

We consider additional renewable resources including PV and mini hydro, and battery energy storage and refer the overall power generation as MHS Smart Grid (SG1) with battery parameters given in Table 3 Selected parameters of BES., where $\eta = 0.73$ this is the typical efficiency of battery can be calculated from efficiency equation as mention in previous chapter. SOC of battery is specified to be between 50% and 90% and for easy to understand we use a unit kWh of energy. Fig. 9 shows economic optimal dispatch for case SG1-3.

We analyze the effect of battery size, efficiency, and TB on the optimal dispatch. We try to reduce TB by decreasing C_B, referring to case SG2-3. In case SG4-6, we gradually increases η to the maximum value while using the battery operating cost at the default pricing of SG1.

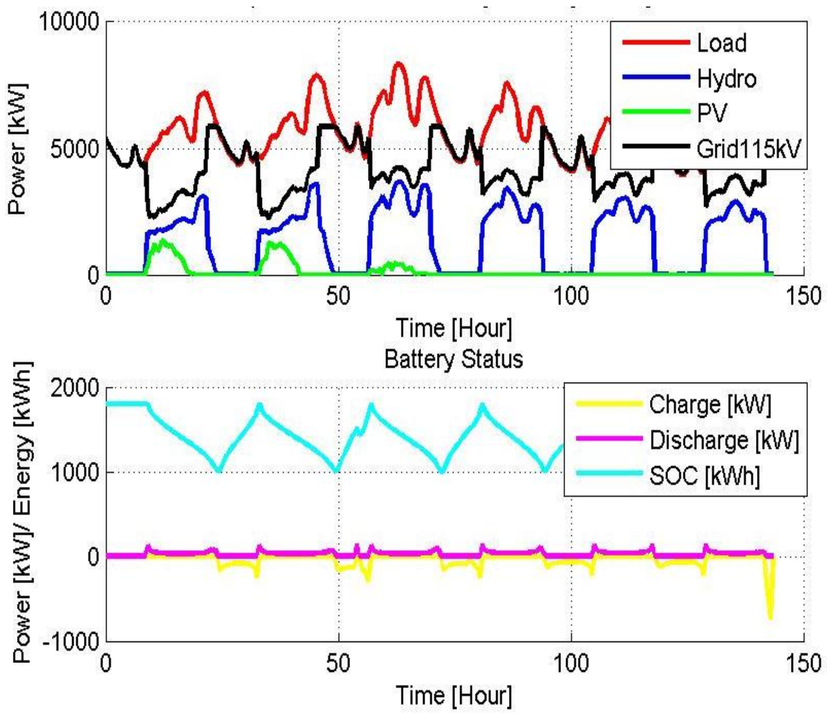

Fig. 9 Economic dispatch profile with BES case SG1,SG2, and SG3 in dry season.

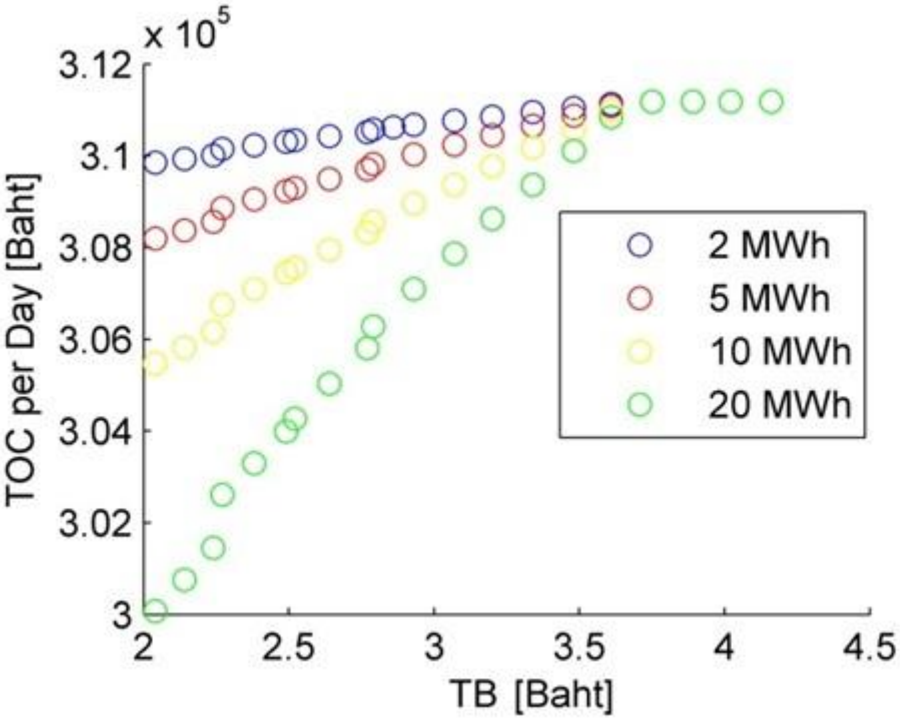

Fig. 10 TOC vs. TB while varying BES size in dry season.

To clarify peak of tie flow affect by the battery parameters, we construct grid table of battery efficiency by varying η_i, η_c and η_d versus C_B of 2 MWh battery which is the default sizing of energy storage in MHS smart grid project in Fig. 11. The result shows that efficiency of battery is the only the battery variable that affect the peak of tie flow as shown in Fig. 11.

Tie flow peak power is related to TB and η. Fig. 11 shows the peak power of tie flow to see its relationship to TB and BES efficiency. The peak is increasing when the efficiency of battery is higher than certain value around 70%. The average peak is increasing to its highest peak at 5,951 kW at efficiency of 75%-80% and is decreasing to the minimum peak at 5,850 kW when efficiency comes closer to 100%. C_B appears to have no affected on peak in dry season of MHS. BES helps energy management even though the cost reduction is still small compared to the installation budget.

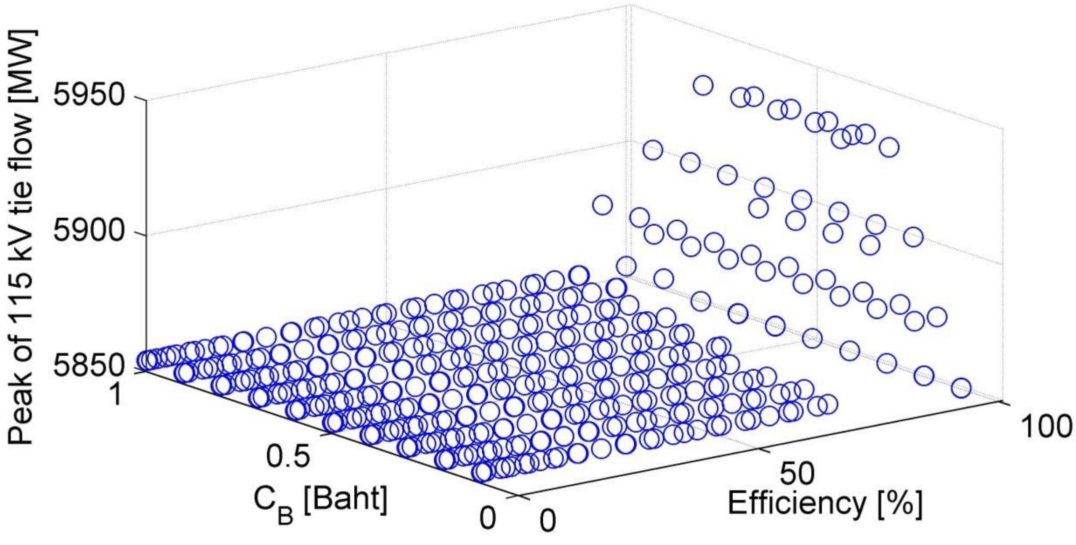

Fig. 11 Peak in kilowatt by vary efficiency and operating cost of battery

In Fig. 9, Fig. 12, Fig. 13, Fig. 14, the dispatch profiles show the result of dispatch in SG cases: SG1 to SG6.

The simulations show that when $C_{p,115} > TB_D$, battery energy storage system (BES) will perform load management. It means that BES will acquire energy from grid during off-peak period, and then it will supply energy to power system in peak period. As a result, TOC is slightly reduced. We also analyze the impact of TB and efficiency of BES onto TOC. In the dry season, TB should be less than 3.68 baht in order to let BES operate for the load management. The profile of SG1, SG2 and SG3 are dispatch in the almost the same pattern only small difference in detail. In summary, BES helps system do load management even though the cost reduction is still small compared to the installation budget.

Table 3 Selected parameters of BES.

Parameter of BES	Dry season						Rainy season	
	SG 1	SG 2	SG 3	SG 4	SG 5	SG 6	SG 7	SG 8
η	0.73	0.73	0.73	0.81	90.25	1.00	0.73	1.00
C_B[Baht]	0.50	0.40	0.30	0.50	0.50	0.50	0.50	0.00
TB	3.48	3.34	3.20	3.14	2.82	2.54	1.37	0.50

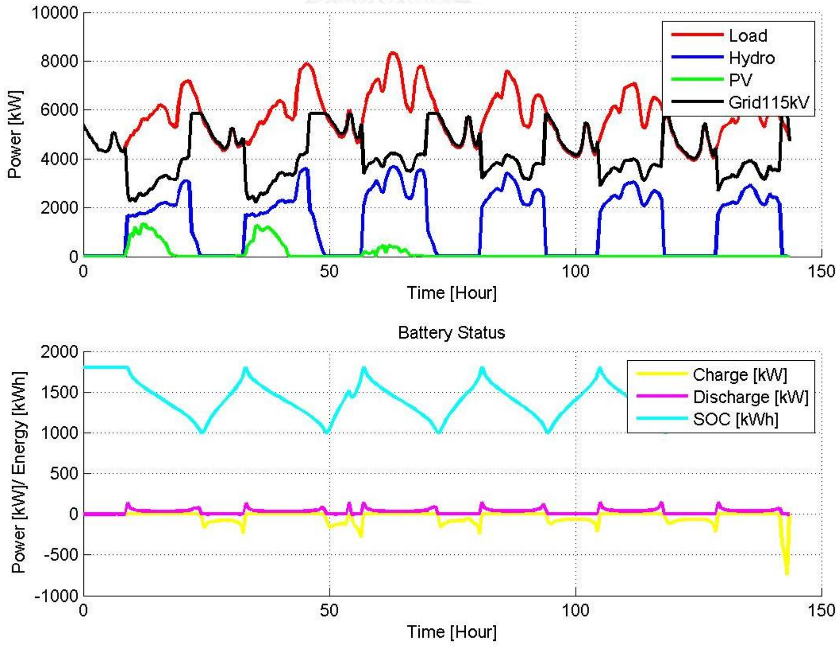

Fig. 12 Economic dispatch profile with BES case SG4 in dry season.

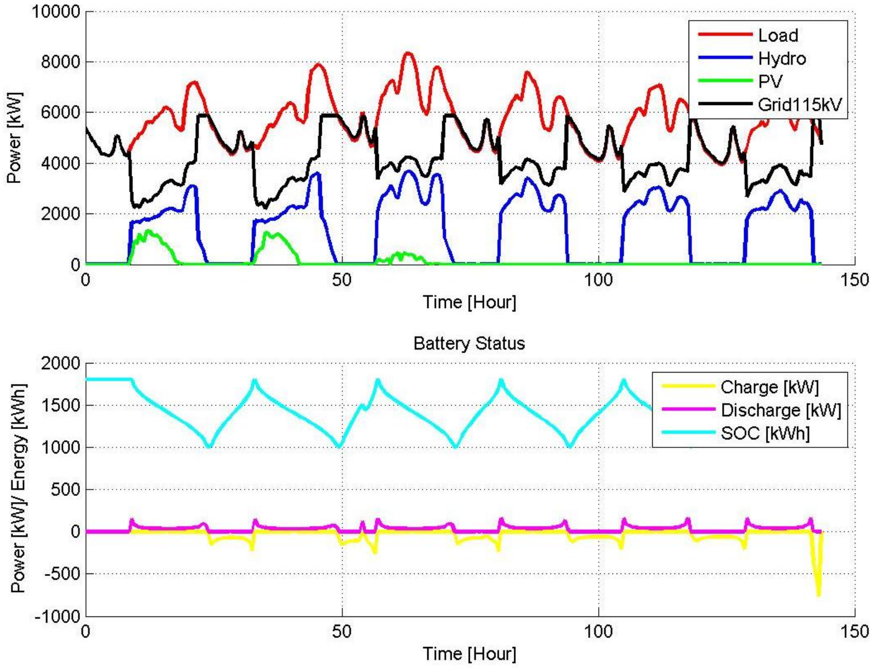

Fig. 13 Economic dispatch profile with BES case SG5 in dry season.

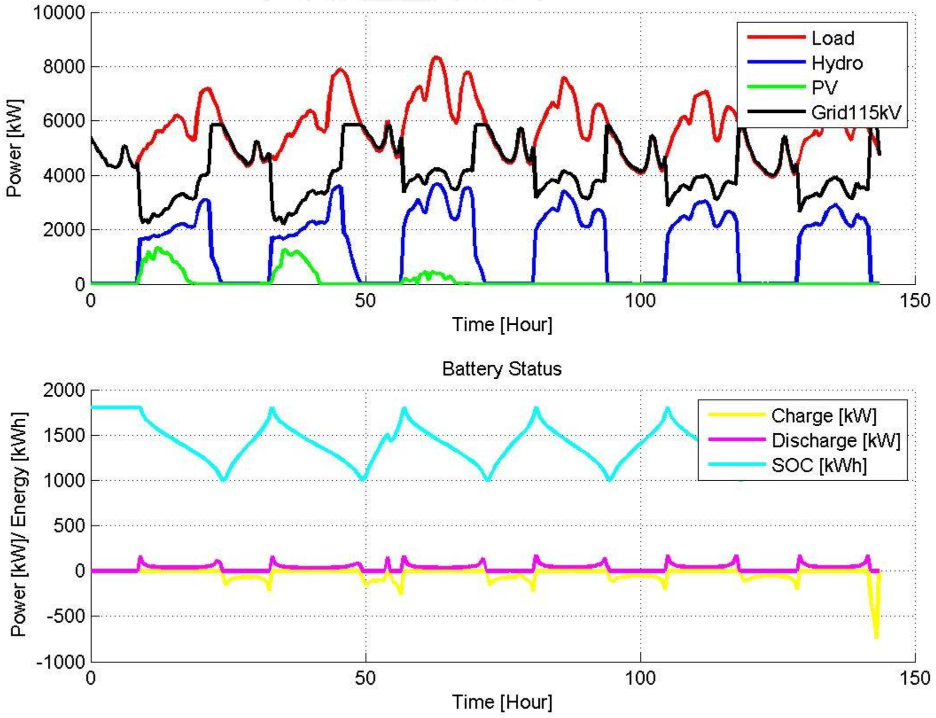

Fig. 14 Economic dispatch profile with BES case SG6 in dry season.

Table 4 Summary of dispatch profile in dry season.

Measure /Case	Manual	Econ	SG 1	SG 2	SG 3	SG 4	SG 5	SG 6
Load [kWh]	817,034	817,034	817,034	817,034	817,034	817,034	817,034	817,034
Mini-Hydro [kWh]	199,077	199,077	199,077	199,077	199,077	199,077	199,077	199,077
PV [kWh]	4,405	4,405	17,618	17,618	17,618	17,618	17,618	17,618
Diesel [kWh]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G_{in}115kV [kWh]	613,552	613,546	601,834	601,834	601,834	601,346	600,831	600,332
Peak 115kV [kW]	7,007	5,854	5,854	5,854	5,854	5,854	5,878	5,850
Peak Cost [B]	100,550	84,003	84,003	84,003	84,003	84,003	84,353	83,951
Energy Cost [B]	1,847,259	1,723,318	1,671,117	1,671,117	1,671,117	1,669,724	1,667,848	1,666,807
TOC [B]	1,950,011	1,909,063	1,866,261	1,866,261	1,866,261	1,864,746	1,863,111	1,861,544
TOC /day [B]	325,002	318,177	311,044	310,951	310,857	310,791	310,518	310,257
TCOE [kg]	337,453	337,450.0	331,009	331,009	331,009	330,741	330,457	330,182
TCOE/ day [kg]	56,242	56,242	55,168	55,168	55,168	55,123	55,076	55,030

Next, we simulate optimal dispatch strategy in normal mode of rainy season of 6 consecutive days. Fig. 15 shows power dispatch profile with manual operation, called 'Manual' in Table 5 Summary of dispatch profile in rainy season. The mini-hydro power which is greater than the demand represents the abundant renewable energy. As a result, there is excess energy that can be sold to the connected area by using 115 kV transmission line.

To determine the optimal power dispatch in rainy season, we consider both TOC and TCOE. In this case, we acquire the minimum TCOE by setting zero power to the tie flow power into the MHS or $x_{Gi,i}(t) = 0$. We simulate optimal operation in rainy season with the existing power MHS resource. TCOE is equal to zero and TOC is even better than the existing case. The optimal power dispatch profile is shown in Fig. 16, namely 'Econ'. The result is summarized in Table 5.

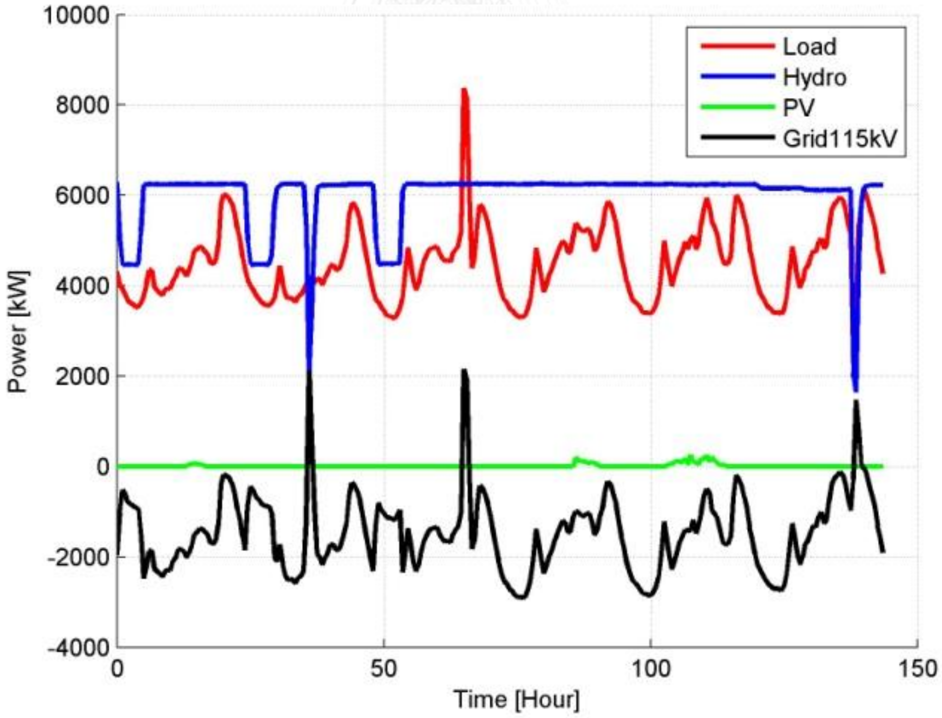

Fig. 15 Power dispatch profile with manual operation in rainy season.

Fig. 17 depicts the results of smart grid case study of rainy season. The optimal set point of both TOC and TCOE are acquired by specifying zero imported power constraint. We observe that battery is not triggered to operate since $TB_R \geq O_H$ where C_H is the cost of energy per unit for load consumption in rainy season. In SG4 case, the BES parameters are set to be the standard condition or $\eta = 0.73$ as in SG1 but the difference is that C_H is used instead of $C_{op,115}$ as a result, TB becomes lower. However, TB is still greater than the cost of renewable energy resource which supplies the whole load in this season. This is the case SG7 and SG 8 shown in Table 5 Summary of dispatch profile in rainy season.

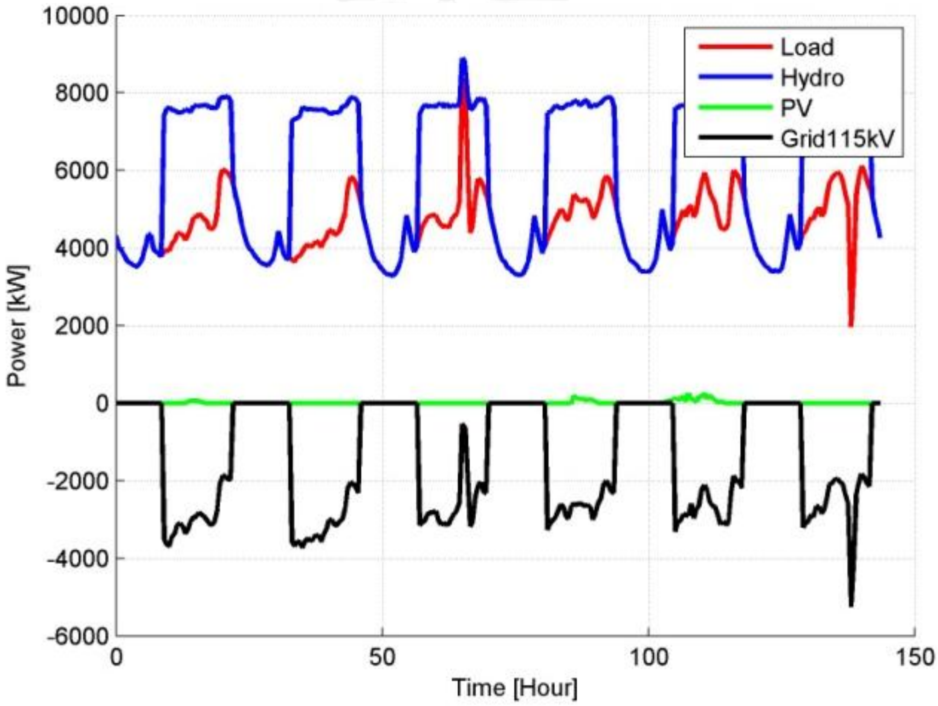

Fig. 16 Dispatch profile from optimal economic operation in rainy season.

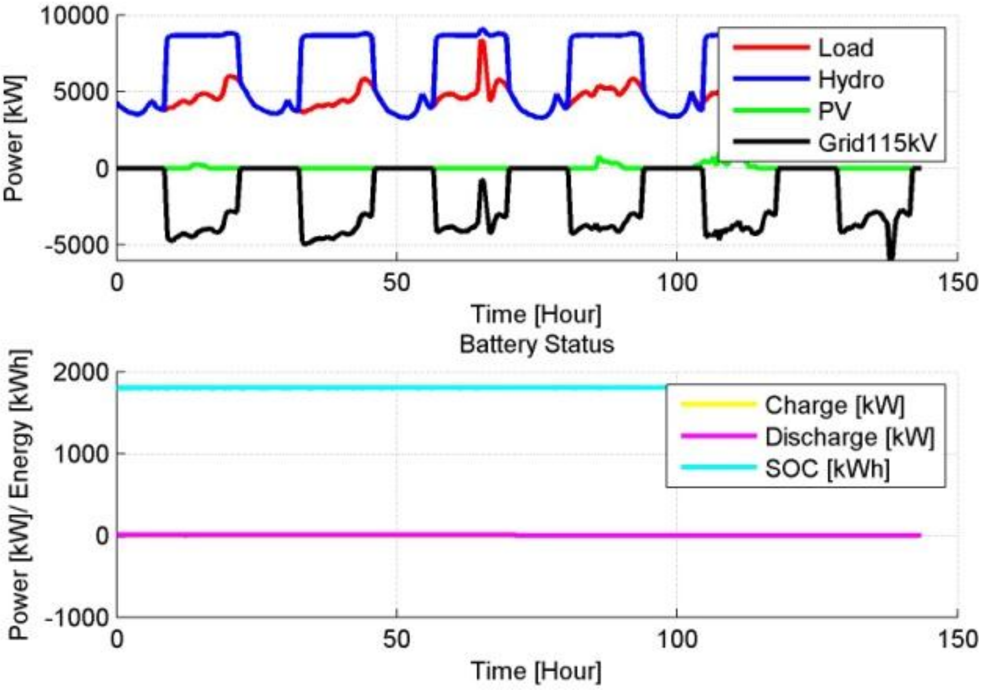

Fig. 17 Optimal dispatch profile with BES case SG7 and SG8 in rainy season.

As a result, BES is still not triggered. In SG5 case, we specify $C_B = 0,\ \eta = 1.$ The power profile of dispatch of SG4 and SG5 are the same and the battery is still not be used.

3.5. Conclusion

MHS region has a plenty of renewable energy resource. When we determine optimal economic dispatch in dry season, the minimum of TOC and TCOE are acquired. With the water management, we obtain the smaller peak of imported power from the grid. Next, we simulate the upgraded smart grid power system with battery. We observe that BES takes an important part of energy management in normal mode. It slightly helps reduce TOC. Both of efficiency and size of battery have effect to reduce TOC. BES helps tie flow of MHS be smoother and efficiently utilizes supply management by exporting RE excess to the transmission grid. In rainy season, we obtain a significant reduction of TOC with the zero CO2 emission. Battery in rainy season is not operated since the optimal dispatch supplies the entire load using renewable energy sources.

Table 5 Summary of dispatch profile in rainy season.

Measure / Case	Manual	Econ	SG 7	SG 8
Load [kWh]	649,204	649,204	649,204	649,204
Mini-Hydro [kWh]	862,635	862,632	939,528	939,528
PV [kWh]	1,838	1,838	7,352	7,352
Diesel [kWh]	0	0	0	0
Gin115kV [kWh]	4,523	0	0	0
Gout115kV [kWh]	214,591	215,267	297,677	297,677
Peak115kV [kW]	2,152	0	0	0
Peak Cost [B]	30,883	0	0	0
Energy Sale [B]	580,970	779,895	1,078,462	1,078,462
TOC [B]	-102,134	-347,660	-605,022	-605,022
TOC/ day [B]	-17,022	-57,943	-100,837	-100,837
TCOE [kg]	2,488	0	0	0
TCOE/ day [kg]	415	0	0	0

Chapter 4

Islanding mode of operation

4.1.Problem statement

MHS power system is not well sustainable due to the long transmission line across the mountain area that likely for fault to occur. On the other hand, MHS' existing power system in 2014 contains various types of renewable energy sources and will be even more renewable energy due to new installation plan for PV and mini-hydro power plant. In this chapter, we classify type of faults specific on transmission line and its consequences to design and simulate how to cope with these situations. And for all the fault consequences and MHS operation, the worst situation is when the faults force MHS power system to be separated from the national grid and operate as islanding operation. In this chapter, we present new variables called virtual power plant which represent for the load that will be shed.

The objective of study in this chapter is as follows

- Design operation when fault occurs on transmission line.
- Balance minimize Total Operating Cost (TOC) and minimize Interruption Electricity Damages (IED)

The islanding mode will be set up in one season that is dry season due to its lacks of renewable energy to supply itself during the islanding mode. In rainy season, because of its abundance of renewable energy, MHS' renewable sources can supply whole province in rainy season so when fault occurs on transmission line; there will be only small impact on MHS power system.

In this chapter, we will focus on **permanent fault** on MHS transmission lines that lead to islanding operation. The simulation will perform in case that the power system has battery energy storage being installed and not being installed.

Power system configuration in islanding operation is as follows in Table 6.

Table 6 Power system configuration in islanding operation.

Existing Power system (2014)	Islanding power system (SG1-i)
• Transmission line 115 kV • Transmission line 22 kV • 10 MW Hydro Gen. @MSN • 850 kW Hydro Gen. @PB • 4.4 MW Diesel Gen. @PB • 500 kW PV Farm @PB	• 10 MW Hydro Gen. @MSN • 2.1 MW Hydro Gen. @PB • 4.4 MW Diesel Gen. @PB • 2 MW PV Farm @PB • 2 MWh Energy, 4 MW Power, Battery

4.2.Power dispatch strategy

Fault locations and consequences

Firstly, we have to find where fault can be located alone the transmission line from Chiang Mai to MHS. Fault that can force MHS to operate as islanding mode of operation supposes to occur on main transmission line that is 115 kV transmission line from Mae Thang district, Chiang Mai that supplies large amount of energy to MHS. This can affect the stability of the MHS power system immediately when it is collapsed. The longer the transmission line the more chance that fault can occur especially for MHS case that the transmission line lie along the saddle of the mountain. Fig. 18 shows the diagram with distance of transmission line of Chiang Mai to MHS in kilometer. Fig. 19 shows the possible fault location in the previous single line diagram. Note that for 115 kV and 22 kV both is hanging on the one electrical post so if severe fault occurs there is highly chance that both will be failure together. Table 5 lists consequences and operation to handling when fault occurs.

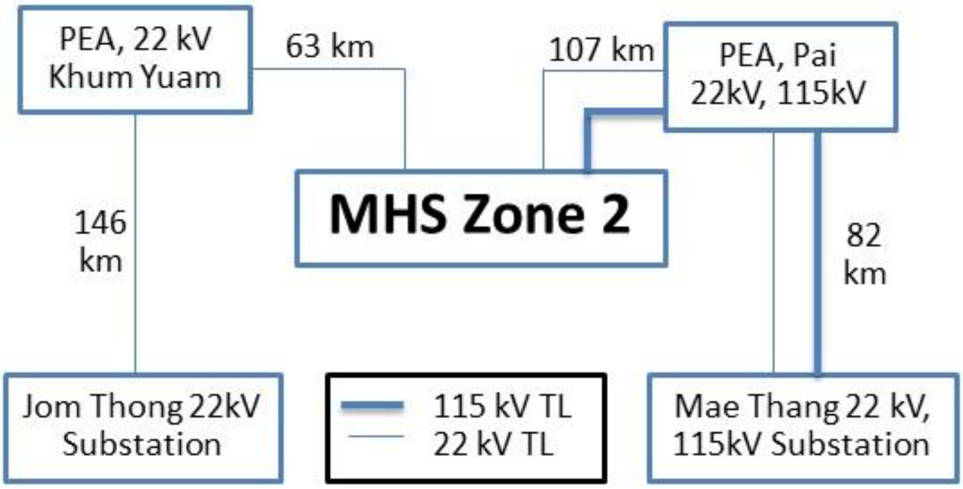

Fig. 18 Transmission line diagram from Chiang Mai to MHS [1].

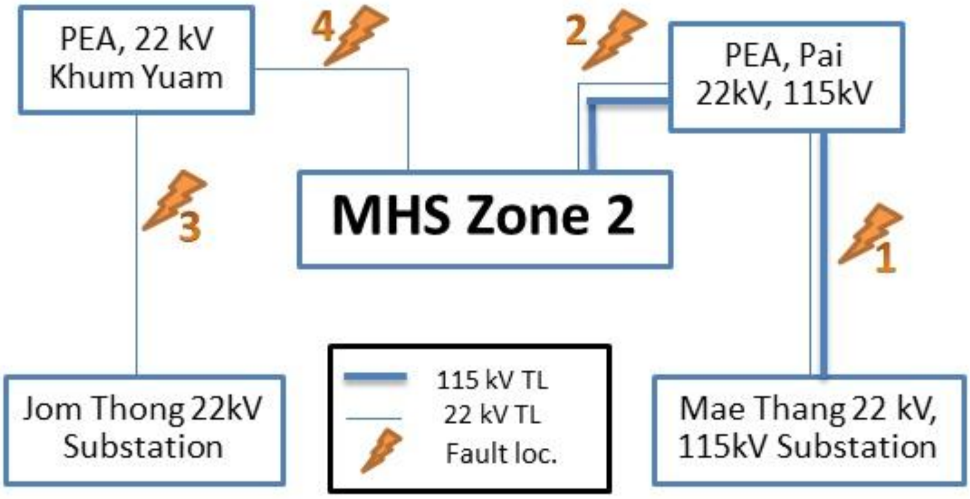

Fig. 19 Fault locations on Transmission line from Chiang Mai to MHS.

Table 7 List of consequences and operations when fault occurs.

Fault Location	Consequence & Operation
1 or 2	MHS system will lack of energy due to main transmission line stuck by faults. This situation is could lead to blackout situation if there is no other components that could substitute supply energy of MHS instead of 115kV transmission line suddenly. Tie flow in feeder 3 is neglected or sectional supply. After clearing fault, system can operate in normal mode without 115kV grid connected.
Both 1 and 2	
3 or 4	This feeder normally uses to supply load out of MHS city zone. The other area of MHS can be maintained while repair this transmission line. Tie flow in feeder 1 is neglected or sectional supply.
Both 3 and 4	
Both 1 and 3	MHS system will lack of energy due to main transmission line stuck by faults. This situation is could lead to blackout situation if there is no other components that could substitute supply energy of MHS instead of 115kV transmission line suddenly. Tie flow in feeder 1and 3 are neglected or sectional supply. This situation leads MHS to operate as islanding operation.
Both 1 and 4	
Both 2 and 3	
Both 2 and 4	
3 points at the same time	
4 points at the same time	

According to Table 7, we found that the consequence can be classified in 3 types. First is when fault occurs only on the 22 kV transmission line whether at 3 or 4 or both of JT to MHS this will result to no severe impact to MHS power system due to 115 kV main transmission line can support the system as shown in dispatch profile in normal mode of operation. The second consequence is when the 115 kV transmission line is stuck by fault whether 1 or 2 or both. The main source of energy supply to MHS is lacking so the 22 kV transmission line of JT to MHS will be start supply to MHS if not enough energy the MHS system can choose whether the will shed some load or start up diesel generator which depend on their objective of operation. Third consequence is when both transmission line stuck by fault this will force MHS power system to operate in islanding operation in which there is no transmission line connected from Chiang Mai to MHS. MHS operator has to operate with their renewable resources or somehow have to shed some load for maintain the whole power system.

Firstly, we present the flow chart of operation when fault occur on 115 kV transmission line and system and substitute 22 kV transmission line to supply.

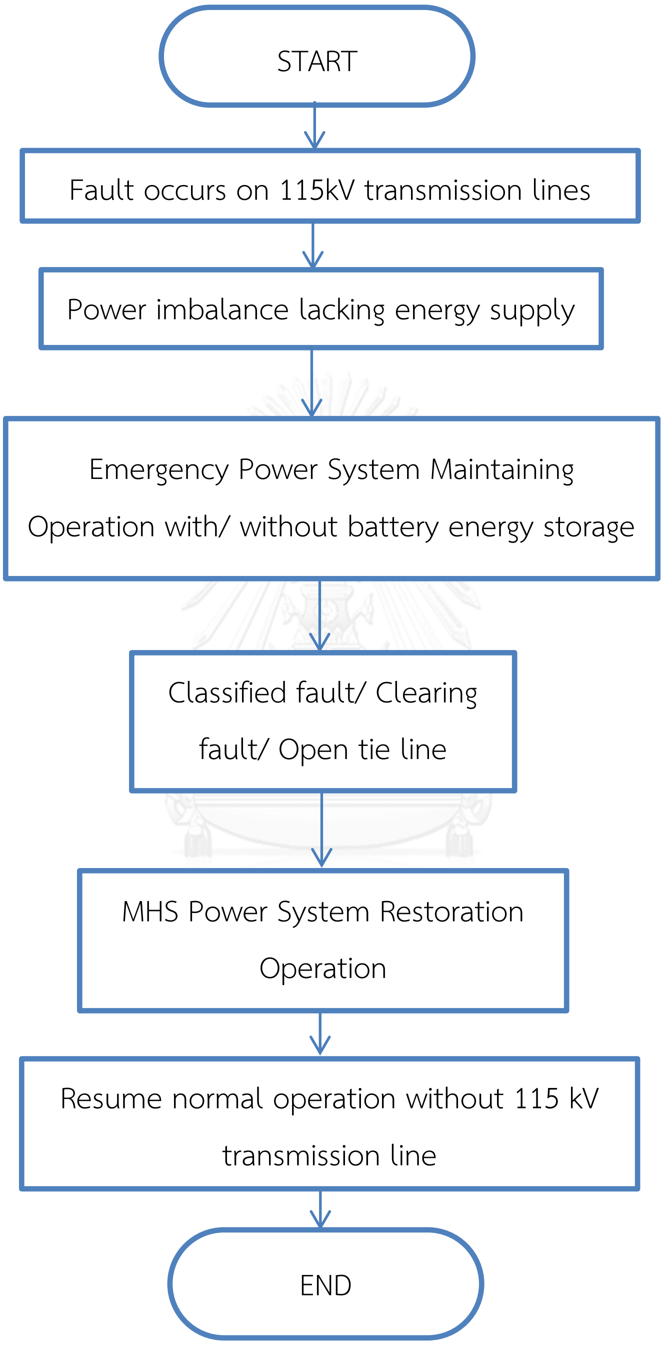

Fig. 20 Flow chart of operation when fault occurs on 115 kV transmission line.

Fig. 20 represents the operation after fault occurs on 115 kV transmission line. In this case, MHS system can operate even if there is lacking of 115 kV transmission line. We called normal operation without 115 kV. The operation is start when fault occurs on 115kV transmission line. Firstly, the imbalance power between demand and supply will lead power system to loss of synchronous state in few seconds the only way to main the power system is using special power system components that could respond at this rate and have enough power to help maintaining the power system. In the emergency plan, the components might be battery, or upgraded mini-hydro, or fast respond 22kV transmission line, or even the standby full speed diesel generator. If system cannot maintain the power system will be collapsed and after clearing the fault feeder, MHS shall operate as black restoration plan in which consume more time than the way to maintain the power system and resume to normal operation without 115 kV transmission line. Fig. 21 and Fig. 22 show the operation with time line of MHS in case fault occurs on 115 kV transmission line as temporary fault and permanent fault. In these cases, for example, we assume use 22kV is stand by and can back up fault immediately.

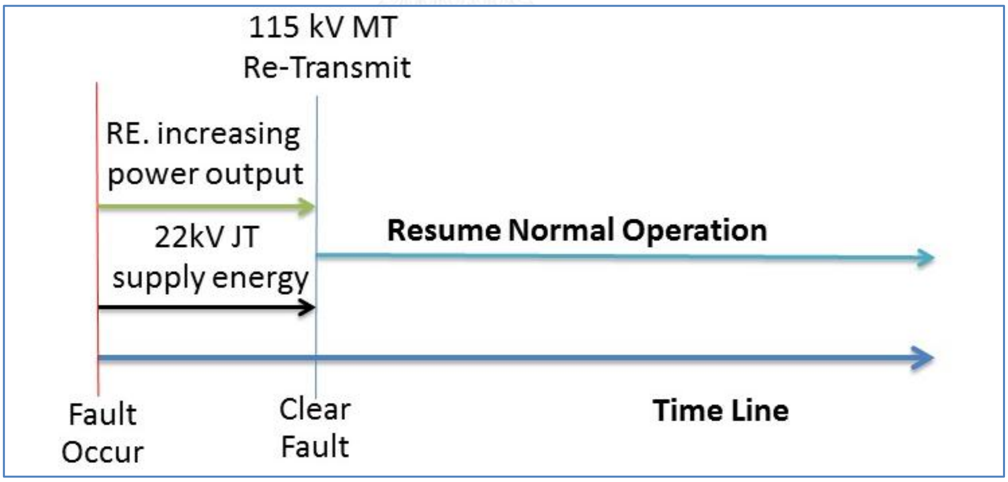

Fig. 21 The operation step when temporary fault on 115 kV transmission line.

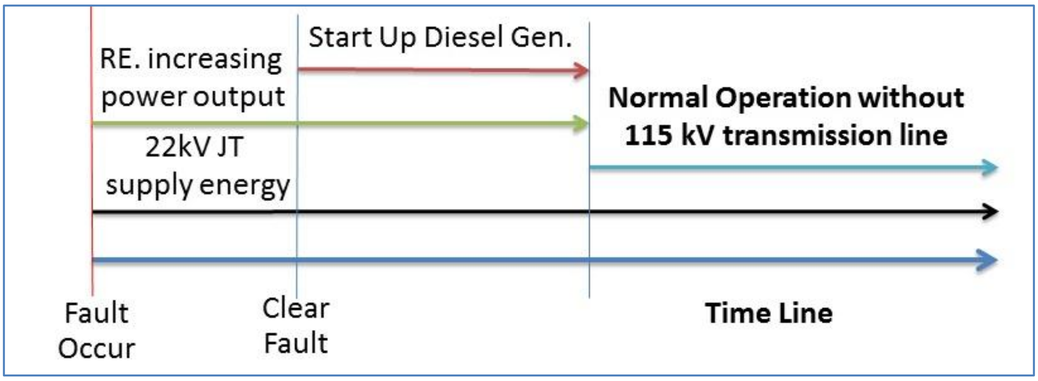

Fig. 22 The operation step when permanent fault on 115 kV transmission line.

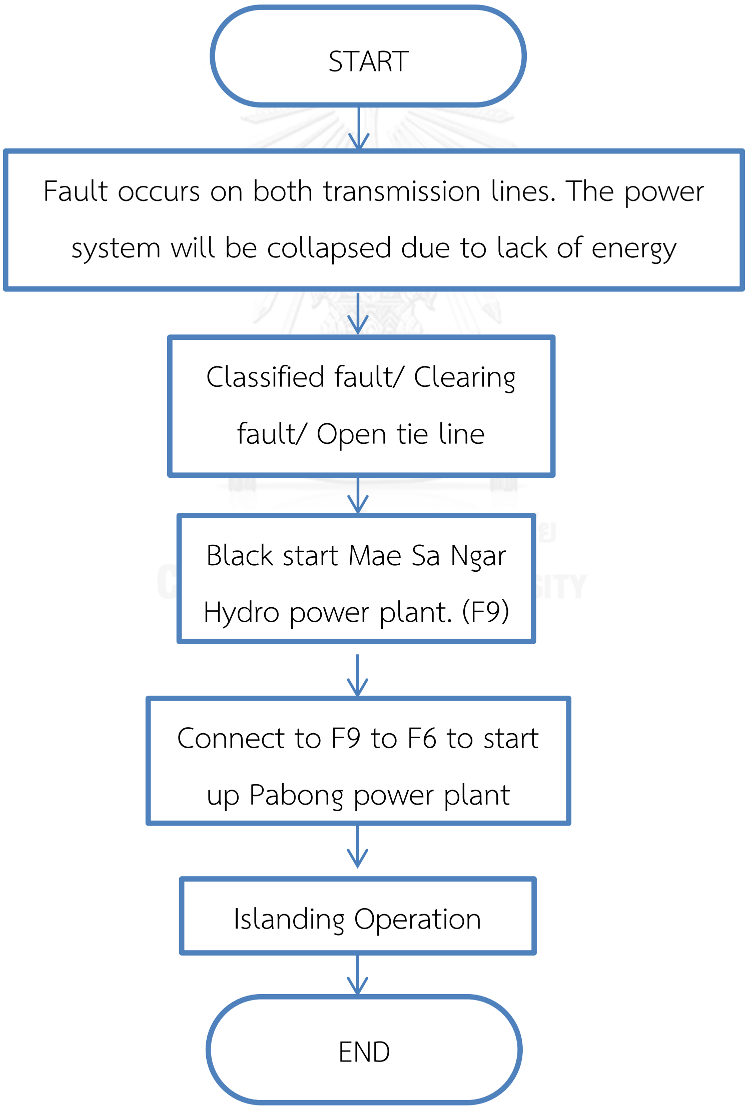

Fig. 23 Flow chart of islanding mode of operation without battery.

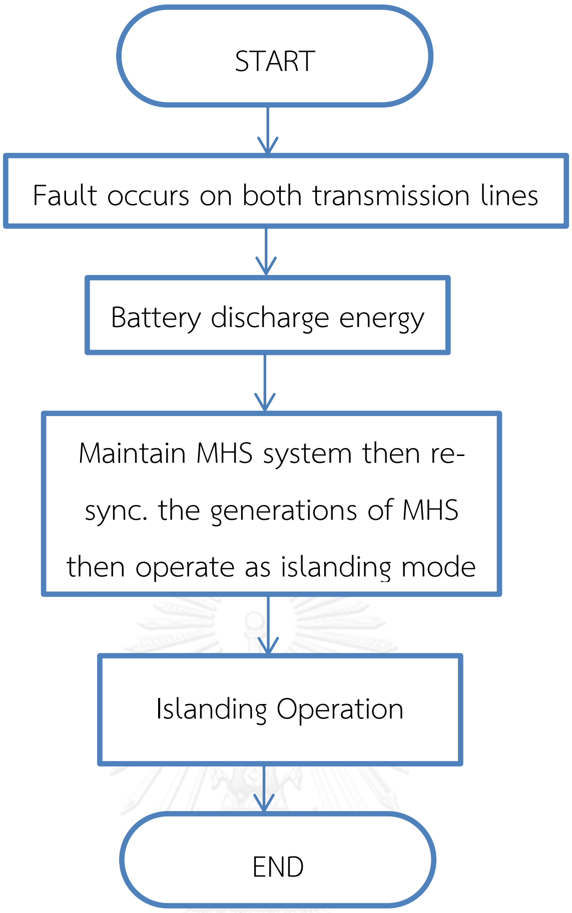

Fig. 24 Flow chart of islanding mode of operation with battery.

This flow chart is the diagram to explain how the system responses when faults occur on both transmission lines shown in Fig. 23. That operation is when the existing system shall perform without battery when fault occurs. Fig. 24 is the flow chart of operation when fault occurs to both transmission lines of MHS power system and force the power system to islanding operation. Fig. 25 and Fig. 26 show the operation that bring the power system to islanding operation in time line chart for case with and without battery of MHS power system.

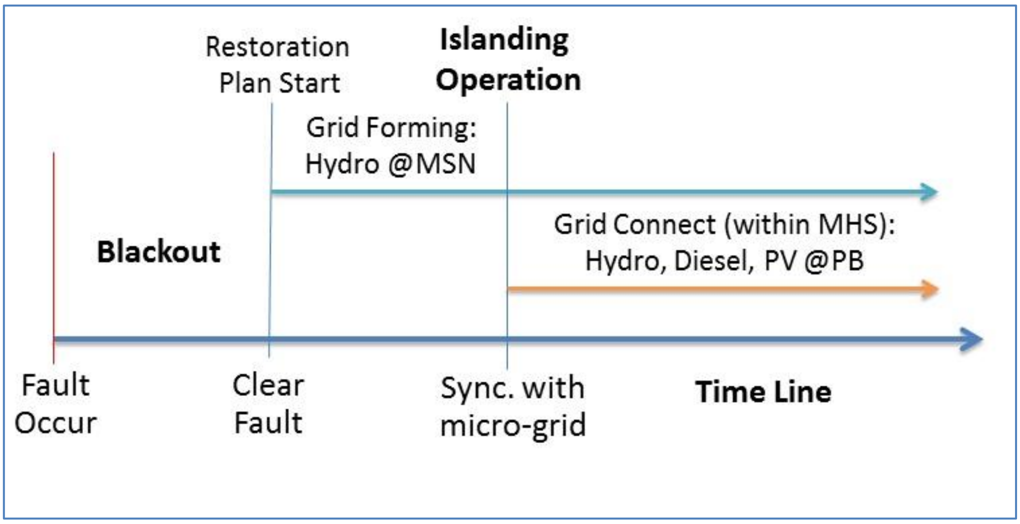

Fig. 25 After fault to islanding operation step without battery.

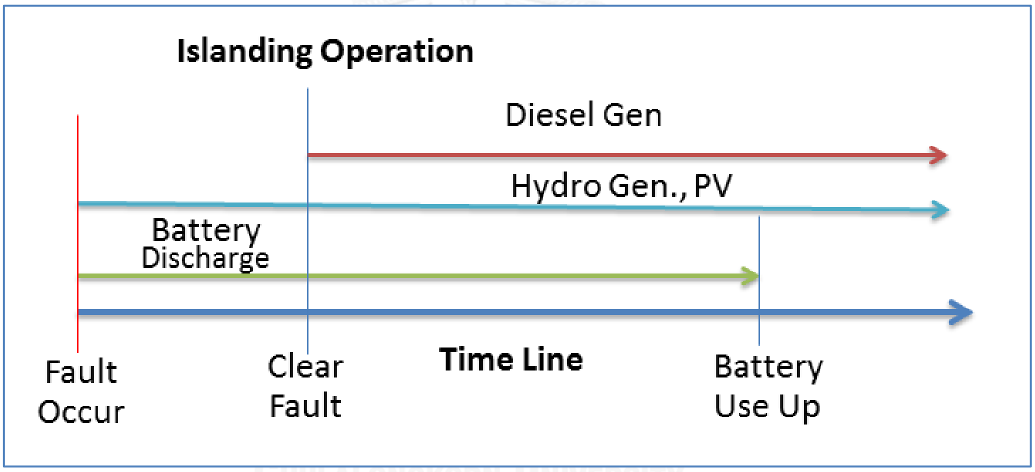

Fig. 26 After fault to islanding operation step with battery.

Islanding operation will be held in case of permanent fault occurs on the both transmission lines. If there is no battery which can be classified as the worst situation every single generation component will be separated from the main power system as them loss of synchronous and with that MHS will face blackout. In that case, while the transmission lines are repairing the main transmission line, Mae Sa Ngar hydro power plant will perform black start and grid forming operation then it will connect itself with Pabong power plant to increase the power system stability then they would gradually supply load step by step. If the generation in MHS cannot supply the whole load especially in dry season some load have to be shed.

In case that there is a battery in power system during a severe fault that could lead MHS power system to blackout, the power system will maintain for some certain period of time during fault and after that every power generation can be re-synchronous as in Fig. 26.

In our dispatch operation, the virtual power plant as state for sectional load shedding is concerned.

4.3.Linear program

In this section, we will describe the variable and constraint on computational of islanding operation where islanding operation is when we focus on case that only main transmission line is stuck by fault and both transmission lines stuck on fault together. That is the really emergency situation where MHS can only rely on its own power plant to operate.

Time step and period of operation

Regular time step of the normal operation is 30 minute but this rate of time is not suitable to the islanding operation which consists of 2 periods of times those are pre-fault period, and after fault period.

In pre-fault period, we will operation as in planned set point in normal operation in this period we use 30 minute time step as the previous chapter describe.

After fault period is the connected time between during-fault and islanding period. In during-fault period, we will operate power system in 1 minute time step as the 30 minute time step is too long to observe the dynamic of how battery performs and effect of ramp rate of each components to tracking the load profile. After clearing fault, we will operate the power system in islanding operation.

Virtual power plant

Virtual power plant is the new introduced optimization variable that uses as the amount of load that have to be shedding or the amount of minimum new power supply energy that is required to supply to the power system calls **Virtual power plant boundary**.

$$0 \le x_{VP,i}(t) \le U_{VP,i} \, , \tag{38}$$

where x_{VP} is the power of virtual power plant that will supply to load the power system in the power balance constraints, $U_{VP,i}$ is the upper limit of virtual power plant. Where the upper limit of the first virtual power plant can be understand as the lower damage compare to other load such as housing or residential in outskirt area so the limit of shedding considers to have limit in percent of the whole MHS load as follows

$$U_{VP,1} = L_s P_L(t) \, , \tag{39}$$

$$L_s = \sum_i L_{s,i} \, , \tag{40}$$

where $L_{s,i}$ is consists of $L_{s,1}$ and $L_{s,3}$ that is the percent of load shedding of the feeder 1 and 3 which is the transmission line connected to the Khum Yuam and Pang Ma Pa respectively. $x_{VP}(t)$ is the optimization variable that will be added in power balancer constraints and also in cost function of the economics dispatch.

Cost function of virtual power plant is written as follows

$$IED = \sum_t C_{VP,1} x_{VP,1}(t) + C_{VP,2} x_{VP,2}(t) \, , \tag{41}$$

where IED is the cost function of virtual power plant supply to the MHS power system. On the other hand, we call it as Interruption Electricity Damage (IED). This damage states for the damage on the enterprises, social facility, community facility, residential area, commercial building etc. We classifies virtual power plant in 2 type depend on cost of compensation or cost per kWh when lacking of electricity. The $C_{VP,1}$ and $C_{VP,2}$ are the interruption electricity rate (IER) of the residential load and important load such as airport, hospital respectively. We called this cost function as **Virtual power plant cost function.** Table 8 shows IER classified by type of load.

Table 8 Interuprtion of Electricity Rate (IER) classified by type of electrical user by Provincial Electricity Authority of Thailand (PEA) [16].

Type of electricity consumer	IRE (Baht per kWh)
Residential	8.62
Small size firm	72.27
Medium size firm	108.40
Large size firm	124.04
Specific purpose firm	52.80
Non-profit organization	9.62

Virtual power plant and IED apply to the power system in case that we choose to solve for the optimal TOC including shedding some load.

Load and PV Fluctuation

As we want to add some fluctuation to load and PV during fault we create 2 more variable as FL_L and FL_{PV} to provide some fluctuation to the load and PV as follows.

$$P_L(t)(1-FL_L) \leq P_{L,new}(t) \leq P_L(t)(1+FL_L)\,, \tag{42}$$
$$P_{PV}(t)(1-FL_{PV}) \leq P_{PV,new}(t) \leq P_{PV}(t)(1+FL_{PV})\,, \tag{43}$$

where fluctuation for load is 10 % and for PV is going to 20 %.

Estimate battery maintaining time.

We using the SOC of battery to calculate the amount of energy that is store and let it supply to maintain the power system.

$$SOC_{kWm} = 60 \cdot SOC_{kWh}\,, \tag{44}$$
$$E_B = SOC_{kWm} \cdot \eta_i n_d\,. \tag{45}$$

t_b is the estimate time of battery that can maintain the MHS power system. E_B is state for the energy that battery is backup and able to supply to the power system. Where t_b is from

$$P_{L,t_b} \leq E_B \leq P_{L,t_b+1}\,, \tag{46}$$
$$P_{L,t_b} = \sum_{t=t_s}^{t_b} P_L(t)(1+L_D)\,, \tag{47}$$

where P_{L,t_b} is the accumulation load from the time that fault occur or the time that fault start, t_s, to $t_b$that is the time that battery can be solely maintain the power system. Note that t_s and t_b is in 1 minute time step.

Power balance constraint after fault

After fault period can be classified in 2 time period, those are during fault and after clearing fault.

For **during fault period**, this is the case of power balance constraint during fault period where all the other components are split off the main distribution line due to out of synchronous by lacking the main transmission line. If in the MHS power system has battery, it is the only part of the power system during fault that can help maintain the power system. The power balance constraint during islanding mode of operation will be written as follows

$$\sum_{t_F} x_i(t_F) = P_L(t_F)(1 + L_D) - \sum_i F_i(t_F) \qquad (48)$$

where t_F is in 1 minute time step and start at fault occur till the fault is clear. The x_i is the electrical components that is able to operate during fault in for example battery and virtual power plant. F_i is the feeder that fault occurs and we shall open the tie line. We call this equation as **power balance constraint during fault.** With the power balance constraint equation above, load has been supplied by sum of battery and virtual power plants. The other generation optimization variable will be set to zero output during fault as follows.

$$x_{H,i}(t_F), x_{PV}(t_F), x_D(t_F), x_{Gi,i}(t_F), x_{Go,i}(t_F) = 0\,, \qquad (49)$$

In case that, the power system is not have any battery storage this mean that the power system will be collapsed as all generators are splitting off this will lead to blackout situation. And the next period of time is **islanding operation period.** We can classify after clearing fault in 2 cases those are the one with 22 kV from Jom Thong to supply some load and both transmission lines are stuck by fault at a time which leads to islanding operation. The equation below states for the power balance constraint during islanding operation where both transmission lines are stuck by fault at a time.

$$x_{H,1}(t) + x_{H,2}(t) + x_{PV}(t) + x_D(t) - x_{sc}(t) + x_{sd}(t) + x_{VP,1}(t) + x_{VP,2}(t) = P_L(t)(1 + L_D) - \sum_i F_i(t)\,. \qquad (50)$$

In this equation, we remove all the other grid connected optimization variables out of the equation since MHS has to operate alone.

Economic Dispatch after fault

With new optimization variables, the new objective function for economical approach is as follows

$$TOC = \sum_t (x_{H,1}(t)C_H + x_{H,2}(t)C_H + x_{PV}(t)C_{PV} + x_D(t)(FC_D + C_D) + x_{sc}(t)C_B + x_{VP,1}(t)C_{VP,1} + x_{VP,2}(t)C_{VP,2}\,. \qquad (51)$$

4.4.Numerical results

We will show the simulation on the cases that lead power system to operate as islanding operation.

Firstly, here below is the Pre-Fault operation as we plan on SG1 case in normal mode of operation. Fault will be occurs at a time in this interval where we don’t know further.

Table 9 Load in Percent of MHS load at 14.30 – 15.00 PM on 25/5/15 (DF) and at time 1.30-2.00 AM on 26/5/15 (NF)

Load/Feeder	F1	F2	F3	F4	F6	F7	F8	Sum load
Load in percent of DF	26.98%	9.19%	6.23%	11.07%	12.53%	17.40%	16.59%	100% (6.139 MW)
Load in percent of NF	27.10%	8.74%	5.12%	8.76%	12.91%	21.29%	16.08%	100% (5.718MW)

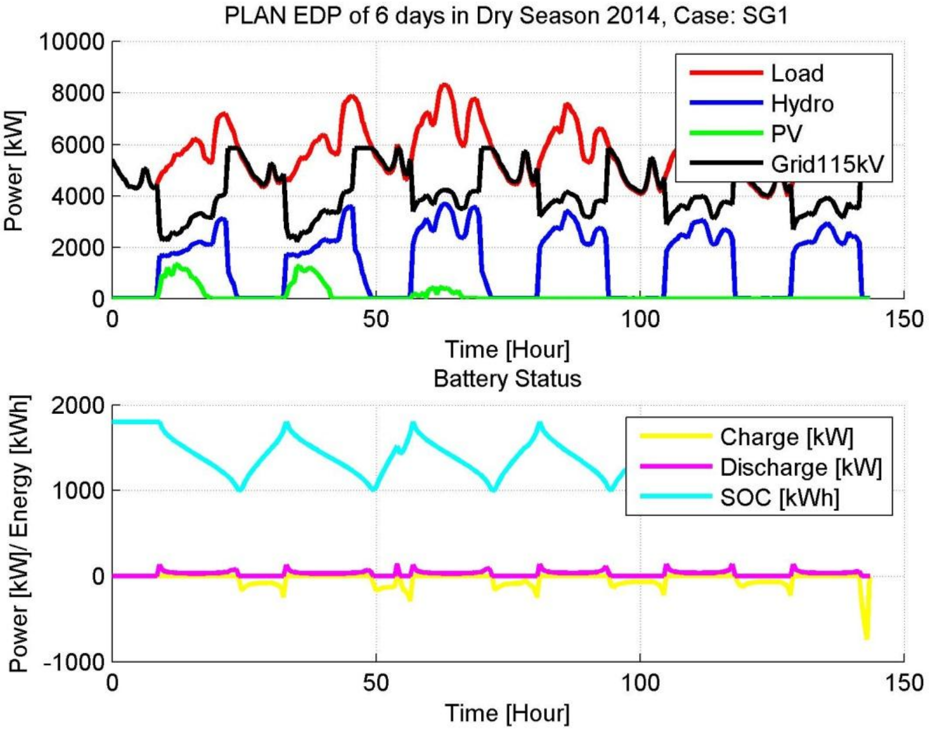

Fig. 9 Economic dispatch profile with BES case SG1,SG2, and SG3 in dry season.

We as the dispatch plan of smart grid power system in dry season which we simulate in previous chapter SG1 as shown in Fig. 9. In this normal operation dispatch as we set SOC of battery to be between 50-90 percent, we wonder that how long battery can be maintain the power system so we try to estimate the battery maintaining time as shown in Fig. 27. The maintaining time depends on the SOC of battery at the time step that fault occurs and also related to how much load at that time step. The minimum maintaining time is 7 minute while the maximum maintaining time is 21 minute of case SG1.

Clearing fault time

Clearing fault time in what we mention is not only the time of relay cut off the line in which fault occurs but what we want to mention is about when fault occur how long battery can maintain power system corresponding to the other electrical device can classified the type of fault then we would know the way to deal with it. When we plan to implement the battery we thinking about is it possible that the battery can maintain the MHS power system for come certain period for clearing fault and re-sync the transmission line to the power system and let do it as fault have not affect the electrical users at all if it is the temporary fault. Even the permanent fault, the MHS power system with battery still have to sometimes to prepare the grid forming operation during battery has maintain the power system. We try to figure out how much SOC is need for emergency case that sufficient both the cut peak operation in normal mode and enough system maintain time for operator to classified fault and manage the component in the proper ways.

Table 10 Maintaining time of MHS power system with different SOC.

Case	SG1	SG9	SG10	SG11
SOC_{min}[kWh]	1,000	1,200	1,400	1,800
SOC_{max} [kWh]	1,800	1,800	1,800	1,800
t_b^{min} [min]	7	8	9	11
t_b^{max} [min]	21	21	21	23
$\overline{t_b}$ [min]	12.73	13.58	14.48	16.27

So we to simulate various in normal mode with varies minimum SOC to observe the maintain time of battery when fault occur at each time step as shown in case SG1, SG9, SG10, and SG11. All of them have $\eta = 0.73$ and $C_B = 0.5$.

The result of varied SOC of battery in case SG1, SG9, SG10, SG11 as shown in table above, the t_b^{min} is varies from 7 minute to 11 minute as we set up SOC minimum from 1000 kWh to 1800 kWh (which is the upper limit of SOC of battery we use in this research). It shown that the variation in t_b is mainly came from the characteristic of load as we can see in case SG11 where the SOC is even stay at 90% SOC but the pattern of t_b still be the same as other cases but only slightly be levitated. SG1 dispatch plan and its battery maintaining time shows as follows.

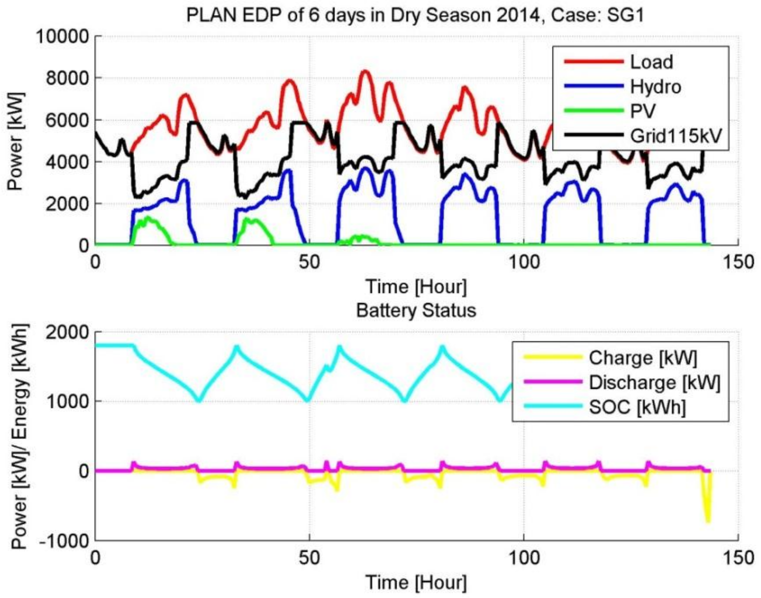

Fig. 9 Economic dispatch profile with BES case SG1,SG2, and SG3 in dry season.

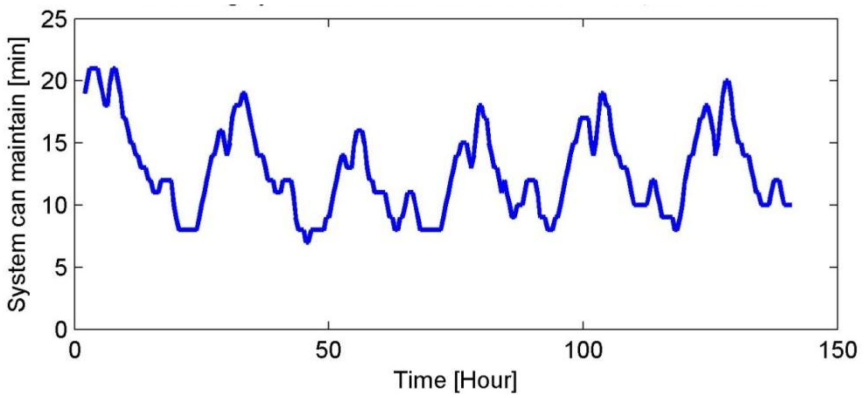

Fig. 27 Battery maintaining time when fault occurs: case SG1.

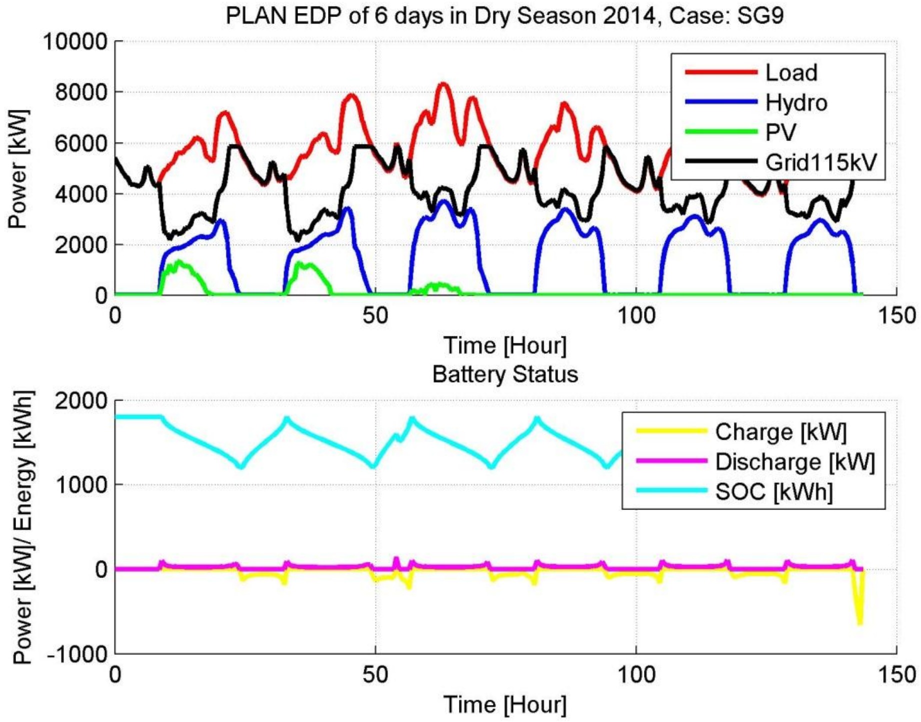

Fig. 28 Economic dispatch profile with BES case SG9 in dry season.

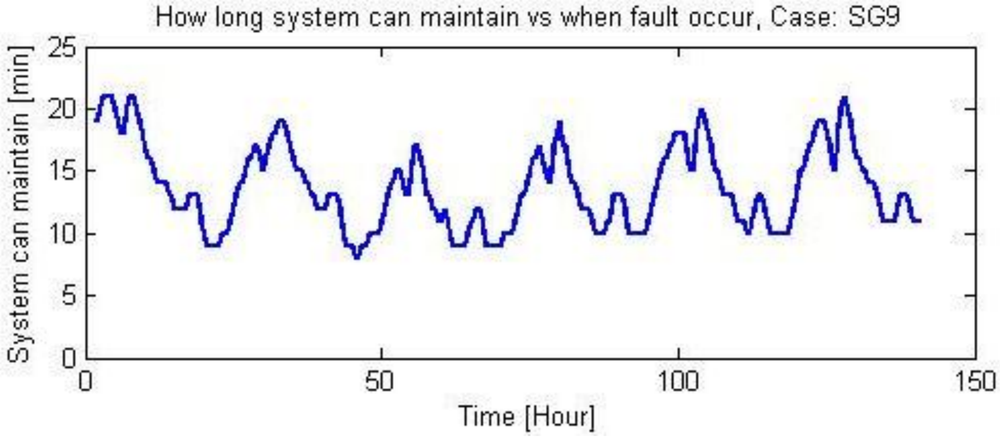

Fig. 29 Battery maintaining time when fault occurs: case SG9.

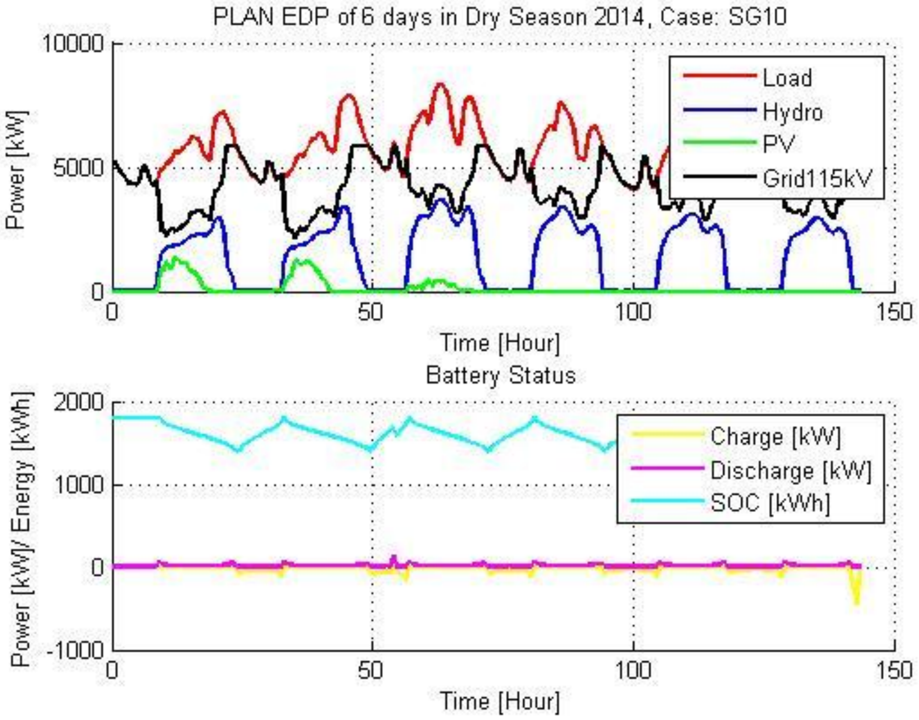

Fig. 30 Economic dispatch profile with BES case SG10 in dry season.

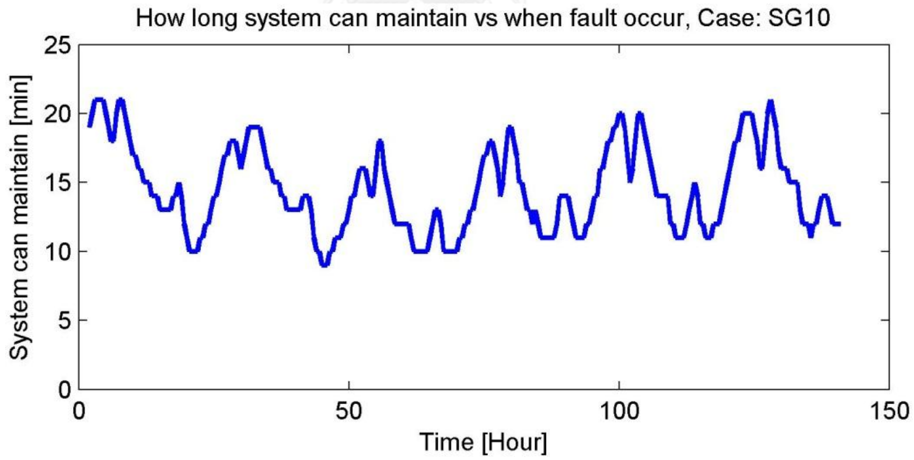

Fig. 31 Battery maintaining time when fault occurs: case SG10

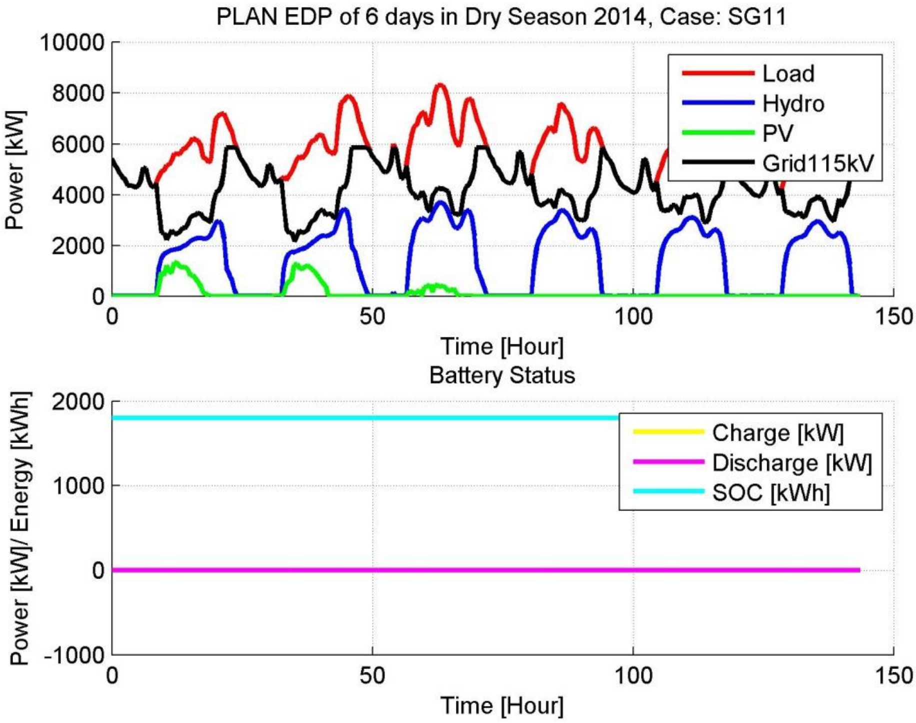

Fig. 32 Economic dispatch profile with BES case SG11 in dry season.

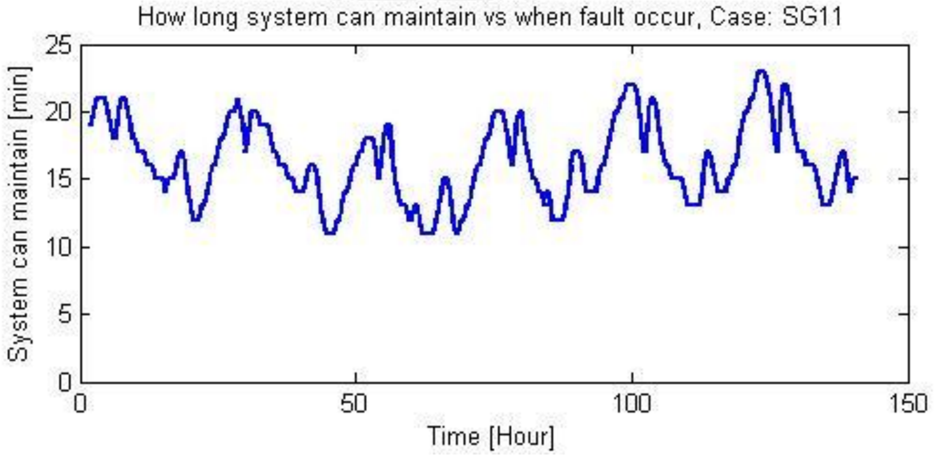

Fig. 33. Battery maintaining time when fault occurs: case SG11

In rainy season as we mention Fig. 17, the MHS power system operates without buying energy from Chiang Mai in which the fault along the transmission line is not directly affect the MHS power system because it not consume energy from the connected area. MHS operator can cut off grid and operates islanding mode imedietly without any concern about insufficietly energy because as we can obviously see that there is aboundance of renewable energy in this season.

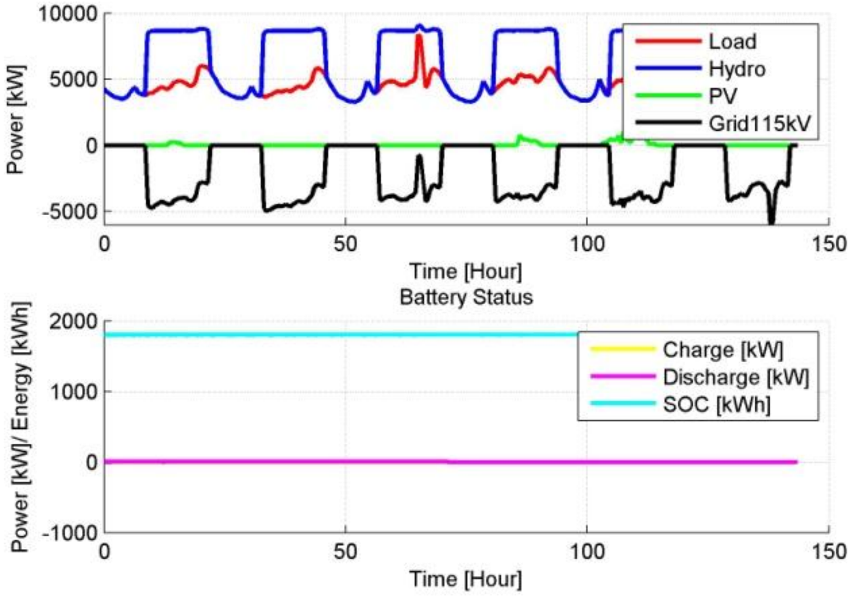

Fig. 17 Optimal dispatch profile with BES case SG7 and SG8 in rainy season.

Islanding Operation

We will simulate in this following cases.

- Islanding operation during the day.
- Islanding operation during the night.

In each case we will operate in case of with and without battery.

Case SG1-I1 is the operation when the fault occurs and both transmission lines have to open tie from 14.30-15.00 on 25/5/14. In Fig. 34, the islanding operation performs without battery as we bring diagram of dispatch operation in Fig. 25 to compare.

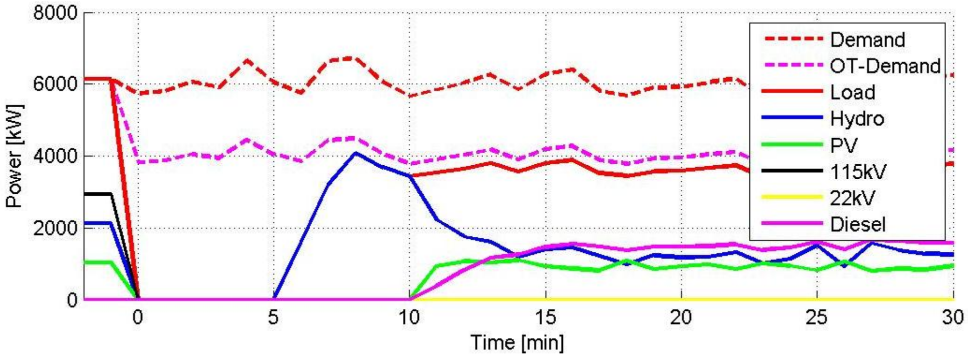

Fig. 34 Islanding operation without battery at day time Case SG1-I1

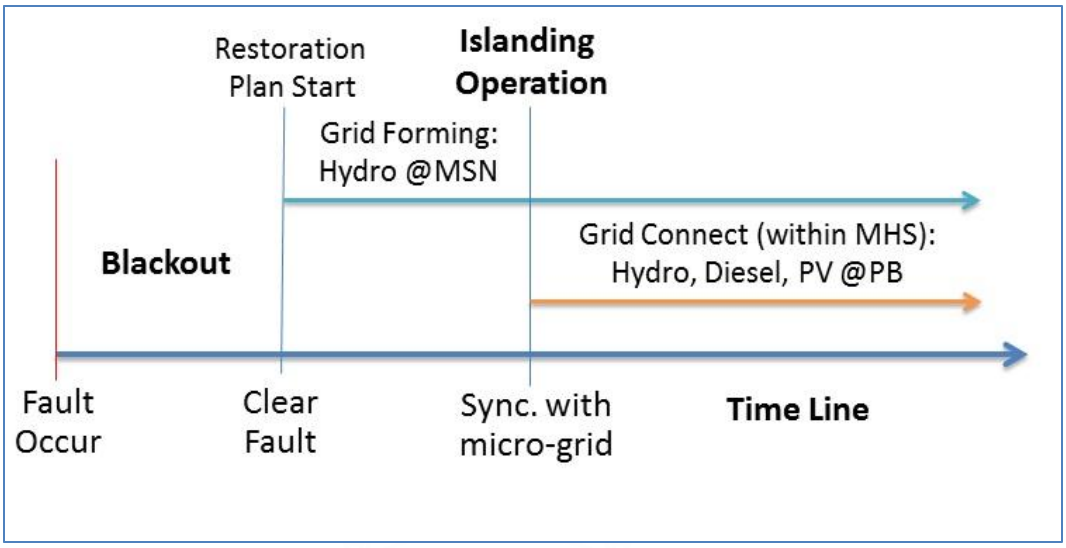

Fig. 25 After fault to islanding operation step without battery.

In the operation above, the power system is collapsed for a short period of time then it start grid forming then connected to other power plant after that is the islanding operation. Open tie line causes the power system to operate with much lower load demand, approximate 35% smaller. In this case some load shedding is concern in Feeder 2 for reduce amount of energy that supply from diesel generator both minimize CO_2 and operating cost.

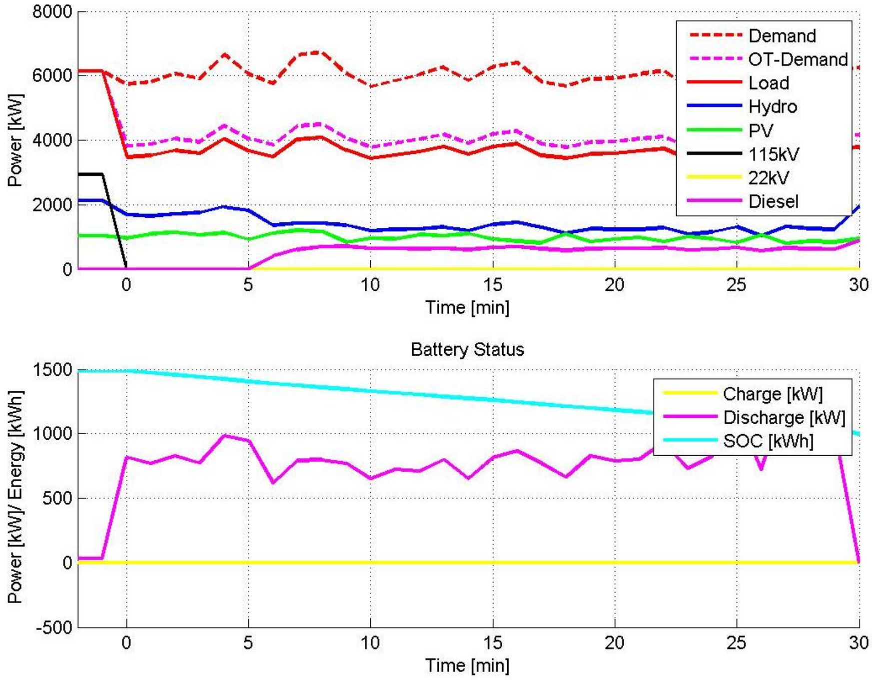

Fig. 35 Islanding operation with battery at day time: Case SG1-I2

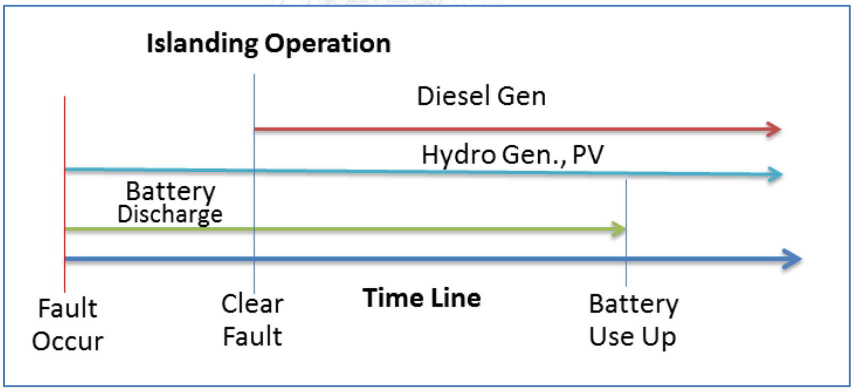

Fig. 26 After fault to islanding operation step with battery.

Case SG1-I2 is the operation and force MHS power system to islanding operation. In this case the power system has battery to back up immediately after fault occurs so the power system is not collapsed. After classified fault, diesel generator will start up.

Next, we consider the islanding operation during the night time. In these following cases there will be no PV power plant to operate since there is no light but meanwhile the load is smaller since it is in the night time. The following cases will consider during 1.30-2.00 AM on 26/5/15.

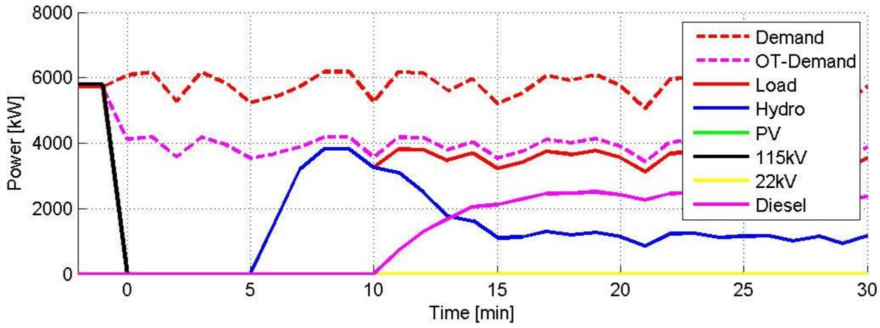

Fig. 36 Islanding operation without battery at night time: Case SG1-I3

In Fig. 36, we consider the faults that lead to islanding at the night time. The pattern of operation compare to the day time is quite similar. In night time, diesel output is seemed to be higher since the PV has no output. Table 11 summarizes day time and night time islanding operation.

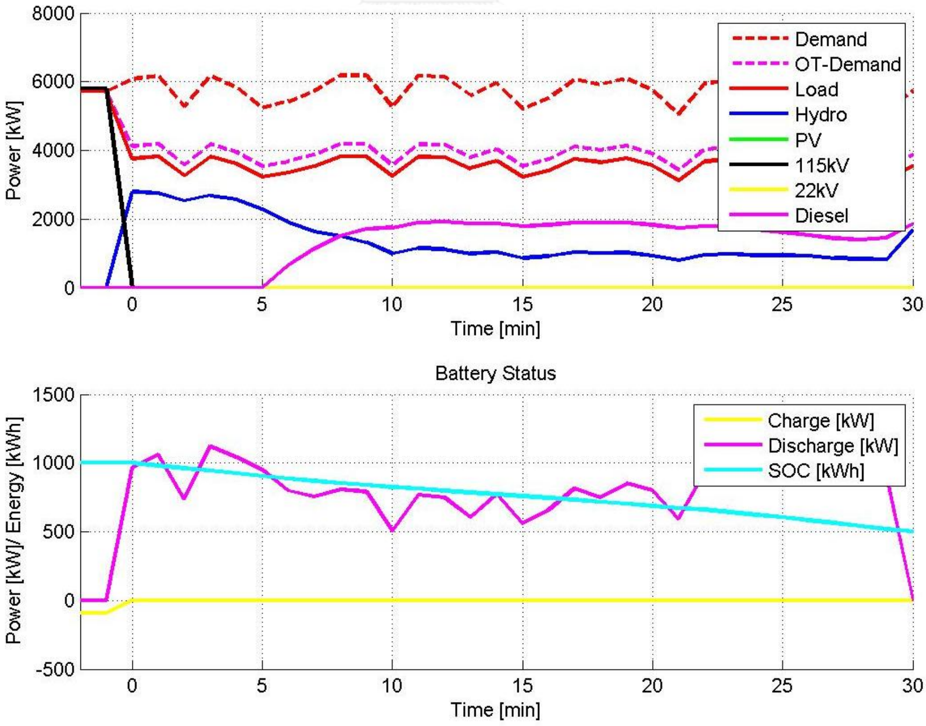

Fig. 37 Islanding operation with battery at night time: Case SG1-I4

In Fig. 37, battery has been considered. It goes the same pattern as in day time fault but hydro have to supply mode energy in the during fault period since there is no PV.

Table 11 Summary data for Islanding operation

No./ Case	SG1-I1	SG1-I2	SG1-I3	SG1-I4
Demand [kWh]	3,137.71	3,137.71	2,972.35	2,972.35
Open-Tie-Demand [kWh]	2,095.68	2,095.68	2,014.57	2,014.57
Load [kWh]	1,491.68	1,903.09	1,445.23	1,838.50
Diesel [kWh]	464.16	266.57	730.94	696.70
Gin115kV [kWh]	-	-	-	-
Gin22kV [kWh]	-	-	-	-
Battery Discharge [kWh]	No Battery	416.04	No Battery	427.50
VP1 [kWh]	192.59	192.59	176.07	176.07
VP2 [kWh]	411.40	0.00	393.26	0.00
IED [Baht]	23,382.18	1,660.15	22,282.00	1,517.75
Total Operating Cost [Baht]	28,769.62	5,069.36	30,314.03	9,190.29
CO2 [kg]	408.46	234.58	643.23	613.10

4.5.Conclusion

Islanding mode of operation is mode that operated when the power system is not connected to grid.

Day and night fault have to similar pattern of operation but for night operation without PV diesel generator have to inject more power to the power system.

Without battery power system has to face the blackout situation. Blackout is not only cause damage in term of cost in baht but it could lead to many dangerous situation such as airport navigation system shut down, medical instrument is has no power, banking system shut down, no traffic light, elevators stuck, etc. They affect not only for cost but mostly on security of life. With battery, power system will be more secured. For the day time and night time cases, without battery the majority cost of TOC is the IED cost with battery IED could be minimize to less than 2,500 baht compare to around 23,000 baht in case of without battery.

With open tie on feeder 1 and feeder 3, we classified feeders in 2 types that are feeder 2 and the rest which the community facility load such as hospital, airport, power plant, government area, and other important load. With customer satisfaction cases, we neglect of shedding any of feeders; we have to inject more 192.59 kW per 30 minute for day time and 176.07 kW per 30 minute for night time or approximate 9,000 kWh per days compare to shedding feeder 2.

Chapter 5
Conclusions

5.1.Summary of important results

In Normal operation, power system operates using the optimal cost function. In dry season, the power system lacks of renewable due to the low level of water so mini-hydro power plant cannot be operate at full capacity. More than 50% of usage energy in MHS comes from 115 kV power grid. In rainy season, the renewable energy in MHS is abundance so MHS no need to get supply energy from power grid on the other hand MHS selling energy back to Chiang Mai via 115 kV transmission line. With the renewable base microgrid of MHS, the optimal set point would acquire both minimum operating cost in baht and minimal CO_2 emission in kilogram.

To link normal mode of operation and islanding mode of operation together, we can choose minimum 50% SOC of 2 MWh battery, we can manage to have more than 7 minute in dry season to maintain MHS power system alone so that is a big gap of time even manages by the operator.

In islanding operation, MHS power system can operate by perform load shedding or start diesel generator to supply load. The research shows that without battery the cost of damages of interruption on electricity would be huge amount even this time when we only calculate on the IER on kWh this still not sum up with the charge per time it is collapsed and startup cost of generator so when the system collapse the cost will be highly and have to be concern. The high IED cost infers the high damage to the community cause by blackout. With battery back up the power system, the cost of IED shall be small or even zero depend on the operator objective.

5.2. Future work

We are looking to add more dynamic behavior to the power system, stability analysis and load flow and uncertainty model to improve dispatch strategy to be more practical. We suggest the following issues be carefully studied.

- Stability analysis of power system during fault and after fault.
- Consideration of load flow and power flow as part of dispatch strategy.
- Uncertainty model in load profile and renewable profile.

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APPENDIX

VITA

Noppasit Piphitpattanaprapt was born in 1991 in Bangkok, Thailand. He received the second-honored Bachelor Degree of Electrical Engineering from Chulalongkorn University in 2013. He has been pursing for Master Degree of Electrical Engineering at Chulalongkorn University, Thailand in 2014. His research interests Energy Manage System.