Operation Management of Micro Grid with Fuzzy Logic Controlled Storage System Using Two-Stage Optimization

Boonchoo Soontornwuttikrai and Pisut Raphisak

Abstract— *The growth of renewable energy increases continuously in micro grid. Management of renewable energy sources in the micro grid systems to suit the demand load is important. Costs and losses in energy supply can be reduced if there is effective management since there are various operation costs consisted in each type of renewable energy. This paper proposes the optimization for managing a variety of renewable energy sources in the micro grid system by using Particle Swarm Optimization algorithm and Fuzzy logic to minimize costs and losses in micro grid. Fuzzy logic is responsible for decision making to charge and discharge the energy storage on rule-based defined. PSO is responsible for a strategy to supply renewable energy to suit each type of demand load at minimum costs and losses. Furthermore, Modified Mae-Sariang micro grid system is considered as a tested system for application of suggested methodology. Results from the study indicate that the PSO algorithm and Fuzzy logic can reduce operation costs and losses in micro grid system which is subject to limited energy resources.*

Keywords— **Optimal operation, renewable energy, micro grid, fuzzy logic.**

1. INTRODUCTION

Currently, the application of alternative energy such as wind, biomass, solar and hydro is used extensively in electrical systems. The distribution generators such as PV, wind turbine and micro turbine will play an important role in supplying energy into power grids in the future. Managing energy sources to suit the load demand is a challenging issue. Micro grids are electrical systems which mostly rely on energy from renewable sources. Various optimization methods are proposed to manage and operate micro grids [1].

The goal of optimization is to solve for value of variables, which meets the objective function under specific constraints, and that can be found in many literatures such as [2]-[4] which used optimization for solving various problems.

Multi-objective operation management of a renewable micro grid with back up micro-turbine/fuel cell/battery hybrid power source is presented in [5]. The effect of solar PV system is not deliberated in this study. Literature [6] proposed a method for operating storage system to obtain optimal economic dispatch. However, loss minimization is not included. The study on the optimal operation of Modified Mae-Sariang micro grid was done in Mae Hong Sorn province, northern part of Thailand. This micro grid consists of wind turbine, photovoltaic system (PV), diesel generator, battery storage system, and external power grid supply as shown in Fig. 1. Particle swarm optimization (PSO) and fuzzy logic aims to minimize costs and losses as fuzzy logic is accountable for making decision of energy storage, while PSO is in charge of a strategy to supply renewable energy to suit each demand load which is subject to limited energy resources.

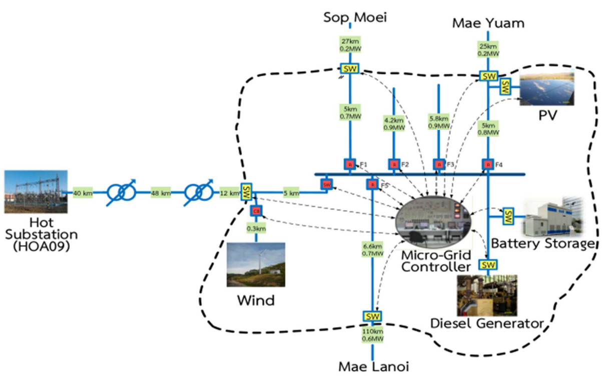

Fig. 1. Mae-Sariang Micro Grid System

2. PROBLEM FORMULATION

The operation management in micro grid is to allocate optimal power generation for individual power source. The power sources in the considered micro grid system include wind turbine, photovoltaic system (PV), diesel generator, battery storage system, and external power grid supply. The optimization problem is mathematically expressed as follows.

Objective of operating cost

The total operation cost is the summation of the costs of all energy sources in the system as shown in (2).

$min\ C_T$

$$\text{where } C_T = \sum_{t=1}^{T} (C_{DG}P_{DG,t} + C_S P_{S,t} + C_W P_{W,t} + C_{Bat}P_{Bat,t} + C_G P_{G,t}) \quad (2)$$

B. Soontornwuttikrai (corresponding author) is with the Energy Field of Study, Electrical Engineering Department, Kasetsart University, 50 Ngamwongwan Road, Ladyao, Chatuchak, Bangkok, 10900 Thailand and also works with Provincial Electricity Authority (PEA), Thailand. E-mail: boonchoo.s@ku.th.

P. Raphisak is Lecturer in Electrical Engineering Department, Kasetsart University, Thailand. E-mail: fengpir@ku.ac.th.

where C represents cost and P represents power, while subscript DG, S, W, Bat, and G designate diesel generator, photovoltaic system, wind turbine, battery, and external grid, respectively. T is number of considered intervals.

Objective of power loss

The power loss in power system can be evaluated using (3) [7].

$\min P_L$

where $$P_L = \sum_m \sum_n P_m B_{mn} P_n \quad (3)$$

where P_L is for power loss, while P_m and P_n are power of source m and n, respectively. B_{mn} represents transmission loss coefficient. N is number of committed units.

Constrains

There are load balance constrain as expressed in (4) and power generation capacity constrains as listed in (5) to (11).

Load balance

$$\sum_{t=1}^{T} (P_{DG,t} + P_{S,t} + P_{W,t} \pm P_{Bat,t} + P_{G,t}) = \sum_{t=1}^{T} D_t + \sum_{i=1}^{N} \sum_{j=1}^{N} P_{L\ j,t} \quad (4)$$

Maximum and Minimum capacity

$$P_{DG,t}^{min} < P_{DG,t} < P_{DG,t}^{max} \quad (5)$$

$$P_{S,t}^{min} < P_{S,t} < P_{S,t}^{max} \quad (6)$$

$$P_{W,t}^{min} < P_{W,t}^{t} < P_{W,t}^{max} \quad (7)$$

$$P_{Bat,t}^{min} < P_{Bat,t} < P_{Bat,t}^{max} \quad (8)$$

$$P_{G,t}^{min} < P_{G,t} < P_{G,t}^{max} \quad (9)$$

$$W_{ess,min} < W_{ess,t} < W_{ess,max} \quad (10)$$

$$P_{charge,t} \le P_{charge,max} , P_{discharge,t} \le P_{discharge,max} \quad (11)$$

where $W_{ess,}$ is the amount of energy storage inside battery at hour t. P_{charge} and $P_{discharge}$ are permitted rate of charge and discharge, respectively. D_t is demand at hour t.

3. OPERATING METHOD

The operating framework is divided into three main steps. First step is determining operation mode of battery (charge or discharge) by using Fuzzy logic. Second step is searching optimal power dispatch of each source under minimum costs and losses by applying the particle swarm optimization (PSO). Last step is re-determining operation mode of battery by considering the remaining battery state of charge (SOC), and grid power flow direction.

Fuzzy logic

Fuzzy logic system was developed by Lotfi Zadeh [8], which introduced a theory about the reason to be used in decision making under the uncertainty. The structure of the fuzzy comprises four components which are rule, fuzzifier, inference and defuzzifier, respectively, as shown in Fig. 2.

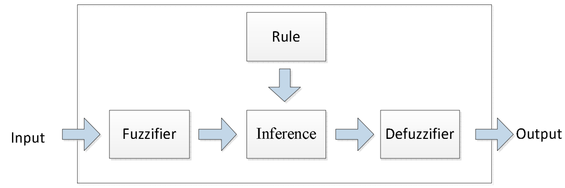

Fig. 2. Fuzzy Logic System.

The fuzzy process is explained in Fig. 3. The PV and wind energy and state-of-charge (SOC) are inputted to the fuzzy process. These inputs variables are converted to fuzzy variables which can be low, medium, or high. Then, the fuzzy rules are initially set according to Table 1-1 and 1-2, which includes rules applied during off-peak and on-peak intervals respectively, is used to determine battery operating mode – i.e. charge, discharge, and no action (zero energy flow). The battery model written in (12) is utilized to optimize fuzzy rules by minimizing cost of charging using PSO [5]. The optimal input and output of fuzzy rules are depicted in Fig. 4.

$$W_{ess,t} = W_{ess,t-1} + \eta_{charge} P_{charge} \Delta t - \frac{1}{\eta_{discharge}} P_{discharge} \Delta t \quad (12)$$

where $W_{ess,t}$ and $W_{ess,t-1}$ are the amount of energy storage inside battery at hour t and t-1, respectively. Δt is one hour time interval. η_{charge} and $\eta_{discharge}$ are battery efficiencies during charge and discharge process, respectively.

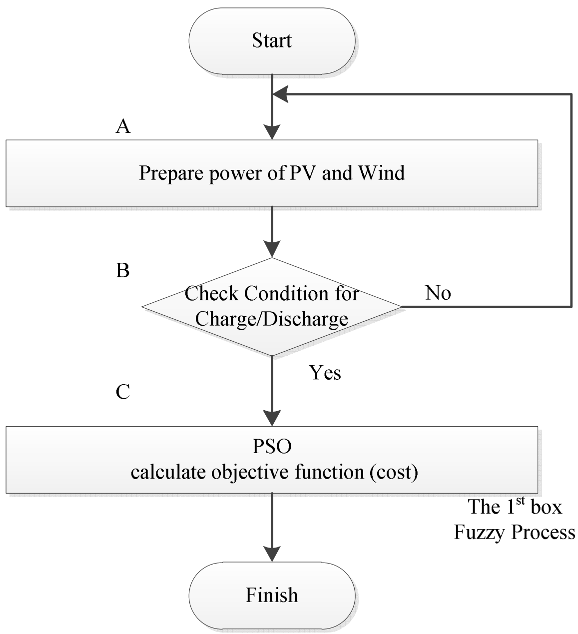

Fig. 3. Operation Mode of Battery using Fuzzy Logic

Table 1. Fuzzy Rule Applied during Off-peak Interval

SOC / PV Wind	Low	Medium	High
Low	HC	HC	HC
Medium	LC	HC	HC
High	Z	Z	LC

Table 2. Rule of Fuzzy Applied during On-peak Interval

SOC / PV Wind	Low	Medium	High
Low	Z	Z	LD
Medium	HD	HD	HD
High	HD	HD	HD

where HD is for high discharge rate of battery,
LD is for low discharge rate of battery,
Z is for no action (zero energy flows),
LC is for low charge rate of battery,
HC is for high charge rate of battery.

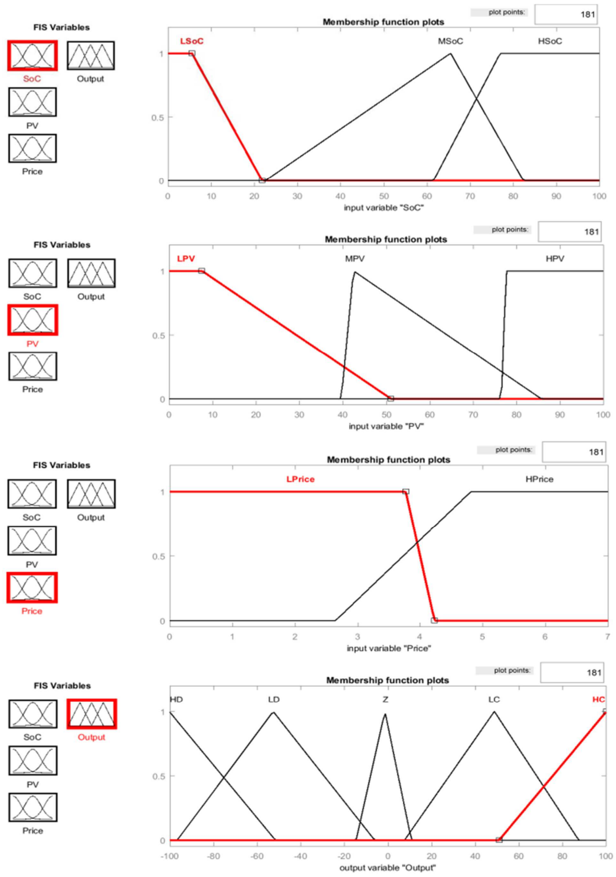

Fig. 4. The Input and Output of Fuzzy Rule after Optimization

Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) was first proposed by Kennedy and Eberhart in 1995 [9]. The basic of PSO mimics the behavior of social animals such as birds, fish or insects in search of food in the area. The herd members are represented by particles. The velocity of the particles depends on three factors namely inertia, cognitive and social components. The particle inertia is set according to the previous behavior of particles. The cognitive component is particle memory of its best locations. The social component is particle memory of best position compared to other particles. The particles will move until they find the optimal position. The mathematical model can be written as in (13). The new position can be updated according to (14) [10].

$$V_{ij,t} = wxV_{ij,t-1} + C_1 rand_1 (Pbest_{ij,t-1} - X_{ij,t-1}) + C_2 rand_2 (Gbest_{ij,t-1} - X_{ij,t-1}) \quad (13)$$

$$X_{ij,t} = X_{ij,t-1} + V_{ij,t} \qquad i = 1,2,...,N_D \quad j = 1,2,...,N_{par} \quad (14)$$

where

i	iteration count,
$V_{ij,t}$	dimension of the velocity of particle,
$X_{ij,t}$	dimension of the position of particle,
w	inertia weight,
C_1, C_2	acceleration coefficients,
$Pbest_{ij,t}$	dimension of the own best position of particle,
$Gbest_{ij,t}$	dimension of the best particle in the swarm,
N_D	dimension of the optimization problem,
N_{par}	number of particles in the swarm.

Searching optimal power dispatch of each source under minimum costs and losses has two stages as follows.

First-stage Optimization

The first-stage is depicted in Figure 5. The battery action and $P_{Bat,t}$ is firstly determined using the optimal fuzzy rules in Fig.4. All power generated by PV ($P_{S,t}$) and wind turbine ($P_{W,t}$) are fully feed into the micro grid. The optimal power dispatches from diesel generator ($P_{DG,t}$) and external grid ($P_{G,t}$) are determined by PSO respect to the objective functions in (2) and (3) and constraints (4), (5), and (9). The optimal $P_{DG,t}$ and $P_{G,t}$ are the result from the flow chart in Fig. 5. This is the first stage optimization.

Second-stage Optimization

Normally, micro grid receives external grid power through a very long transmission line. High external grid dispatch introduces high power loss. In extent, the power flows either into or out from the external grid causes power loss. In this case, if the battery has available discharge capability, energy supply from battery will reduce grid power usage and, consequently, decrease power loss. Since the battery action is predetermined before applying PSO, there are some room to optimize $P_{Bat,t}$ to minimize power loss. The flowchart of the second-stage optimization is displayed in Fig. 6. If micro grid system has surplus energy from PV and wind turbine, it will be charged into the battery. In contrast, when the system lacks of energy, the process will check the percentage of SOC of the battery. If percentage of SOC is greater than lower bound, the battery will discharge until percentage SOC reaches lower bound again. This second-stage optimization helps decreasing power loss due to external power transmission.

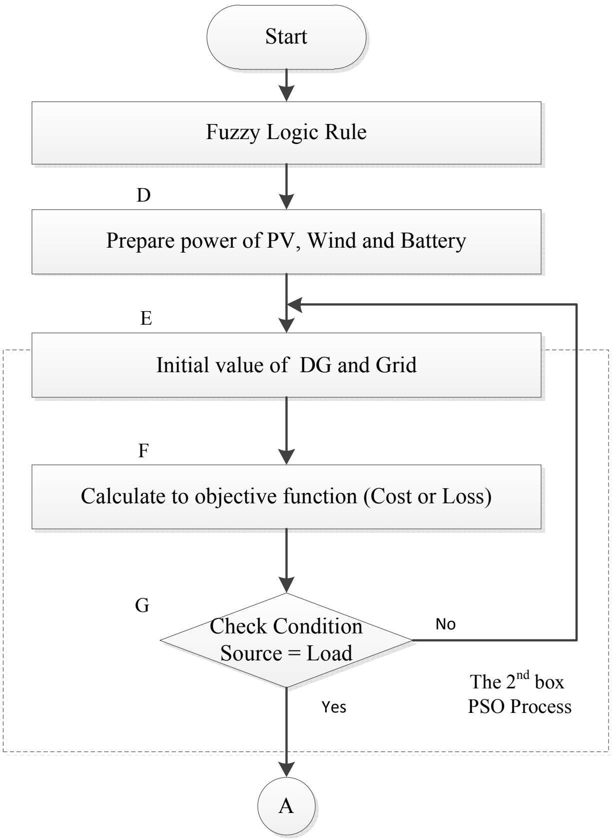

Fig. 5. Power Dispatch Optimization (First-stage Optimization).

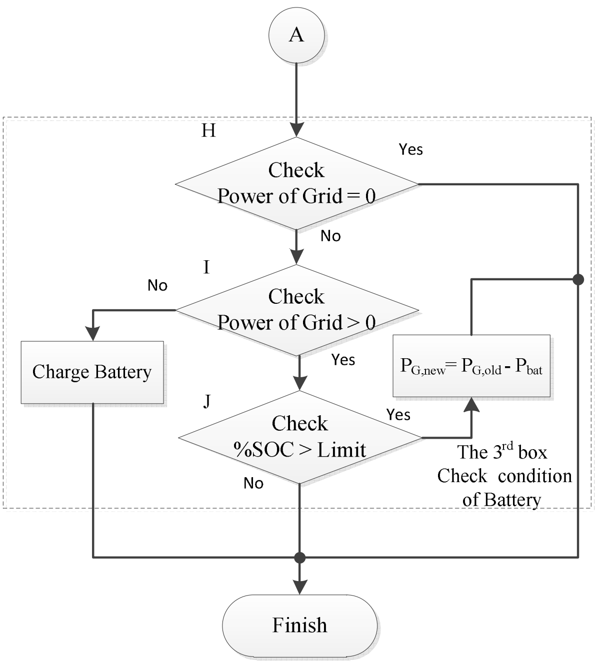

Fig. 6. Battery Action Refinement (Second-stage optimization).

4. CASE STUDY

Mae-Sariang micro grid which is displayed in Fig. 1 is used as the case study. The operation data of renewable energy and battery storage are provided in Table 2.

Table 2. Renewable Energy and Battery are installed

ID	Type	Min(MW)	Max(MW)	THB/Kwh
1	External Grid	-10	10	2.182 / 5.267
2	Wind	0	2	1.073
3	PV	0	2	2.584
4	Diesel	0	4	1.555
5	Battery	-2	2	0

Power meters were installed to record power delivered by wind turbine and solar PV system, and load demand. Fig.7 displays the measured power.

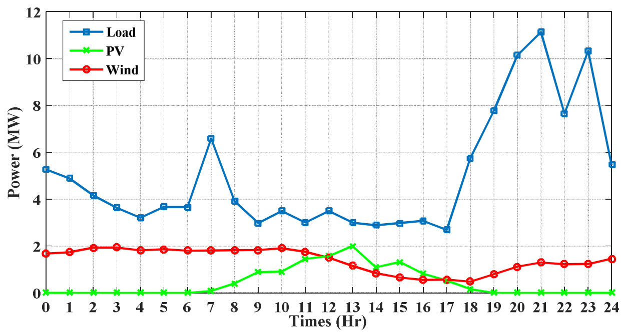

Fig. 7. Power of Renewable Energy in One Day

Electricity rate is Time of Use rate (TOU). It has two pricing periods including on-peak and off-peak as shown in Fig. 8.

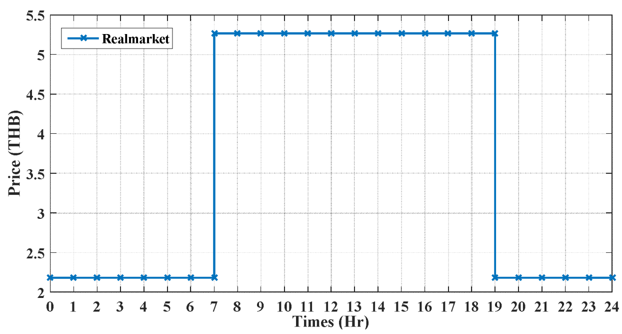

Fig. 8. Electricity Price : Times of Use Rate (TOU).

5. RESULT AND DISCUSSION

The proposed operating method is applied to the case study. The dispatch schedule shown in Fig. 9 is the result from the first-stage optimization. The total cost is THB 213,571, and total loss is 4542 W. The graph shows high demand after hour 17. This causes increment of diesel power generation and external grid power usage. The result from the second-stage optimization is shown in Fig.10. The total cost is THB 205,387, and total loss is 3354 W. Fig. 11-12 display the power of battery including before and after reducing power loss, respectively. Fig. 13-14 demonstrate the comparation of power loss and SOC at each time preriod.

Table 3 shows the comparison of power costs and losses in system before and after dropping at 20:00 and 21:00, which can be reduced losses by 54.97% and 43.91% as well as costs by 23.73% and 18.77% respectively.

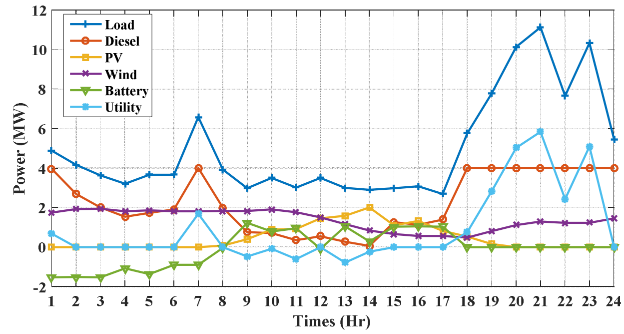

Fig. 9. The Dispatch Schedule from the first-stage optimization.

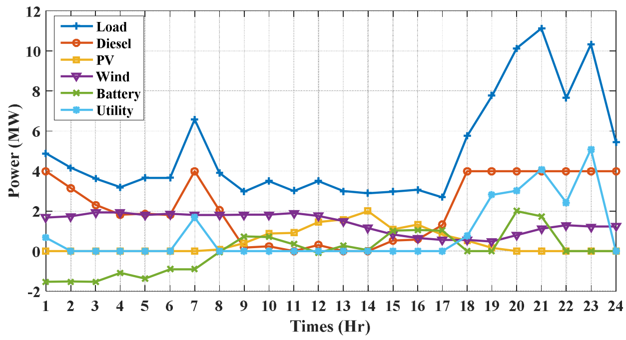

Fig. 10. The Dispatch Schedule from the second-stage optimization.

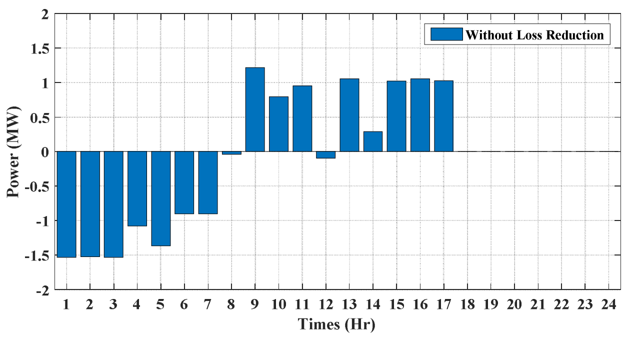

Fig. 11. Battery Power without loss reduction (applying only first-stage optimization).

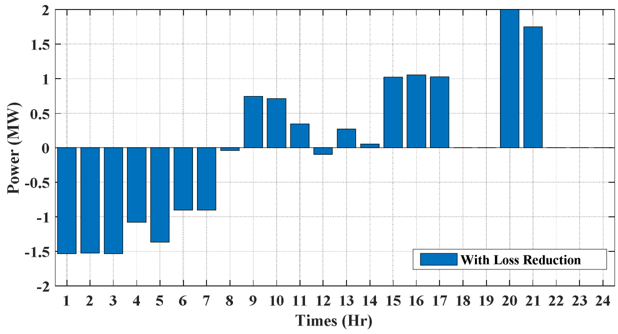

Fig. 12. Battery Power with loss reduction (applying two-stage optimization).

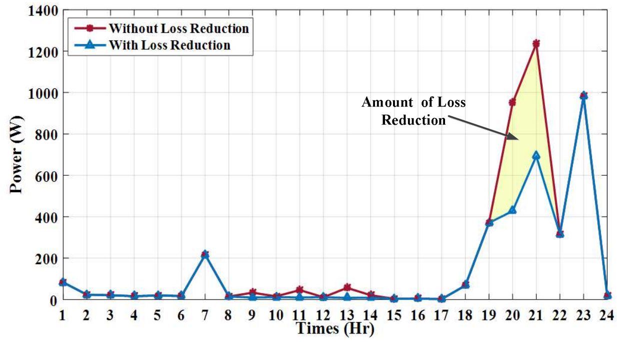

Fig. 13. Power Loss Comparison.

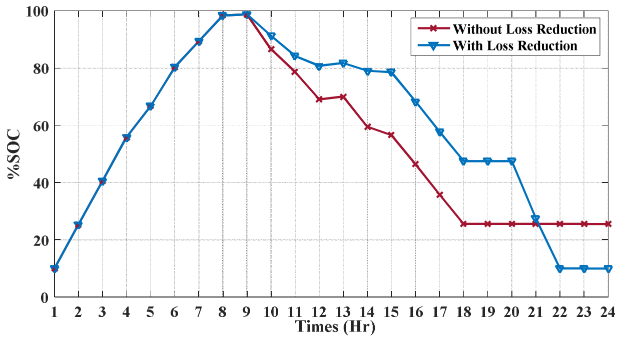

Fig. 14. SOC Comparison.

Table 3. Compare Loss and Cost at 20:00-21:00

Hour	Cost (THB/Hr)			Power Loss(W/Hr)		
	Before	After	% Reduc -tion	Before	After	% Reduc-tion
20:00	18,392	14,026	23.73	949	427	54
21:00	20,341	16,523	18.77	1235	692	43

6. CONCLUSION

This paper introduces an optimization framework based on Particle Swarm Optimization (PSO) algorithm and Fuzzy logic which focus on checking the condition of battery to increase the efficiency of management of micro grid systems. Modified Mae-Sariang micro grid system is considered as renewable generator and energy storage, DGs, utility, and load. It can be seen from the case study with the proposed method. The total loss can be significantly reduced by 54.97% and 43.91% as well as costs by 23.73% and 18.77% respectively.

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