OPTIMAL BATTERY ENERGY STORAGE ALLOCATION CONSIDERING OPTIMAL DAILY SCHEDULING USING MIXED-INTEGER PARTICLE SWARM OPTIMIZATION

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การจัดสรรระบบกักเก็บพลังงานแบบแบตเตอรี่ที่เหมาะสมที่สุดโดยพิจารณา จากการจัดตารางเวลารายวันด้วยวิธีฝูงอนุภาคแบบผสมจำนวนเต็ม

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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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คำสำคัญ : ระบบกักเก็บพลังงานแบบแบตเตอรี่/กำลังสูญเสียรายวัน/การจัดตารางเวลาที่เหมาะสมที่สุด/ตำแหน่งการติดตั้งที่เหมาะสมที่สุด/วิธีหาค่าที่เหมาะสมด้วยฝูงอนุภาค.

วิทยานิพนธ์นี้นำเสนอแนวทางการหาค่าที่เหมาะสมที่สุดของการจับกลุ่มอนุภาคแบบผสมจำนวนเต็มสำหรับการจัดวางระบบการจัดเก็บพลังงานแบบแบตเตอรี่ที่เหมาะสมที่สุดโดยติดตั้งร่วมกับตัวเก็บประจุและระบบพลังงานหมุนเวียน ซึ่งพิจารณาการจัดตารางเวลาของระบบกักเก็บพลังงานแบบแบตเตอรี่เพื่อลดการสูญเสียพลังงานในระบบแบบรายวันโดยการคำนวณการสูญเสียรายวันนั้นจะใช้วิธีสมการการไหลของนิวตันราฟสันเพื่อกำหนดค่าการสูญเสียรายวันในระบบการกระจายแบบแขนง วิธีการที่นำเสนอจะนำกำลังสูญเสียรายวันที่คำนวณได้ในระบบการกระจายแบบแขนง มาใช้พิจารณาในการตั้งเวลาหาช่วงเวลากักเก็บพลังงานหรือปลอดปล่อยพลังงานของแบตเตอรี่โดยการปรับช่วงเวลาให้เหมาะสมด้วยกลุ่มอนุภาค ในขณะเดียวกันการใช้วิธีกลุ่มอนุภาคแบบปัดเศษจะถูกนำมาใช้ในการจัดสรรหน่วยกักเก็บพลังงานที่เหมาะสมที่สุดโดยผสมผสานผลลัพธ์ให้ได้การสูญเสียพลังงานในระบบให้น้อยที่สุด วิธีการนี้ถูกทดสอบในระบบมาตรฐานแขนงแบบกระจาย 33 บัส โดยข้อมูลการใช้โหลดจะใช้ระบบการใช้โหลดทางไฟฟ้าในประเทศไทย นอกจากนี้ปัญหาการจัดวางตัวเก็บประจุที่เหมาะสมได้รับการตรวจสอบโดยใช้วิธีการที่นำเสนอซึ่งนำมาผสมผสานเข้ากับวิธีการจัดวางระบบกักเก็บพลังงานงานแบบแบตเตอรี่ และในวิทยานิพนธ์นี้ยังได้ศึกษาผลกระทบของโรงไฟฟ้าพลังงานแสงอาทิตย์ ผลการศึกษาแสดงให้เห็นว่าวิธีการที่นำเสนอสามารถลดการสูญเสียรายวันได้อย่างมีประสิทธิภาพด้วยวิธีการจัดตารางเวลาของระบบกักเก็บพลังงานแบบแบตเตอรี่ เมื่อได้การตั้งเวลาที่เหมาะสมของระบบกักเก็บพลังงานแบบแบตเตอรี่แล้ว วิธีการที่นำเสนอสามารถค้นหาตำแหน่งการติดตั้งที่เหมาะสมของระบบกักเก็บพลังงานแบบแบตเตอรี่ได้อีกด้วย.

สาขาวิชาวิศวกรรมไฟฟ้า ลายมือชื่อนักศึกษา ....
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KORAWITCH KAIYAWONG : OPTIMAL BATTERY ENERGY STORAGE ALLOCATION CONSIDERING OPTIMAL DAILY SCHEDULING USING MIXED-INTEGER PARTICLE SWARM OPTIMIZATION. THESIS ADVISOR : ASSOC. PROF. KEERATI CHAYAKULKHEEREE, Ph. D., 120 PP.

Keyword : Battery energy storage system/ Daily loss/Optimal scheduling/ Optimal placement/Particle swarm optimization.

This thesis proposes a mixed-integer particle swarm optimization (MIPSO) approach for coordinated optimal placement problem (COPP) of battery energy storage system (BESS) considering BESS scheduling for minimizing daily loss. The Newton-Raphson load flow is used to determine the daily loss in radial distribution system (RDS). In the proposed method, the distribution system daily loss minimization (DSDLM) for optimal BESS daily scheduling is solved by particle swarm optimization (PSO). Meanwhile, the optimal battery energy storage allocation (OBESA) is solved by round-off particle swarm optimization (RPSO), incorporating the result from DSDLM. The proposed method had been tested with IEEE 33-bus radial distribution test system, using load profile of Thailand power system. In addition, the optimal capacitor bank (CB) placement problem has been investigated using the proposed method and integrated into OBESA. The results on the distribution system with photovoltaic power plant have also been investigated. The simulation results showed that the proposed method can efficiently minimize the total daily loss by BESS scheduling. Moreover, the proposed MIPSO algorithm can achieve the optimal placement of BESS considering optimal daily scheduling.

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LIST OF ABBREVIATIONS

ESS	=	Energy storage system
BESS	=	Battery energy storage system
MIPSO	=	Mixed-integer particle swarm optimization
COPP	=	Coordinated optimal placement problem
RDS	=	Radial distribution system
DSDLM	=	Distribution system daily loss minimization
DSALM	=	Distribution system annual loss minimization
PSO	=	Particle swarm optimization
GA	=	Genetic algorithms
NRPF	=	Newton-Raphson power flow
OBESA	=	Optimal battery energy storage allocation
RPSO	=	Round-off particle swarm optimization
CB	=	Capacitor bank
PV	=	Photovoltaic
OBESSS	=	Optimal battery energy storage system scheduling
DLP	=	Daily load profile
ALTC	=	Automatic load tap changing
TCSC	=	Thyristor Controlled Series Capacitor
PIPSO	=	Parameter Improved Particle Swarm Optimization
DSCOs	=	Distribution companies
MPSO	=	Modified particle swarm optimization
SOP	=	Soft Open Point
NOP	=	Normally open points in network distribution
OCP	=	Optimal capacitor placement
LS	=	Locust Search
DG	=	Distributed generation
QPSO	=	Quantum-behaved particle swarm optimization
BFA	=	Binary firefly algorithm
OPF	=	Optimal power flow
RERs	=	Renewable energy resources
EMA	=	Exchange market algorithm

LIST OF ABBREVIATIONS (Continued)

VESS	=	Virtual energy storage system
TCLs	=	Thermostatically controlled loads
EMS	=	Energy management system
VPPC	=	Virtual power plant clusters

LIST OF NOMENCLATURES

ADL	=	the average daily loss (kWh)
TAL	=	the total annual loss (kWh)
D	=	the number of days
D^s	=	the number of days in summer
D^r	=	the number of days in rainy
D^w	=	the number of days in winter
$P_{loss,total}$	=	the total daily loss (kWh)
$P^s{}_{loss,total}$	=	the average total daily loss in summer day (kWh)
$P^r{}_{loss,total}$	=	the average total daily loss in rainy day (kWh)
$P^w{}_{loss,total}$	=	the average total daily loss in winter day (kWh)
$P_{loss}{}^h$	=	the hourly loss in each hour (kW)
G_{ij}	=	the conductance of the lines between bus i and bus j for $j \neq i$
$V_{ij}{}^h$	=	the voltage of bus i,j in each hour (kV)
$\delta_{ij}{}^h$	=	the voltage angle difference between bus i and j for each hour
$P_{Gi}{}^h$	=	the active power of generator at bus i in each hour
$P_{Gi}{}^{min}$	=	the minimize active power generation (MW)
$P_{Gi}{}^{max}$	=	the maximum active power generation (MW)
$Q_{Gi}{}^h$	=	the reactive power of generator at bus i in each hour
$Q_{Gi}{}^{min}$	=	the minimize reactive power generation (Mvar)
$Q_{Gi}{}^{max}$	=	the maximum reactive power generation (Mvar)
f_i	=	the MVA flow of line i in each hour is $f_i{}^h$ (MVA)
$f_i{}^{max}$	=	the limit of line flow (MVA)
$\lvert V_i \rvert^h$	=	the voltage magnitude of bus i (kV)
$\lvert V_i{}^{min}$	=	the minimum voltage magnitude for bus i (kV)
$\lvert V_i \rvert^{max}$	=	the maximum voltage magnitude for bus (kV)
$\lvert y_{ij} \rvert$	=	the magnitude of the y_{ij} element of Y_{bus} (mho)
θ_{ij}	=	the angle of the y_{ij} element of Y_{bus} (radian)

LIST OF NOMENCLATURES (Continued)

NB	=	the total number of buses
NG	=	the total number of generators
NL	=	the total number of lines
$\mathbf{ES}$	=	the matrix representing capacity of BESS (kWh)
ES_i^h	=	the capacity of i^{th} BESS at hour h (kW)
$\mathbf{C_{bess}}$	=	the matrix of charge/discharge by BESS (kW)
$C^h{}_{bess,i}$	=	the charge/discharge of i^{th} BESS at hour h (kW)
$C^h{}_{rate,i}$	=	the charge/discharge rate of i^{th} BESS at hour h (%)
$SOC^h{}_i$	=	the state of charge of i^{th} BESS at hour h (%)
η_c, η_d	=	the charging and discharging efficiency of BESS
$NBESS$	=	the number of BESS in the system
$\mathbf{CBS}$	=	the matrix representing size of CB (kvar)
cbs_i	=	the size of CB to be installed (kvar)
NCB	=	the number of CB in the system
$P^h{}_{PV,i}$	=	the active power of PV in each hour (kW)
NPV	=	the number of photovoltaics in the system
$\mathbf{B}$	=	the matrix representing bus number with BESS and CB
b_i	=	the bus number connected with BESS and CB
$\mathbf{B_{bess}}$	=	the matrix representing bus number with BESS,
$b_{bess,i}$	=	the bus number connected with BESS.
w	=	the inertia weight factor
c_1,c_2	=	the acceleration constants
r_1,r_2	=	the uniform random values
t	=	the number of iteratin
v	=	the velocity of particle
x	=	the position of particle
$pbest$	=	the best particle position
$gbest$	=	the best group position
p	=	the particle.

CHAPTER 1
INTRODUCTION

1.1 General Introduction

Over the years, the renewable energy resources installation on distribution networks are becoming extremely prevalent, because it is an environmentally friendly source of energy It may also assist in reducing the price of generating electricity from other resources. However, its high cost installation and difficult to predict the power generated. it has become more complex under conditions of highly distributed energy renewable resources. It's also have necessitated a change in traditional power distribution system operation, and management. Thereby, battery energy storage system (BESS) can play a vital role in overcoming these problems and appears to be a crucial part of the future smart grids. BESS have been the most challenging and complex issues in the industry, whether it is for electric utilities or for industrial applications. The new application is seen in the areas of electric vehicles, portable electronics, and the storage of electric energy produced by renewables like solar or wind generators, which means the uncertainty of their energy generation can be solved by BESS.

Nowadays, the demand for electricity is increasing with dramatic characteristics. There are high fluctuations in energy consumption that are difficult to predict, including transmission and distribution, which have high losses from the total power transmission. Therefore, the reduction in power loss is very important for the system to operate economically and reliably. Generally, capacitor bank (CB) is traditionally utilized and installed for mitigation of voltage drop, and also can potentially reduce power loss in electrical system (P. Diaz, et al, 2017). Therefore, this problem can be solved by installing a CB to compensate for reactive power and power consumption variations that can be managed with a BESS. Finally, the BESS application is also included in the master plan for the development of the smart grid system to study the impacts and approach to application in Thailand in the future.

1.2 Problem Statement

Thailand has a policy to promote the master plan for development of the smart grid system according to the Energy Master Plan 2015-2035. The objectives of the master plan for development of the smart grid system include three main objectives: load response and justice management, forecasting system for electricity produced from renewable energy, microgrids and battery energy storage systems. The objectives of the master plan for development of the smart grid system consists of various elements, including power purchase can be reduced during peak periods, encouraging private sector involvement in the load response, arrangement for commercial use of the main power system produced renewable energy, commercial arrangements for microgrids and BESS lead to the development of a commercial microgrid with BESS.

The master plan also concerns developing knowledge and technology, along with enhancing national security. Accordingly, the realization of BESS has been promoted to optimally operate distributed networks more effectively and economically.

Therefore, the BESS can be feasibly solved particularly in terms of optimizing the available capacity, increasing reliability and balance the fluctuations in supply and meet the ever-growing demand of electricity. Fig 1.1 explains that the system demand can be handled efficiently if storage is incorporated into the electrical network. As shown, during the early hours of the day, when demand is low, the storage is charged from the base load generating plant. Then, the demand rises during the day the generating plants belonging to mid merit category, account for the demand. If storage is considered during peak periods, the demand can be met by a peaking plant that only operates for a few hours per day, reducing the total cost of operating such a storage-integrated system. Thereby, we can see that when the generation profile with storage is taken, there is a much controlled demand graph as storage takes care of the load leveling and then it is charged again at the end of the day from the baseload generating plant (A.Joseph, et al, 2006.). When properly allocated, BESS provide benefit in significant reductions on power loss. However, the high cost of BESS creates significant concern and necessitates the development of a techno-economic solution.

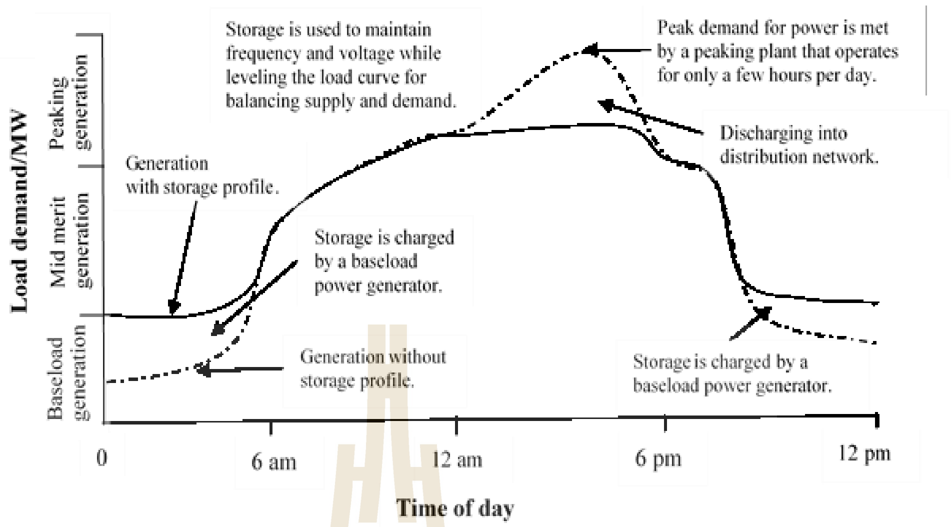

Figure 1.1 Operation system of BESS

In this thesis, optimal battery energy storage system scheduling (OBESSS), coordinated optimal placement problem (COPP) of BESS and CB, an optimal battery energy storage allocation (OBESA) considering optimal daily scheduling for distribution system daily loss minimization (DSDLM) are proposed. The proposed method is expected to be benefit in help minimize the total daily loss by considering BESS scheduling.

1.3 Research Objectives

The main objective of this thesis is to take advantage of optimal placement of BESS, considering optimal BESS scheduling for minimize energy losses in distribution system to determine the optimal allocation and scheduling of BESS. Mixed-integer particle swarm optimization is proposed. In particular, the main objective comprises of,

1.3.1 To develop method for determine the optimal scheduling of BESS to minimize losses in distribution system for planning of energy management system.

1.3.2 To develop the method for optimal placement of BESS considering optimal daily scheduling of BESS.

1.3.3 To develop the method for COPP of BESS and CB.

1.3.4 To apply the Mixed-Integer Particle Swarm Optimization (MIPSO) to solve the OBESA, considering OBESSS.

1.4 Scope and Limitation

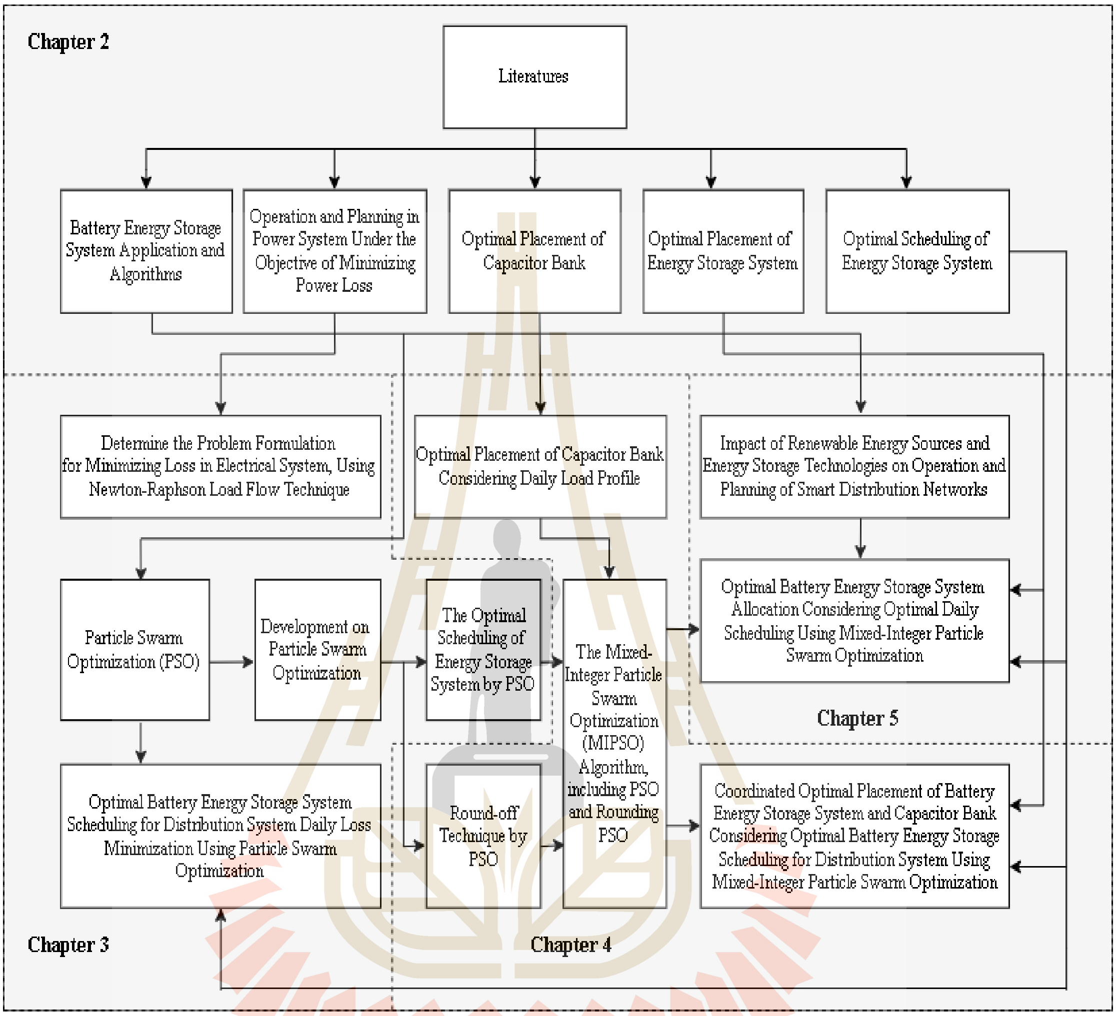

Figure 1.2 Framework of thesis

The scope and limitations of this thesis can be expressed as follows,

1.4.1 The optimal battery energy storage system scheduling (OBESSS) for distribution system daily loss minimization (DSDLM) is proposed. The proposed OBESSS is solved by PSO and tested with the 33-bus distribution test system. The propose method resulted in the minimal daily loss of distribution system with OBESSS. The OBESSS was compared to fixed time operation of BESS (charging when peak load and discharging when light load).

1.4.2 The proposed coordinated optimal placement problem (COPP) of BESS and CB considering optimal BESS scheduling (OBESSS) for distribution system daily loss minimization (DSDLM) is proposed. The proposed method used the mixed-integer particle swarm optimization (MIPSO) to optimal placement of BESS and CBs, while OBESSS is solved by PSO. The COPP was compared to (P. Diaz, et al, 2017) for single load profile to confirm the proposed method.

1.4.3 The optimal battery energy storage allocation (OBESA) considering optimal daily scheduling incorporating DSALM is proposed. The PV station was connected to the distribution system. The proposed OBESA is solved by MIPSO in coordination with the DSDLM, considering BESS scheduling, which is solved by PSO.

1.4.4 These proposed methods were tested with the radial IEEE 33-bus distribution test system using Thailand's power system load profile. This thesis was considered power balance system only. The results show that the proposed method can successfully provide the optimal allocation of BESS considering optimal daily scheduling. Finally, the cost of operation of BESS was not considered in these works. In Figure 1.2 demonstrates summarizes the framework of this thesis.

1.5 Conception

In this thesis, a method to determine optimal placement of BESS considering optimal scheduling of BESS. The IEEE 33 buses radial distribution system has been applied as case study, the results are simulated by MATLAB to find the value of appropriateness. In addition, coordinated optimal placement of BESS and CB have been investigated for verify results comparison with existing work. The total losses system reduction in distribution system is focus in this work.

1.6 Research Benefits

The proposed method can be used to determine the optimal scheduling and allocation of BESS in distribution systems, useful for planning of energy management system. The results show that the proposed method can effectively reduce daily loss.

1.7 Thesis Outline

The organization of this thesis is as follows. Chapter 2. addresses the literature are including, the research related energy storage application and algorithms, operation and planning in power system under the objective of minimizing power loss, optimal placement of capacitor bank, optimal placement of ESS and optimal scheduling of ESS. Then, the OBESSS considering DSDLM problem and PSO are described in Chapter 3. The COPP considering DSDLM and MIPSO are illustrated in Chapter 4. In addition, the OBESA considering DSALM problem are given in Chapter 5. Lastly, the conclusion is given in Chapter 6.

1.8 Chapter Summary

This Chapter 1 provides a general introduction to electrical power system problems on distribution systems and power loss problem of transmission line, with an emphasis on BESS to manage energy from renewable sources. The Energy Master Plan 2015–2035 is also described in the problem statement. The concept with limited scope is provided to optimize battery energy storage systems for minimizing losses, including OBESSS, COPP, and OBESA. After that, it is implemented with the DSDLM computational procedure detailed in the methodology section to contend with the benefits of this framework. In particular, the relevant study areas of BESS, OBESSS, and OBESA would be provided in the literature review section.

CHAPTER 2
LITERATURE REVIEWS

2.1 Introduction

Nowadays, BESS is very interesting application for planning and operation in power system. In this chapter, general data of energy storage system have been provided. many researches have been done under the objective of reduce energy loss, improve voltage and minimize operation cost. In addition, optimal allocation of energy storage systems was represented. Finally, this chapter provides some of relevant researches to present and compare the result of different methods.

2.2 Literature Overview

Implicated researches to this thesis can be classified into five groups, contains energy storage system application, researches under objective minimizing power loss, optimal placement of CB, optimal placement of ESS, and optimal scheduling of ESS. There are several researches in each group with different methods. Anywise, the majority of review related optimization researches are focused on the objective of minimizing power loss. For expedience, this section overview provides an overview of relevant research in a tabular format. Table 2.1 shows the research related battery energy storage application and algorithms. Table 2.2 presents many researches have been done under the objective of minimizing power loss. Table 2.3 presents research about optimal placement of capacitor bank. Table 2.4 presents research related optimal placement of energy storage system. Table 2.5 presents research about optimal scheduling of energy storage system. The detail of the mention reference is addressed under tabular in each group, the explanation can be following in section 2.3, 2.4, 2.5, 2.6 and 2.7.

Table 2.1 The research related energy storage application and algorithms

Proposed	Topic	Descript
A.Joseph, et al, 2006.	Battery Storage System in Electric Power Systems	Explain each energy storage technology, with an exceptional focus on BESS, its environmental impact, and efficiency.
L. Yao, et al, 2016.	Challenges and progresses of energy storage technology and its application in power systems	Application scenarios of energy storage technology are reviewed, taking into consider their impacts on power generation, the cost and policy to guide and support the development of ESS.
H. Abdi, et al, 2017.	Energy Storage Systems	The technical and economic considerations in the utilization of energy storage systems with DGs was discussed.
W. Xin, et al, 2017.	Analysis of Energy Storage Technology and Their Application for Micro Grid	W. Xin, et al clarifies the need for the creation of a microgrid with its own energy storage unit and highlights the distinctive and academic features of such a system.
E. Ghiani, et al, 2018.	Impact of Renewable Energy Sources and Energy Storage Technologies on the Operation and Planning of Smart Distribution Networks	The key technological challenges deriving from the inconstancy and non-programmability of distribution energy resources that will be integrated in future distribution networks are described.
J. Kenneny, et al, 1995.	Particle Swarm optimization	A concept for the optimization of nonlinear function using particle swarm methodology is introduced.

Table 2.1 The research related energy storage application and algorithms (Cont.)

Proposed	Topic	Descript
K.Deb, et al, 1999.	An introduction to genetic algorithms	The purpose of this paper is to familiarize readers to the concept of GAs and their scope of application.
P. Lohray, et al, 2019.	Rounding Technique Analysis for Power-Area & Energy Efficient Approximate Multiplier Design	To manage the level of accuracy for each range of data, an input data rounding pattern and the probability of repetition for rounded values have been introduced.

Table 2.2 Operation and planning in power system under the objective of minimizing power loss

Proposed	Method	Objective	Significant finding
D. Lukman, et al, 2001	Newton-Raphson load flow analysis	-Improving the voltage level of power system. -Minimize power loss in transmission line.	The proposed method used switch capacitor banks to illustrate voltage control and loss minimization, and the results of such a simulation are discussed.
F.G. Bagriyanik, et al, 2003	-Fuzzy multi-objective -Genetic algorithm	-Improving the voltage profiles. -Reducing the transmission system	Using the proposed method, the most satisfactory solution for multiple objectives can be obtained, and the optimization issue can be described more realistically.

Table 2.2 Operation and planning in power system under the objective of minimizing power loss (Cont.)

Proposed	Method	Objective	Significant finding
S. Angalaeswari, et al, 2015	-Improved particle swarm optimization	- real power loss reduction - improved bus voltage profile	The results of the proposed approach show that real power loss is reduced and the bus voltage profile is improved. In terms of power loss reduction and computational time, the proposed PIPSO approach clearly outperforms and outperforms the existing PSO method.
F. Flaih, et al, 2016	-Modified particle swarm optimization	-Reduce the high real loss -Manage the poor voltage profile	The real power loss is decreased by 31%, the average system voltage is increased by 2%, and the lowest voltage is improved by 2.5 percent, according to the numerical results of the test.
B. Gaur, et al, 2019	-STATCOM	-Real power transmission loss reduction -Bus voltages of the power network	In the presence of STATCOM, an optimum reactive power dispatch problem is solved real power transmission losses and the results are analyzed under different loading situations.

Table 2.2 Operation and planning in power system under the objective of minimizing power loss (Cont.)

Proposed	Method	Objective	Significant finding
F. Rafael, et al, 2019	-Particle swarm optimization	-Reducing power losses	The efficiency of the process is confirmed achieving a loss reduction of 8.38%. The loss of active power converges after 100 iterations from 13,393 to 12.27 MW.
M. Ismail, et al, 2020	- Soft Open Point (SOPs) -Interior point method	- Reduces the power losses in the distribution network	The strategy targeted to determine the optimal set point of SOPs operation. The objective function was to minimize the system power losses.

Table 2.3 Optimal placement of capacitor bank

Proposed	Method	Objective	Significant finding
P. Diaz, et al, 2017	-Locust Search method	-Reductions on power loss -energy saving and cost reductions	This formulation is known in the literature as Optimal Capacitor Placement problem and compared against that of other techniques.
M. B. Nappu, et al, 2018	- Load flow analysis	- Improve voltage buses	this paper is locating the correct size and position for reactive power.

Table 2.3 Optimal placement of capacitor bank (Cont.)

Proposed	Method	Objective	Significant finding
R.N.D. Costa Filho, et al, 2018	- Quantum-behaved particle swarm optimization	-Minimize cost operation -Power loss -Improve voltage profile	The objective in this paper is minimize the annual cost incurred due to kW losses and the annual cost due to capacitor installation while satisfying the technical constraints on the network.
O. Ivanov, et al, 2019	- Sperm whale algorithm	-Loss reduction	This paper presents an improved method for loss reduction in MV distribution networks, using an optimal placement of capacitor banks, with a recently proposed metaheuristic, a sperm whale method.
A. Mujezinović, et al, 2019	- Integer genetic algorithm	-Annual cost of looses -Loss reduction	In this paper, the load flow calculation method and the integer genetic algorithm are utilized in this algorithm for optimal placement and size of shunt capacitor.
V.Cholapandian, et al, 2021	-Cuckoo search algorithm	-Decreases the losses -Cost operation reduce	In this paper is implemented to determine the weak bus to place the capacitor, which has been implemented to identify the best kVAR of the CB.

Table 2.4 Optimal placement of energy storage system

Proposed	Strategy	Objective	Significant finding
M. Nick, et al, 2013	-Heuristic techniques. -Genetic algorithm. -Optimal power flow.	-Improving voltage support of ESS to the grid. -Reduce power loss, and cost energy.	It has been applied to the IEEE 13 bus test feeder. The proposed method is a consistent technique capable of contributing to the energy balance as well as grid ancillary services support.
S. Bhaskar, et al, 2013	-Newton-Raphson load flow analysis. -Particle swarm optimization.	-Reduce the distribution power loss	IEEE 34 bus systems were used to test the suggested technique. The total system loss has been minimized due to the BESS and wind generator, as well as an improvement in the voltage profile of the system's various buses.
W. Ling Ai, et al, 2014	-Binary firefly algorithm	-Minimizing the voltage deviation.	The proposed method used the binary firefly algorithm (BFA) to determine the best location for battery energy storage systems in a solar generating integrated radial distribution network to mitigate the voltage increase problem.

Table 2.4 Optimal placement of energy storage system (Cont.)

Proposed	Method	Objective	Significant finding
S. Vattanak, et al, 2017	-Newton-Raphson load flow analysis. -PV connected distribution	-Reduce power losses in distribution system.	Simulation results show that optimal siting and sizing of ESS can help keeping voltages within the range and also minimizing energy losses in IEEE 34-bus test system.
D. A. Rapits, et al, 2018	-Unified particle swarm optimization technique.	-Minimize the energy losses of the system.	The deployment of BESS units in a Distribution Network with high PV Penetration results in significant advancements in energy losses, voltage, and line ampacity profile.
Y. Kai Sun, et al, 2018	-Yalmip toolkit algorithm	-Minimizing the investment. -Minimizing the operational costs.	This paper considered optimal charging and dis-charging, placement and sizing of grid-scale energy storage. A practical solution model is verified using the IEEE 9-bus system.
S. Shafiq, et al, 2019	-Voltage to load sensitivity approach	-Reduce system losses. -Improve voltage profile.	This paper proposed a voltage-to-load sensitivity approach to determine an optimal node location for the BESS to reduce system losses and improve voltage profile.

Table 2.4 Optimal placement of energy storage system (Cont.)

Proposed	Method	Objective	Significant finding
B. Constantin Neagu, et al,2019	-Particle swarm optimization	-Minimization of active energy losses. -Voltage improvement	The energy loss advantage of the ESS-based PSO technique results in the biggest percentage decrease of 9.97 percent.
A. Alzahrani, et al, 2019	-Genetic algorithm -PV connected distribution	-Minimization of power losses -Increasing reliability	The results show a significant reduction in system losses, especially when using distributed BESS placement (reduce loss about 57.6 %).
A. Trpovski, et al, 2020	-Meta-heuristic Genetic Algorithm (GA) -Mixed integer quadratically constrained program (MIQCP)	-A cost-effective line expansion strategy.	In this paper, a robust distribution system expansion planning approach for a combined installation of new lines and energy storage systems is proposed.

Table 2.5 Optimal scheduling of energy storage system

Proposed	Strategy	Objective	Significant finding
Y. Oka, et al, 2013	-Tabu search algorithm. -The net present value method.	-reduce cost of fuel and CO2 emission.	The simulation results suggest that the proposed strategy is successful for scheduling BESS operation in a power system with a high penetration of PVs.
M. Chehreghani, et al, 2014	-Multi-objective. -Power flow. -IPOPT optimization.	-Minimization of losses. -Imbalanced power at the substation. -Reduce energy cost.	To demonstrate the efficiency of the suggested strategy for optimally operating IEEE 33 bus systems. The charging and discharging schedule of the ESS depends on the placement of the ESS as well as the objective function.
A.Garces, et al, 2014	-Power Flow. -Lagrange multipliers.	-Minimizing energy losses.	Simulation results on the IEEE 37-bus test feeder demonstrate that reshaping the load curve with an energy storage system can reduce transmission losses in a distribution system.
T. Khalili, et al, 2017	-Exchange market algorithm (EMA).	-Minimize the peak generation. -Reduce power loss.	The proposes is investigated in IEEE 33 bus radial distribution system to prove the EMA's performance and resilience. The results show that as the number of storages increases, active power loss decreases.

Table 2.5 Optimal scheduling of energy storage system (Cont.)

Proposed	Method	Objective	Significant finding
W. Lee, et al, 2017	-Load forecasting -Renewable energy forecasting	-Maximize the customer's profit. -Minimize peak load and charge cycles.	Result shows significant reduction of electricity charge (82.7%) and peak load (78%) by applying this algorithm.
C. P. Barala, et al, 2019	-The demand response of thermostatically controlled loads (TCLs)	-Minimize cost operation with ESS	This paper proposed optimal scheduling of residential consumer demand with manage the energy consumption of thermostatically controlled loads for cost saving.
M. Yin, et al, 2020	-Power flow. -Stochastic optimization.	-Minimize the cost of energy losses.	In this paper, depending on where the BESS are located and scheduling, BESS can assist the grid in regulating power generation from both PV and substations to reduce loss costs.
Felipe O. Ramos, et al, 2021	-Energy time shift. -Demand charge management. -Reactive power control	-Electricity charges. -Increasing reliability of energy supply.	A scenario-based study of a BESS installed in a final customer is described with the main aim of decreasing electricity costs and increasing energy supply reliability.
J. Wang, et al, 2021	-Generation-grid-load-storage coordination	-Reducing the operating cost of the system	This paper proposes an optimal scheduling method of VPPC considering generation-grid-load-storage coordination.

2.3 Battery energy storage system application and algorithms

Energy storage system has been the most challenging and complex issue of the industry whether it is the electric utilities or for industrial applications, when employed as a generation resource in the utility industry, energy storage can reduce operational costs, capital expenditures and when combined with renewable, can improve the usability of solar and wind-generated electricity by aligning supply with peak load demand. The integration of wind and solar energy into the electric grid may be aided by energy storage. A type of energy storage system including pumped hydropower, compressed air energy storage, batteries, flywheels, super conducing magnetic energy storage, super capacitors and hydrogen storage. Conventional pumped hydro facilities consist of two reservoirs, each of which is built at two different levels, Water will be the source of energy, which is stored at high level and water is released to low level when energy is required. while causing the water to flow though hydraulic turbines while generate electric power high as 1000 MW. Compressed air energy storage systems store energy by compressing air within an air reservoir using a compressor powered by low cost electric energy. A flywheel storage device is made up of a fast-spinning flywheel, an integrated electrical apparatus that can be used as a motor to turn the flywheel and store energy or as a generator to generate electrical power on demand utilizing the energy stored in the flywheel. An electrochemical capacitor has components related to both a battery and a capacity. Therefore, cell voltage is limited to a few volt (A. Joseph, M. Shahidehpour.,2006).

In few years ago, much of the energy technology focus on the development of electric storage has been on battery storage. Electric batteries are electrochemical energy storage devices that deliver direct current electricity. Electrode plates, which are often made of chemically reactive materials, are submerged in an electrolyte, which aids in ion transfer within the battery. The oxidation part of the oxidation-reduction electrochemical process causes the negative electrode, or anode, to “give up” electrons during discharge. These electrons give up energy as they move through the electric load connected to the battery. The electrons are subsequently transferred to the cathode, or positive electrode, for electrochemical reduction. During charging, the process is reversed. Cells with a characteristic operating voltage and maximum current capability are built in various series/parallel arrays to produce the desired voltage and current in battery systems. The battery charge discharge efficiency, the type of cycling regime, the battery service life, and the energy requirements for battery manufacture are all important parameters that determine energy flows in battery systems (A. Joseph, M. Shahidehpour.,2006).

For nickel-cadmium, nickel-metal hydride, and lead-acid batteries, service life, energy density, and energy requirements for battery manufacture are all equally important. In future, battery energy storage systems are a disruptive technology altering power system planning and operation because a life cycle viewpoint, the environmental effect of battery systems can be decreased by matching operating conditions and battery properties. To reduce the environmental impact of battery systems, battery technology development should focus on material recycling, longer service life, higher energy densities and metals with a reasonably high natural occurrence should be utilized in battery systems to reduce the environmental impact, and laws should be enacted to reduce the demand for virgin metals (A. Joseph, M. Shahidehpour.,2006).

As a power source that is adaptable, energy storage has a wide range of applications in renewable energy generation, grid integration, power transmission and distribution, distributed generation, micro grids, and auxiliary services like frequency management, etc. In terms of technical maturity, efficiency, scalability, lifespan, cost, and applications, the most recent energy storage technology profile is reviewed and evaluated, considering their impact on the entire power system, including generation, transmission, distribution, and consumption. The potential markets for energy storage applications in the worldwide and Chinese markets are defined, as well as the application scenarios for energy storage technologies are evaluated and studied. From a technological and economic standpoint, the challenges of large-scale energy storage application in power systems are discussed. Meanwhile, the worldwide energy storage market's development prospects are anticipated, and the application prospects of energy storage are verified (L. Yao, et al.,2016).

With a greater emphasis on the concept of the distribution generator, the influence of distribution generators on the network must be evaluated. The technological consequences are one of the many challenges that continue in joining distributed generators to the grid. The energy storage device is an important component of the distribution generator. Energy storage devices are crucial components, particularly in systems that utilize renewable energy sources like wind and solar energy (H. Abdi, et al.,2017).

W. Xin, et al clarifies the need for the creation of a microgrid with its own energy storage unit and highlights the distinctive and academic features of such a system. the advantages and disadvantages of battery energy storage, superconductive magnetic energy storage, flywheel energy storage, super capacitor energy storage, and hybrid energy storage in the micro grid are discussed and the properties and requirements of the micro grid are then considered. Finally, the future development trend of energy storage technology is discussed, as well as the application research of energy storage systems (W. Xin, L. Yun.,2017).

The key technological challenges deriving from the inconstancy and non-programmability of distribution energy resources that will be integrated in future distribution networks are described. The effects of renewable energy resources on distribution networks necessitate a change in traditional power distribution system development, operation, and management. The development of the future energy system will be based on distribution system planning and management in accordance with the Smart Grid philosophy, which includes extensive use of information/communication technologies and innovative control systems to enable the realization of smart distribution systems, active demand participation, and energy storage (E. Ghiani, G. Pisano.,2018).

The particle swarm approach to optimize nonlinear functions is presented by J. Kennedy and R. Eberhart. The evolution of numerous paradigms is addressed, as well as the execution of one of the paradigms. The paradigm's benchmark testing is detailed, and applications such as nonlinear function optimization and neural network training are suggested. The relationships between particle swarm optimization and both artificial life and genetic algorithms are described (J. Kennedy, R. Eberhart.,1995).

Genetic algorithms (GAs) are search and optimization technologies that operate in a different way than traditional search and optimization techniques. Because ease of use, and global perspective, GAs have been increasingly applied to various search and optimization problems in the recent past. GAs for limited optimization problems are discussed. They've also been adapted to tackle additional search and optimization issues effectively, such as multimodal, multi-objective, and scheduling issues, as well as fuzzy-GA and neuro-GA implementations, thanks to their population method. The goal of this study is to introduce readers to the notion of GAs and their potential applications (K. Deb.,1999).

Approximate computing is one of the most efficient data processing methods for mistake applications like signal and image processing, computer vision, machine learning, and data mining, and many others. Approximate computing reduces accuracy, which may well be acceptable as a trade-off for improving circuit characteristics, depending on the application. The minimum point for controlling the trade-off between accuracy and circuit characteristics within the control of the circuit designer is called desirable accuracy. The rounding technique is provided as an effective method for controlling this trade-off in this paper. Multiplier circuits, which are a crucial building block for computation in most processors, have been considered for evaluating the rounding technique's efficiency in this regard. By comparing the circuit characteristics of three multipliers, the impact of the rounding method is investigated. The conventional Wallace tree exact multiplier, the recently introduced approximate multiplier, and the rounded based approximate multiplier proposed in this paper are the three multipliers. To manage the level of accuracy for each range of data, an input data rounding pattern and the probability of repetition for rounded values have been introduced (P. Lohray, et al, 2019).

2.4 The operation and planning in power system for minimizing power loss

D. Lukman and R. Blackburn proposed methods for improving the voltage level of a power system while reduce losses, which are known as voltage control methods. The Newton-Raphson algorithm was used to calculate and manage the voltage, estimate real and reactive power flows, and compute real power losses in a MATLAB load flow simulation program. Under balanced three phase steady state conditions, a Power Flow or Load Flow software computes the voltage magnitude and angle at each bus in a power system. Real and reactive power flows for all equipment interconnecting the buses, as well as equipment fosses, are estimated once they've been determined. The voltage control, such as automatic load tap changing (ALTC) transformers, PV Generator reactive power adjustment, and capacitive and reactive compensation. This method can then be used to increase the voltage level. This loss minimization methodology can be utilized in industrial power systems with changeable speed drives that have a complicated combination of fixed and variable losses, including losses owing to harmonics induced by power electronic loads (D. Lukman, R. Blackburn.,2001).

F.G. Bagriyanik and M.Bagriyanik presents a fuzzy multi-objective optimization and genetic algorithm based method to find optimum power system operating conditions. Fuzzy sets are used to model the objectives and restrictions. The challenge is expressed as a multi-objective problem with operational and electrical limitations. To solve the funny optimization problem, the suggested solution employs genetic algorithms (GA). In addition to active power losses, series reactive power losses in power transmission systems are also considered as one of the various objectives. Together with shunt VAR sources, generators, and transformers, the TCSC (Thyristor Controlled Series Capacitor) is considered a control device. The proposed method's efficiency is demonstrated by simulation results derived from test systems. Using the proposed method, the most satisfactory solution for multiple objectives can be obtained, and the optimization issue can be described more realistically. (F.G. Bagriyanik, M.Bagriyanik .,2003).

S. Angalaeswari, et al, proposed a methodology for optimal sizing and placement of a distributed generation in IEEE 33 bus and IEEE 69 bus radial distribution networks using Parameter Improved Particle Swarm Optimization technique (PIPSO). The distribution line active power loss has been chosen as the fitness function for each particle in the proposed algorithm since it plays such an important role in the economic operation of the power system. The results of the proposed approach show that real power loss is reduced and the bus voltage profile is improved. In terms of power loss reduction and computational time, the proposed PIPSO approach clearly outperforms and outperforms the existing PSO method (S. Angalaeswari, et al, 2015).

Distribution companies (DSCOs) are attempting to decrease large actual losses and manage a poor voltage profile, therefore power loss reduction and voltage profile improvement are the key and critical duties that electrical engineers in the distribution system will be faced with DSCOs. To reach this goal, distribution system reconfiguration (DSR) is one of the most important and crucial analyses to reduce power loss and improve the voltage profile of the system. In the presence of a typical set of restrictions, F. Flaih, et al modified particle swarm optimization (MPSO) is utilized to solve the DSR with the goal of minimizing real power loss. To demonstrate the applicability of the suggested method, MPSO was used to operate a conventional IEEE 33-bus system and the results were compared to the results of other common algorithms. The real power loss is decreased by 31%, the average system voltage is increased by 2%, and the lowest voltage is improved by 2.5 percent, according to the numerical results of the test (F. Flaih, et al.,2016).

Modernization in all sectors has resulted in an ever-increasing electrical power demand on a daily basis. As a result, issues such as significant real and reactive power loss, as well as voltage instability, have surfaced. B. Gaur, et al, (2019) proposed the presence of STATCOM, an optimum reactive power dispatch problem is solved. In the standard IEEE 14 bus test system, real power transmission losses are reduced and the results are analyzed under different loading situations. The simulation results show that STATCOM has a significant role in actual power transmission loss reduction and power network bus voltages (B. Gaur, R. Ucheniya and A. Saraswat, 2019).

Due to the high cost of electricity, attaining the best active (actual) loss reduction during power transmission is critical. The values of leakage losses in coastal lines are quite high and produce huge transverse active losses, reducing these losses is critical in Peru. Using the Particle Swarm Optimization (PSO) approach, F. Rafael Cabezas Soldevilla and F. Alfredo Cabezas verified the decrease of active power losses through the optimal dispatch of reactive power and the optimal control of voltages. MATLAB was used to carry out this work, while MATPOWER was employed as the engine to solve the load flow. The process' efficiency is proven using a 14-bar IEEE test power system, which achieves an 8.38 percent loss reduction. After 100 iterations, the active power loss converges from 13,393 to 12.27 MW. During the inquiry, it was discovered that the PSO can solve problems with a complex objective function with great efficiency. As a result, it may be used to address the problem of lowering losses in the national network, as well as key issues like reactive power planning and transmission network growth planning (F. Rafael Cabezas Soldevilla, F. Alfredo Cabezas., 2019).

Soft Open Point (SOP) is a type of power electrical component that can be used to replace traditional switches or normally open points in network distribution (NOP). To decrease power losses, (M. Ismail, et al, 2020) proposed an adaptive distribution network technique that works with and without SOP. A distribution network with two feeders and six loads was developed using Matlab/Simulink and the Power

System Analysis Toolbox to investigate the performance of our proposed system (PSAT), The simulation results in this paper show that using SOP reduces power losses in the distribution network significantly. (M. Ismail, E. Hassane, E. M. Hassan, et al, 2020).

2.5 Optimal placement of capacitor bank

Capacitor banks are frequently deployed within Radial Distribution Networks (RDNs) to compensate reactive power correction. When appropriately distributed, have various benefits, including an improvement in the feeder's voltage profile and considerable reductions in power loss, which leads to significant energy and cost savings. This formulation is known in the literature as optimal capacitor placement (OCP) problem. Due to its significant multi-modality, discontinuity, and non-linearity, OCP is considered highly complex in terms of optimization. The swarm optimization algorithm known as Locust Search (LS) is proposed for solving the OCP problem. The proposed solution was evaluated using numerous IEEE radial distribution test systems, and its performance was compared to that of existing strategies for solving the OCP problem currently published in the literature. Their results show that the suggested LS-based method is capable of solving the OCP problem with comparable accuracy and resilience (P. Diaz, et al.,2017).

The integration of the Poso hydropower plant into the power systems of Indonesia's Southern Sulawesi has various effects, such as undervoltage. As a consequence, M. B. Nappu, etal, goal is to locate the correct size and position for both reactive power compensation and distributed generation (DG) to solve those problems. From before and after the integration, a load flow study is used to identify the weakest buses in terms of unstable voltage. After that, simulation is used to determine the size and position of both the DG and the capacitor bank. As the appropriate combination approach is achieved, the results show that some lower voltage buses also improve to a stable level at the same time (M. B. Nappu, A. Arief, and M. Imran Bachtiar, 2018).

R.N.D. Costa Filho (2018) proposed the capacitor placement problem in a radial distribution system is formulated and solved using Quantum-Behaved Particle Swarm Optimization (QPSO). QPSO is a population-based optimization technique that is based on the standard PSO and quantum mechanics theories. The aim of this paper is decreasing the annual cost of kW losses and the annual cost of capacitor installation while fulfilling the network's physical and technological constraints. The approach is sorely tested on two radial test systems, one with 33 nodes and the other with 69. The results of the QPSO method are compared to those of the standard PSO algorithm. Simulated results in the case studies show that the QPSO generates more accurate results than the standard PSO (R.N.D. Costa Filho, 2018).

The operating conditions in electricity distribution networks grow increasingly complicated. as changes in consumption patterns and the expansion of retail power markets alter conventional demand patterns. Voltage compensation and loss mitigation are becoming more important in heavy load MV and LV distribution networks feeding large residential communities as industrial platforms near a city reduce their activity and the number of residential customers increases. VAR compensation using capacitor banks remains a cost-effective solution for this problem. The Sperm Whale Algorithm is used to present a improved technique for loss reduction in MV distribution networks, based on optimal placement of capacitor (O. Ivanov, 2019).

A. Mujezinović, etal, proposed algorithm for placement and sizing of the shunt capacitor banks in distribution networks of radial structure. The load flow calculation method and the integer genetic algorithm are utilized in this algorithm for optimal placement and size of shunt capacitor banks. Firstly, the study discusses the problem of shunt capacitor bank placement and sizing with constraints. The paper describes a method for calculating load flow in radial distribution networks. In addition, a regularly used integer genetic algorithm is presented. Finally, the proposed algorithm was demonstrated in operation on an actual 10-kV distribution network in Bosnia and Herzegovina (A. Mujezinović, N. Turković, N. Dautbašić, M. Muftić Dedović, and I. Turković, 2019).

Nowadays, losses in power system increases the energy demand and the number of consumers and proper allocation of capacitors bank around the distributed system. The minimizes of losses caused from bus voltage and the incompatibility of the capacitor bank, which to mitigate the system's advantages. The main objective of this procedure is to reduce the losses of a radial distribution system that meets all conditions. In this paper, Cuckoo Search Algorithm is to find the placement of capacitor bank and optimal location of capacitor bank of typical radial distribution system for pre-identity the appropriate sitting of the capacitor bank with the Power Loss Index. The approach for mitigation of losses has been implemented on IEEE 34 bus. This result is compared to the existing method to illustrate whether efficient and effective that it's in comparison to the current algorithm (V. Cholapandian, T. Yuvaraj and K. Devabalaji, 2021).

2.6 Optimal placement of energy storage system

Distributed storage systems provide energy balance and ancillary services to active distribution networks, which are two parts of a single problem that must be adequately addressed in light of typical distribution network features. M. Nick, et al, focuses on the problem of the optimal siting and sizing of distributed storage systems. The research provides a problem formulation that considering the voltage support of storage systems to the grid, network losses, and the cost of energy flow to the external grid. Because the formulated problem is mixed-integer, non-convex, and non-linear, it necessitates the use of heuristic techniques to solve it. A two-stage iterative technique is presented in this regard. The procedure's initial stage employs a genetic algorithm to determine the locations and sizes of distributed storage systems and the second stage evaluates the fitness of the solution provided by the first part by solving a daily AC optimal power flow. To demonstrate and illustrate the efficacy of the suggested technique, an application example based on the IEEE 13 busses test feeder is presented (M. Nick, M. Hohmann, R. Cherkaoui, M. Paolone.,2013).

The capacity and placement of the BESS in the system are the key challenges in integrating the Battery Energy Storage System (BESS) and renewable energy sources with the current power system network. Multiple stakeholders in the distribution system can benefit from battery energy storage. Installation of BESS units at inconvenient locations might result in an increase in cost, including system losses and increased battery capacity, and so have the opposite impact expected. As a result, using a methodology capable of studying the impact of BESS allocation and scaling on some system parameters is particularly valuable for system planning. To reduce distribution power loss, a method for optimal placement and size of the BESS in the distribution system is proposed. S. Bhaskar Karanki, et al proposed algorithm's performance was demonstrated using IEEE distribution test data (S. Bhaskar Karanki, D. Xu, Bala Venkatesh, Birendra N. Singh.,2013).

W. Ling Ai, et al, proposed the binary firefly algorithm (BFA) to determine the best location for battery energy storage systems (BESS) in a solar generating integrated radial distribution network to mitigate the voltage increase problem. The aim of the optimization method is to find the best location by minimizing the voltage variation of the PVDG bus. For each optimization, a BESS placement (BP) vector is utilized to determine the position of BESS, and the optimization procedure is repeated until the optimal BESS location is achieved. The effectiveness of the proposed method is demonstrated by using this to a 69-bus distribution system, with the result demonstrating that BFA is successful in locating BESS at the most optimal location (W. Ling Ai, H. Shareef, A. Asrul Ibrahim, A. Mohamed, 2014).

2.7 Optimal scheduling of energy storage system

Photovoltaic (PV) generators have recently been deployed in a considerable number of power systems. Nevertheless, the PV's power output is random and unpredictable. Consequently, the operation of a power system is complicated by PV generating. BESS is thought to be capable of dealing with them, but its high cost prevents it from being installed in the system. However, the current cost argument only addresses the initial cost, and the economic value of BESS installation is not taken into considered. Y. Oka, A. Yokoyama used the daily optimal operation of BESS is scheduled by using the Tabu search algorithm, and the net present value technique considers the reduced amount of fuel and CO2 emissions by the BESS installation in its economic evaluation. As a result, the proposed method has made it possible to evaluate the optimum amount of installed BESS in the power system (Y. Oka, A. Yokoyama.,2013).

The framework for efficient operation scheduling of Energy Storage Systems (ESSs) in distribution systems in conjunction with renewable energy resources (RERs). An efficient three-phase unbalanced distribution optimal power flow (DOPF) model is included in the proposed framework, which is a multi-time interval optimization issue. Multiple objective functions such as loss minimization, imbalanced power at the substation, total energy costs, and peak demand are formulated to optimally operate distribution networks from the perspective of a local distribution company, and mathematical models for RERs and ESS are integrated into the problem. While the technical and operational constraints of distribution networks and ESSs, the proposed framework generates optimal charge/discharge scheduling of ESSs. To demonstrate the efficiency of the suggested strategy, relevant simulation results for a test system with multiple solar PVs and two ESSs are provided and discussed (M. Chehreghani Bozchalui.,2014).

A. Garces, et al proposed a method for the optimal scheduling of distributed energy storage units. An exact model based on Lagrange relaxation is proposed. Simulation studies on the IEEE 37-bus test feeder show that leveling the load curve with an energy storage system can reduce transmission losses in a distribution system. The goal function and optimization technique are the key contributions of this technique. Lagrange multipliers are used to figure out where and how big the energy storage units should be. There is also a discussion of the effects of energy storage units on distribution planning (A. Garces, C. Correa, R. Bolanos.,2014).

The development of approaches for identifying the appropriate ratings and placements of storage devices is motivated by the large-scale integration of grid-scale ESS. The exchange market algorithm (EMA) is used to achieve the best optimal results. The EMA approach is a new meta-heuristic for solving optimization problems. The procedure for trading stocks on the stock market inspired this optimization algorithm. This program was developed after intellectuals evaluated how stocks are exchanged on the stock market. This study presents a method for determining where ESSs should be placed in order to work optimally. It was put through its paces on a typical 33-bus radial distribution system. It is proposed a method for identifying the best operation of ESSs in order to achieve the least amount of power loss. The major goal of the operating strategy is to reduce peak generation by using power plants that produce the least amount of oscillation. Various scenarios are studied to validate the usefulness of this strategy. Several comparisons have been made in order to prove this optimization strategy. Finally, the storage's optimal charge and discharge rates, as well as its location and power loss reduction, are described. The results demonstrate the EMA's capacity to determine the storage's worldwide optimum position and hourly charging rate (T. Khalili, A. Jafari, E. Babaei.,2017).

The 24-hour optimal scheduling algorithm for ESS using load forecasting and renewable energy forecasting in South Korea electricity tariff structure. A 24-hour multivariate forecasting model incorporating very-short-term and short-term forecasting models is created for load forecasting and renewable energy forecasting. The optimum ESS scheduling algorithm is then fed load and renewable projections. The objective of this algorithm is to optimize the customer's profit through energy arbitrage, decrease peak load to lower contract power, and minimize charging/discharging cycles to extend the ESS's estimated life. Result shows significant reduction of electricity charge (82.7%) and peak load (78%) by applying this algorithm. (W. Lee, M. Lee, J. Jung.,2017).

The virtual energy storage system (VESS) achieved by using the demand response of thermostatically controlled loads (TCLs) is becoming more popular for smart grid. TCLs utilize demand response to provide a cost-effective real-time solution for power mismatches caused by intermittent renewable energy supply and to prevent excessive costs associated with meeting peak demand. Residential customers perform energy management in line with grid power, renewable production, energy storage, demand response of TCLs, and electricity pricing in order to extract energy savings and reduce electricity costs. C. P. Barala, et al, proposed the optimal scheduling of residential consumer demand as well as the management of TCL energy consumption in saving cost. Firstly, a mathematical model of TCLs and a VESS based on TCLs are developed. Then, in order to reduce residential users' electricity costs, an optimal scheduling model is developed. The simulations show that the cost of power is decreasing, and VESS serves customers similar to traditional energy storage (C. P. Barala, P. Mathuria, R. Bhakar, 2019).

Accommodation of various dispersed generation resources and battery energy storage systems is one of the hallmarks of the modern smart grid. Because renewable energy output is intermittent and unpredictable, the BESS can assist with power generation, voltage, and even system frequency management. In a power system with uncertain photovoltaic power supply and demand, the authors propose a short-term (24-hour) energy scheduling of batteries. Loss costs are kept to a minimum while both equality and inequality restrictions are met. The power flow equations and the energy balance equations for batteries make up the equality constraints. The power and energy restrictions of batteries are included in the inequality restrictions. The charging and draining states of batteries are determined by power pricing. Due to the uncertainty of PV powers and loads, the problem is tackled in two loops: the outer loop uses the point-estimation approach, while the inner loop uses the interior-point approach to calculate the 24 hours optimal power flow using deterministic PV generations and loads. The proposed method's deterministic and stochastic findings were validated and contrasted. (Y. Yi Hong, M. Yin Wu, S. Huei Lee.,2020).

Battery Energy Storage Systems can be used in a variety of applications the electrical, including generation, transmission, and ultimate customer. Although there are many similarities in product design, there are numerous ways to customize the operating routine for each customer using the Energy Management System (EMS).

A scenario-based study of a BESS installed in a final customer is described by Felipe O. Ramos, et al, with the main aim of decreasing electricity costs and increasing energy supply reliability. Three different load scenarios were tested (low, medium, and high) on the combination of the following operation modes: energy time shift, demand charge management, and reactive power control. As a result, of the controls and the system's appropriate design, the system was able to work effectively. Finally, the result shows a brief description of the BESS components and the local tariff structure is also detailed (Felipe O. Ramos, et al, 2021).

How to optimize the scheduling of virtual power plant clusters (VPPC) by considering the cooperative and complementary capabilities of 'generation-grid-load-storage' is an urgent problem that needs to be solved in order to improve the operating economy and clean energy consumption capacity of the distribution network under VPPC's jurisdiction. J. Wang, et al, proposes an optimal scheduling method of VPPC considering generation-grid-load-storage coordination. Firstly, the VPPC's fundamental functioning structure was established. Within VPP, many resource models of generation-grid-load-storage are constructed. Secondly, a two-stage VPPC optimal scheduling model is established, considering the coordination of generation, grid, load, and storage. Finally, a VPPC with 5 VPPs is built for simulation based on the improved IEEE 33-node power distribution system. The results show that the method proposed is beneficial to minimizing the system's operating costs while increasing clean energy consumption in the presence of transaction access constraints. The results show that the method proposed in this paper is conducive to reducing the operating cost of the system and improving the consumption of clean energy under the environment of transaction access constraints (J. Wang, W. Du, D. Yang, G. Liu, H. Chen, 2021).

2.8 Chapter summary

In Chapter 2, introduction and overview of energy storage system application is provided. In section 2.3 described about impact of installing ESS conjunction with renewable energy, characteristic of ESS in each type and general data of ESS. A number of methods have been presented with the purpose of reducing power loss and improving voltage in electrical power systems provided in section 2.4. Optimal CB placement is a technique of locating the appropriate CB installation for the maximum benefit of the electrical system. The capacitor placement problem is well-known and discussed in section 2.5. As discussed in section 2.6, the size and location of the ESS in the system are the key challenges in integrating the ESS and renewable energy sources with the current power system network. Many researches have been done, as discussed in this section. In addition, section 2.7 provides research about optimal scheduling of ESS. This problem is also important for day-to-day operation and planning maximum benefit for the electrical system

CHAPTER 3
OPTIMAL BATTERY ENERGY STORAGE SYSTEM SCHEDULING FOR DISTRIBUTION SYSTEM DAILY LOSS MINIMIZATION USING PARTICLE SWARM OPTIMIZATION[1]

3.1 Introduction

In section 2.4, the many research has been done objective function to minimize energy loss for the system to operate economically and reliably such as reconfiguration in transmission line method, optimal power flow from many algorithms, multi objective and etc. These methods can efficient minimize loss in electrical power system. In section 2.7, battery energy storage system (BESS) can play a vital role in overcoming minimize energy loss problems and appears to be a crucial part of the future smart grids. When properly allocated, BESS provide benefit in significant reductions on energy loss.

This chapter presents a particle swarm optimization (PSO) approach for optimal scheduling battery energy storage system (BESS) in electrical distribution network (EDNs) for minimizing daily loss. The continued development in BESS technologies has introduced new possible applications for EDNs. The distribution system daily loss minimization (DSDLM) algorithm had been tested with IEEE 33 buses system. The simulation result shown that the proposed algorithm can efficiently minimize the total daily loss by considering BESS scheduling.

3.2 Problem Formulation

The main objective of this thesis is to take advantage of optimal BESS scheduling for minimize daily losses in distribution system to determine the optimal operation of BESS. This chapter is used PSO techniques for scheduling battery energy storage system is proposed.

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[1] Part of this work was presented at the "Electrical Engineering Conference 43rd (EECON 43)", Thailand, 2021.

In this thesis, the Newton-Raphson Power Flow (NRPF) technique (P. Diaz, et al, 2017, A. Alzahrani, et al, 2019) is used to find power loss in transmission line.

This section provided constraints include power balance, line flow limit, power generation, and bus voltage. Moreover, the constraints of BESS have been described.

The objective function of distribution system daily loss minimization problem is formulated as follows:

Minimize:

$$P_{loss,total} = \sum_{h=1}^{24} P_{loss}^{h}, \tag{3.1}$$

The considered time interval is one day (24 hour),

where,

$$P_{loss}^{h} = \sum_{i=1}^{NB} \sum_{\substack{j=1 \\ j \neq i}}^{NB} G_{ij} \left[\left(V_i^h\right)^2 + \left(V_j^h\right)^2 - 2V_i^h V_j^h \cos(\delta_i^h - \delta_j^h) \right],$$

$$\text{for } i = 1, \ldots, NB, h = 1, \ldots, 24, \tag{3.2}$$

Subject to the power balance constraints,

$$P_{Gi}^{h} - (P_{Di}^{h} \pm (C_{bess,i}^{h} \cdot (\eta_c / \eta_d))) = \sum_{j=1}^{NB} | V_i^h || V_j^h || y_{ij} | \cos(\theta_{ij} - \delta_{ij}^h),$$

$$\text{for } i = 1, \ldots, NB, h = 1, \ldots, 24, \tag{3.3}$$

$$Q_{Gi}^{h} - Q_{Di}^{h} = -\sum_{j=1}^{NB} | V_i^h || V_j^h || y_{ij} | \sin(\theta_{ij} - \delta_{ij}^h),$$

$$\text{for } i = 1, \ldots, NB, h = 1, \ldots, 24, \tag{3.4}$$

Line flow limit constraints,

$$| f_i^h | \leq f_i^{\max}, \quad \text{for } i = 1, \ldots, NL, h = 1, \ldots, 24, \tag{3.5}$$

Power generation constraint,

$$P_{Gi}^{\min} \leq P_{Gi}^{h} \leq P_{Gi}^{\max}, \quad \text{for } i = 1, \ldots, NG, h = 1, \ldots, 24, \tag{3.6}$$

$$Q_{Gi}^{\min} \leq Q_{Gi}^{h} \leq Q_{Gi}^{\max}, \quad \text{for } i = 1, \ldots, NG, h = 1, \ldots, 24, \tag{3.7}$$

Bus voltage limit constraint,

$$\left|V_i^{\min}\right| \le \left|V_i^h\right| \le \left|V_i^{\max}\right|, \quad \text{for } i = 1,\ldots, NB, h = 1,\ldots,24, \tag{3.8}$$

The energy capacity, as well as the capacity for power charging and discharging, state of charge and discharge and rate of charge constraint are included in BESS model. In addition, the efficiency of charging and discharging represented by (W.LEE, et al, 2017).

$$\mathbf{ES} = [ES_i^1,\ldots,ES_i^h,\ldots ES_i^{24}], \text{ for } i = 1,\ldots, NBESS, h = 1,\ldots,24, \tag{3.9}$$

$$ES_i^{h,\min} \le ES_i^h \le ES_i^{h,\max}, \text{ for } i = 1,\ldots, NBESS, h = 1,\ldots,24, \tag{3.10}$$

$$\mathbf{C}_{\mathbf{bess}} = [C_{bess,i}^1,\ldots,C_{bess,i}^h,\ldots C_{bess,i}^{24}], \text{ for } i = 1,\ldots, NBESS, h = 1,\ldots,24, \tag{3.11}$$

$$C_{bess,i}^{h,\min} \le C_{bess,i}^h \le C_{bess,i}^{h,\max}, \text{ for } i = 1,\ldots, NBESS, h = 1,\ldots,24, \tag{3.12}$$

$$C_{bess,i}^h = \begin{cases} ES_i^1, h=1 \\ ES_i^h - ES_i^{h-1}, h=2,\ldots,24 \end{cases}, \text{ for } i = 1,\ldots, NBESS, h = 1,\ldots,24, \tag{3.13}$$

$$C_{rate,i}^{h,\min} \le C_{rate,i}^h \le C_{rate,i}^{h,\max}, \text{ for } i = 1,\ldots, NBESS, h = 1,\ldots,24, \tag{3.14}$$

$$C_{rate,i}^h = \frac{C_{bess,i}^h}{C_{bess,i}^{h,\max}} \times 100\%, \text{ for } i = 1,\ldots, NBESS, h = 1,\ldots,24, \tag{3.15}$$

$$SOC_i^{\min} \le SOC_i^h \le SOC_i^{\max} \quad \text{for } i = 1,\ldots, NBESS, h = 1,\ldots,24, \tag{3.16}$$

$$SOC_i^h = \frac{ES_i^h}{ES_i^{h,\max}} \times 100\% \text{ for } i = 1,\ldots, NBESS, h = 1,\ldots,24. \tag{3.17}$$

In this thesis, if $C^h_{bess,i} < 0$, the BESS is in discharging condition, if $C^h_{bess,i} > 0$, the BESS is in charging condition as shown in Figs 3.1 and 3.2.

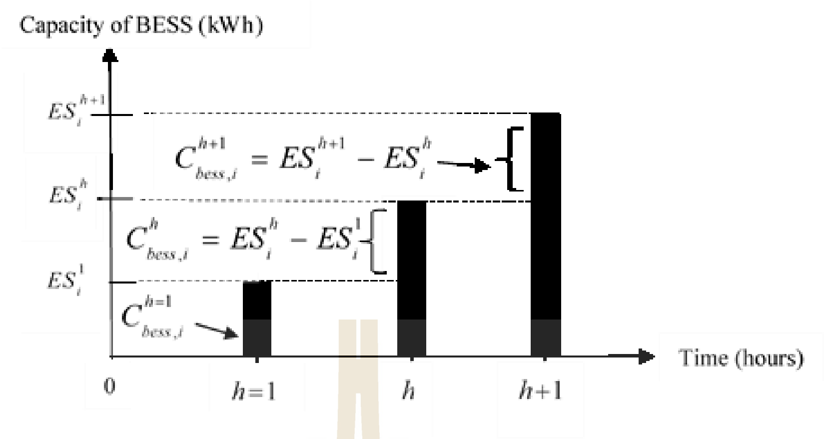

Figure 3.1 The capacity of power charging

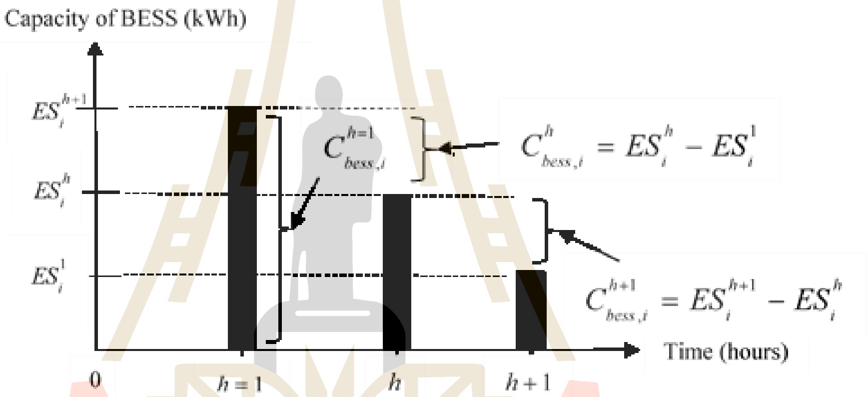

Figure 3.2 The capacity of power discharging

3.3 General Mathematical Model Formulation of Optimization

Among stochastic optimization methods, PSO is a famous stochastic base optimization technique, inspired by social of behavior of bird flocking or fish schooling. PSO was proven to be one of the best stochastic optimization methods for several problems. The research investigation for optimal BESS scheduling using PSO. Therefore, PSO is used for benefit to power distribution system planning. From the proposed method in Section 3.2, the DSDLM is solved by PSO.

In PSO system, the computation can be explained as follow,

$$v_i^{t+1} = wv_i^t + c_1r_1(pbest_i^t - p_i^t) + c_2r_2(gbest^t - p_i^t) \qquad (3.18)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \qquad (3.19)$$

3.4 Thailand Daily Load Profiles

The Thailand daily load profiles, is used as the system load profile including summer season (April 14th, 2018), rainy season (September 9th, 2018) and winter season (January 1st, 2018). Daily load curves of the test system are shown in Figures 3.3-3.5.

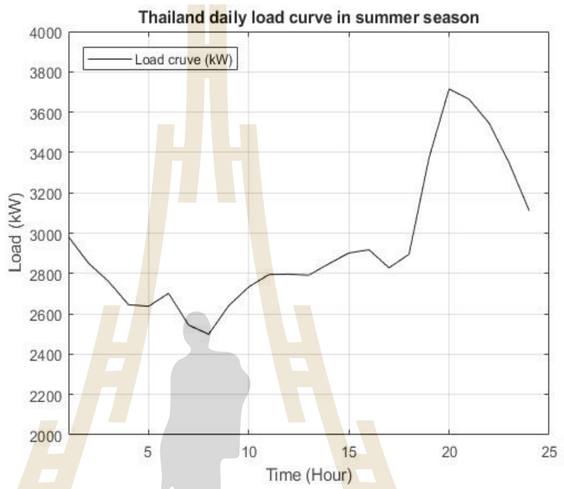

Figure 3.3 Thailand daily load curve in summer season

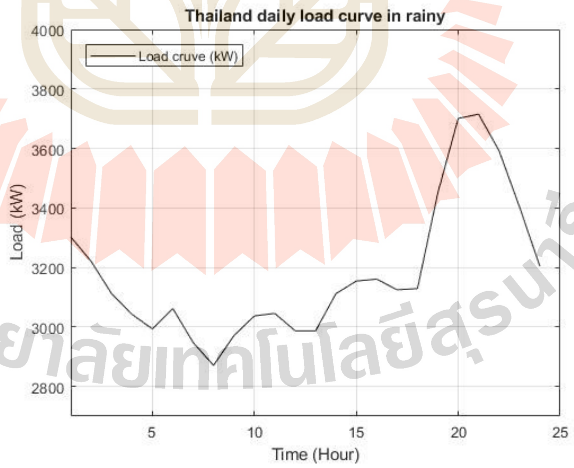

Figure 3.4 Thailand daily load curve in rainy season

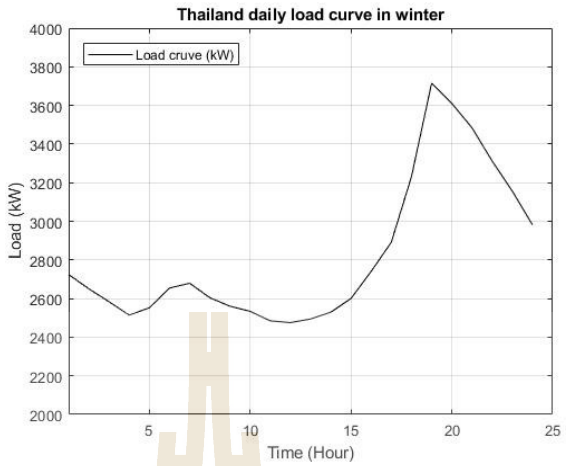

Figure 3.5 Thailand daily load curve in winter season

The load at hour *h* can be calculated as,

$$P^{h}_{load,profile} = P_{load} \cdot LF^{h}, \text{ for } h=1,\ldots,24, \tag{3.20}$$

$$LF^{h} = \frac{P^{h}_{load}}{P^{\max}_{load}}, \text{ for } h=1,\ldots,24. \tag{3.21}$$

Where,

$P^{h}{}_{load,profile}$ is the load at hour *h* of the modified IEEE 33-bus radial distribution test system, P_{load} is the single load value from the IEEE 33-bus radial distribution test system, LF^{h} is the load factor at hour *h*, $P^{h}{}_{load}$ is the load of Thailand peak day at hour *h*, and $P^{max}{}_{load}$ is the peak load of the day.

The load factor (LF^{h}) in each hour was multiplied with load demand in the power balance equation constraints from Eq. (3.3) and (3.4). As shown in Eq (3.22) and (3.23).

$$P^{h}_{Gi} - (P^{h}_{Di} \pm (C^{h}_{bess,i} \cdot (\eta_c / \eta_d))) \cdot LF^{h} = \sum_{j=1}^{NB} |V^{h}_{i}||V^{h}_{j}||y_{ij}| \cos(\theta_{ij} - \delta^{h}_{ij}),$$

$$\text{for } i = 1,\ldots,NB, h = 1,\ldots,24, \tag{3.22}$$

$$Q^{h}_{Gi} - (Q^{h}_{Di} \cdot LF^{h}) = -\sum_{j=1}^{NB} |V^{h}_{i}||V^{h}_{j}||y_{ij}| \sin(\theta_{ij} - \delta^{h}_{ij}),$$

$$\text{for } i = 1,\ldots,NB, h = 1,\ldots,24, \tag{3.23}$$

3.5 PSO based OBESSS for DSDLM

Optimal battery energy storage system scheduling (OBESSS) for distribution system daily loss minimization (DSDLM) is proposed. The proposed OBESSS is solved by PSO and tested with IEEE 33-bus radial distribution test system. The propose method resulted in the minimize daily loss of distribution system with OBESSS.

In this problem, the objective function distribution system daily loss minimization (DSDLM) problem is formulated follow in Section 3.2. In this problem was considered only BESS shown in Fig 3.6.

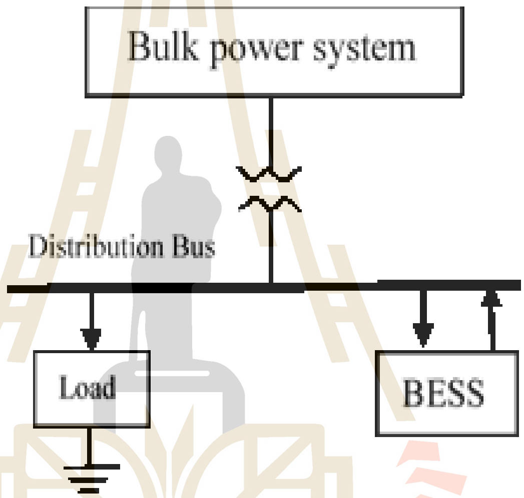

Figure 3.6 A structure of distribution system with BESS

In order to obtain DSDLM, the **ES** in Eq. (3.9) is used to find $C^{h}_{bess,i}$ each particle in Eq. (3.11) for solved power balance in Eq. (3.3) and (3.4), the best value is a scheduling of BESS is call *pbest*. The load flow analysis is preformed and the daily loss is used as the objective function in Eq. (3.1), the best value is a daily loss minimize is call *gbest*. The DSDLM problem computational procedure can be illustrated as in Fig 3.7

The proposed method has 6 computational steps as follows,

Step 1 : Initial set of particles for scheduling of BESS is obtained by Eq. (3.9)-(3.17).

Step 2 : Compute minimum daily loss by the DSDLM in Section 3.2, using PSO.

Step 3 : Evaluate the fitness function of each particle and determine the initial *pbest* and *gbest*. The load flow analysis is preformed and the daily loss is used as the objective function in Eq. (3.1). The value is a daily loss is call *gbest*, and the best value is a scheduling of BESS is call *pbest*.

Step 4 : Compute velocity of particle and update position of particle. In order to obtain DSDLM. The schedule $C_{bess,i}^{h}$ in Eq.(3.11) is used for obtain daily loss in Eq.(3.1), the scheduling were update position by Eq. (3.18) and (3.19).

Step 5 : If computation reach maximum number of iterations, go to 6, else go to 2.

Step 6 : Obtain the best solution and stop.

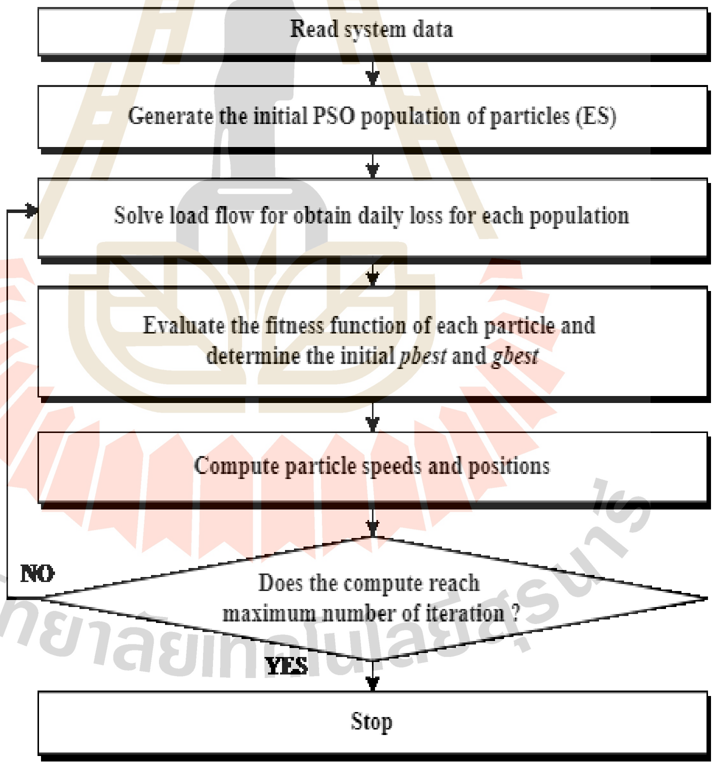

Figure 3.7 The DSDLM problem computational procedure

3.6 Simulation Results

The proposed PSO based DSDLM has been verified on the radial distribution IEEE 33 -bus radial distribution test system shown in Fig 3.8.

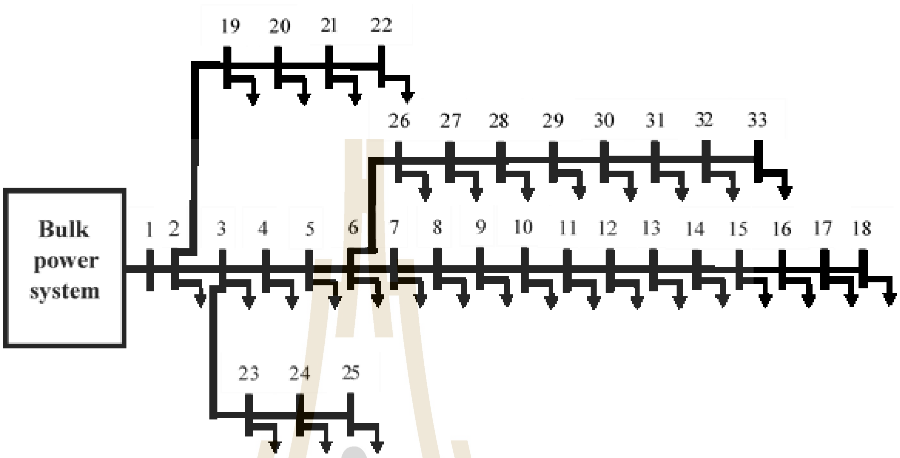

Figure 3.8 IEEE 33-bus radial distribution test system

The system line data and bus data were obtained from (P. Diaz, et al, 2017), The Thailand daily load curve on 14 April 2018, which is annual peak day shown in Fig 3.3, is used as the system load profile. The result is shown in Tables 3.1.

The simulation study includes,

Case 1 : Distribution system without BESS,

Case 2 : Distribution system with the simple BESS operation, and

Case 3 : Distribution system with BESS using PSO based OBESSS for DSDLM.

3.6.1 Distribution system without BESS

The IEEE 33 buses system are including substation bus and load buses (P. Diaz, et al, 2017), This system is comprised by the 33 buses and 32 lines, 12.66 kV is voltage supplied of substation, total active power is 3,715.00 kW and total reactive power is 2,300.00 kvar, all offer by the remaining 32 load buses. From Table 3.1 illustrates the hourly loss, the result shown the system daily loss without battery energy storage system is 3114.8 kWh.

Table 3.1 The hourly loss of IEEE 33-bus radial distribution system

Time(Hr)	Ploss(kW)			Time(Hr)	Ploss(kW)		
	Case 1	Case 2	Case 3		Case 1	Case 2	Case 3
01:00	131.7	131.7	131.7	13:00	114.5	114.5	114.5
02:00	119.7	119.7	119.7	14:00	119.5	119.5	119.5
03:00	111.8	111.8	111.8	15:00	124.2	124.2	124.2
04:00	102.1	102.1	104.6	16:00	125.7	125.7	122.9
05:00	101.5	101.5	101.5	17:00	117.7	117.7	120.4
06:00	106.8	106.8	104.3	18:00	123.7	123.7	123.7
07:00	94.1	94.1	94.1	19:00	171.4	171.4	171.4
08:00	90.6	92.8	92.8	20:00	211.0	205.9	205.9
09:00	101.7	101.7	101.7	21:00	204.7	204.7	204.7
10:00	109.5	109.5	109.5	22:00	190.7	190.7	190.7
11:00	114.7	114.7	114.7	23:00	168.5	168.5	168.5
12:00	114.9	114.9	114.9	24:00	144.1	144.1	144.1

3.6.2 Distribution system with the simple BESS operation

The simple BESS operation, Sets the period the BESS to charge energy during specific period of time during minimal load requirements and discharge the energy back to the system during peak hour. In this case, the 20 kw/20 kwh is size capacity of BESS is used to test the proposed algorithm. Moreover, the location of the BESS was investigated by solving for minimum daily loss as shown in Fig 3.9 and Table 3.2.

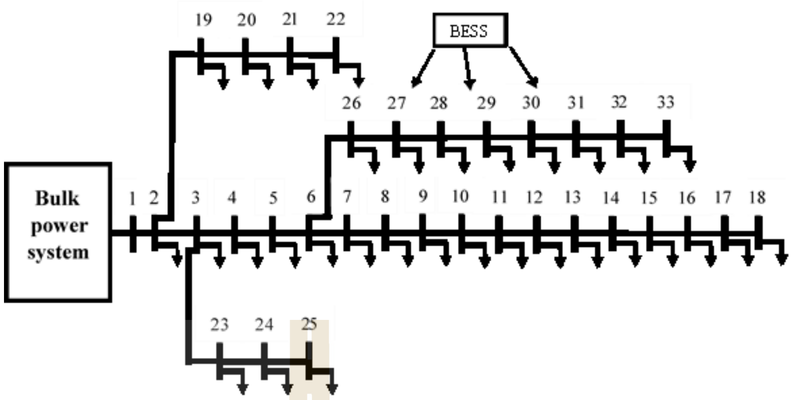

Figure 3.9 IEEE 33 bus radial distribution test system with the simple operation BESS

Table 3.2 The daily loss when install BESS in each bus using simple BESS operation of IEEE 33 buses radial distribution test system

From Bus	Daily loss (kWh)	From Bus	Daily loss (kWh)	From Bus	Daily loss (kWh)
1	3114.8	12	3112.3	23	3114.2
2	3114.7	13	3112.1	24	3114.0
3	3114.3	14	3112.0	25	3114.6
4	3114.1	15	3112.0	26	3113.2
5	3113.8	16	3112.0	27	3113.1
6	3113.3	17	3112.0	28	3112.8
7	3113.2	**18**	**3111.9**	29	3112.5
8	3112.8	19	3114.7	30	3112.4
9	3112.6	20	3114.7	31	3112.2
10	3112.4	21	3114.6	32	3112.2
11	3112.4	22	3114.6	33	3112.2

From Table 3.2, Bus number 18 was chosen for install the BESS, due to minimum daily loss with the simple BESS operation, of 3111.9 kWh.

3.6.3 Distribution system with BESS using PSO based OBESSS for DSDLM

In this case, Bus Number 18 was chosen to install BESS shown in Fig 3.10 because this bus can reduce more daily losses than another buses (from table 3.2 the daily when install BESS in each bus using simple BESS operation of IEEE 33 buses system), the 20 kw/20kwh is size capacity of battery energy storage system is used to test the proposed algorithm. The BESS efficiency of charge and discharge are 95% (W. Lee, et al, 2017).

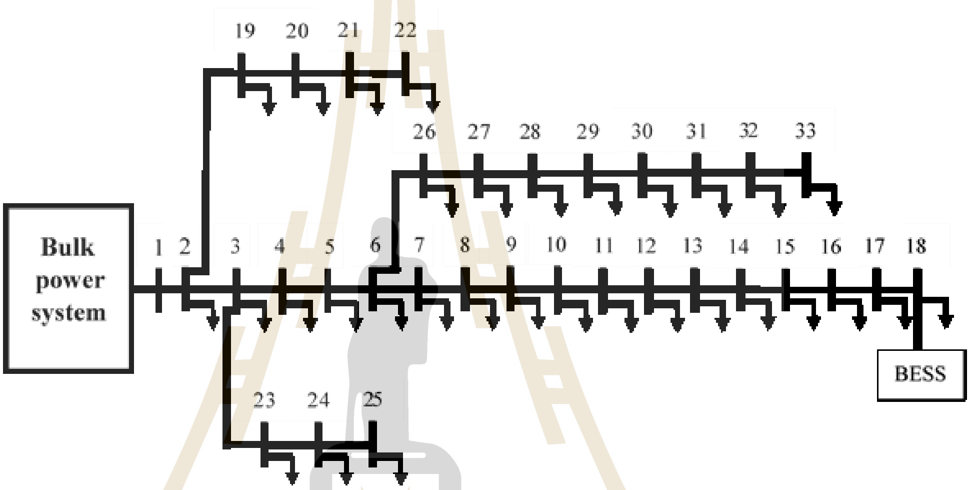

Figure 3.10 Bus Number 18 was chosen for install the BESS

The PSO parameters are setting, as follow,

c_1 = 2, c_2 = 2, W_{max} = 0.9, W_{min} = 0.4, population size = 600, and maximum iteration = 20.

The best OBESSS for DSDLM using PSO solution are shown in Figs 3.11, 3.12 and 3.13.

Fig 3.11 show that PSO algorithm is checking to find the best answer, the best value is starting to convergence in 8 iterations.

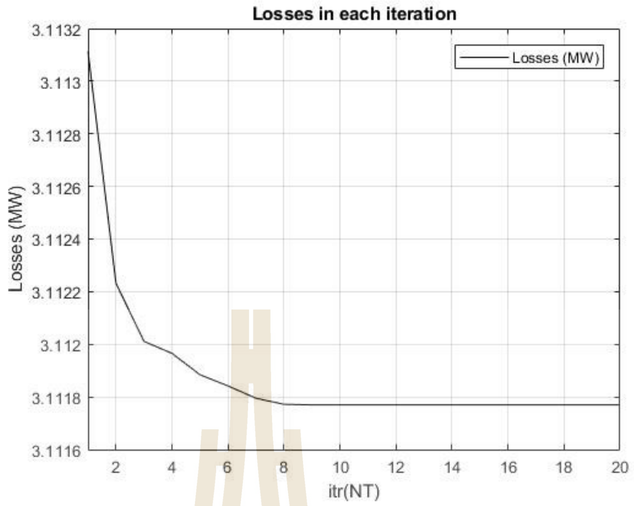

Figure 3.11 Power loss in each iteration

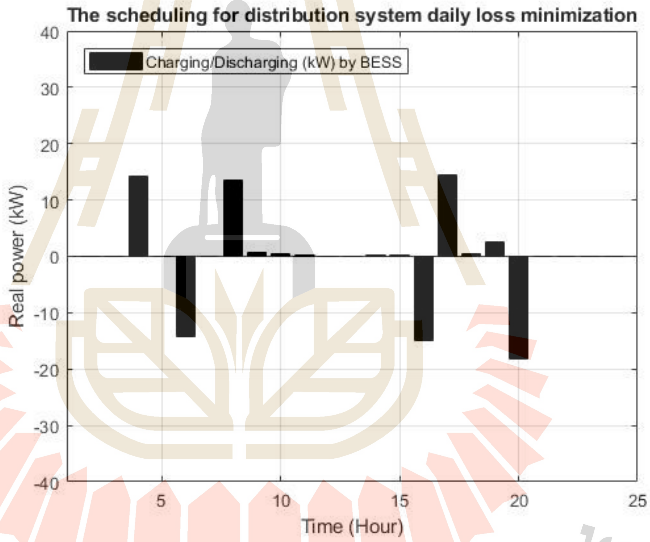

Figure 3.12 BESS scheduling for distribution system daily loss

From Fig 3.12, is explain scheduling of battery energy storage system. The load profile is leveling from this scheduling, this answer is the best particle for minimize daily losses from install BESS at bus 18. The rate of charge and the state of charge by BESS as shown in Fig 3.13.

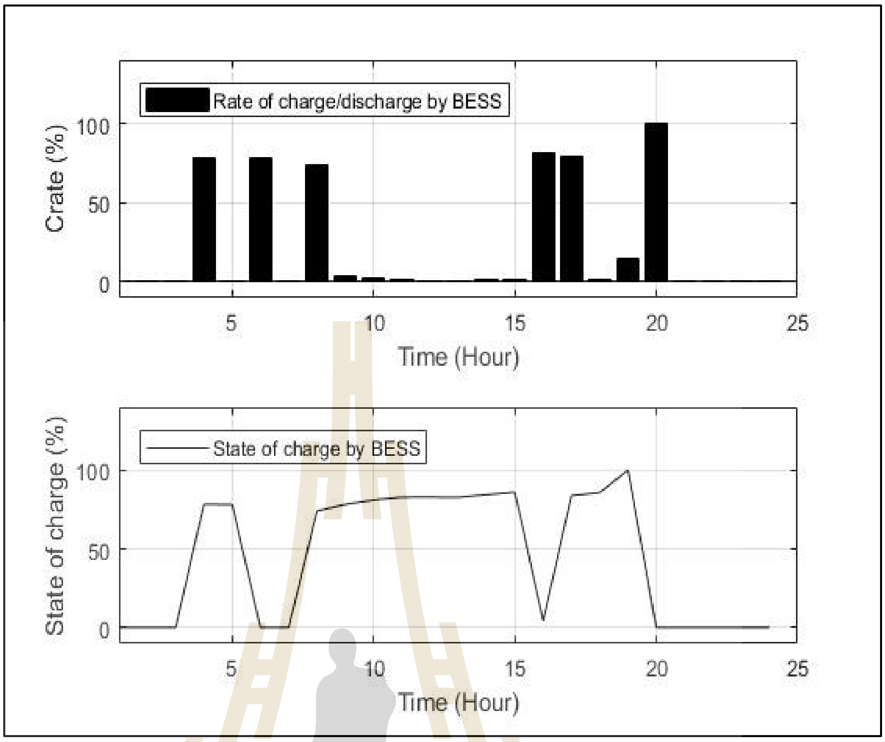

Figure 3.13 The rate of charge and the state of charge by BESS

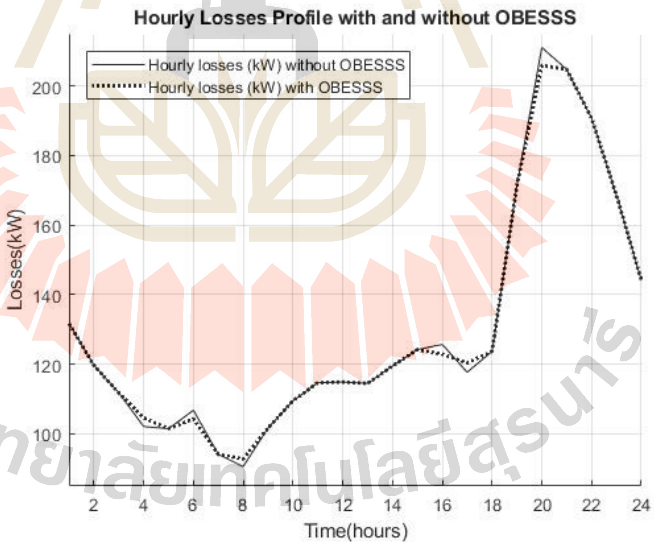

Figure 3.14 System hourly loss with and without OBESSS

The results reveal the scheduling of battery energy storage to supply the prosumers during peak load that lead to energy savings, because energy is not supplied from the system and the losses are reduced.

From Fig 3.14, with the propose PSO based OBESSS for DSDLM, the daily loss of IEEE 33 bus radial distribution test system is reduced to 3111.77 kWh, lower than that of without BESS and the simple BESS operation. Therefore, the proposed method is efficiency minimize the daily loss at distribution system by scheduling the BESS.

3.7 Conclusion

In Chapter 3, the PSO based OBESSS for DSDLM is proposed and investigated. The total daily loss can be minimized successfully. The results have shown that distribution system daily loss minimization problem can be efficiently solved. Therefore, the BESS can be an option to be installed in the system in order to help save energy in the long run.

CHAPTER 4
COORDINATED OPTIMAL PLACEMENT OF BATTERY ENERGY STORAGE SYSTEM AND CAPACITOR BANK CONSIDERING OPTIMAL BATTERY ENERGY STORAGE SCHEDULING FOR DISTRIBUTION SYSTEM USING MIXED-INTEGER PARTICLE SWARM OPTIMIZATION[2]

4.1 Introduction

From literature in section 2.5, The most of researches on optimal CB placement solve the total loss minimization using single loading condition. Meanwhile, the optimal scheduling of BESS is solved without optimal allocation. In section 2.6, BESS was investigated for optimal allocation with daily load profile condition.

Therefore, this chapter proposes a mixed-integer particle swarm optimization (MIPSO) for coordinated optimal placement of battery energy storage system (BESS) and capacitor bank (CB). In the propose method, optimal BESS scheduling (OBESSS) is solved by particle swarm optimization (PSO), as a subproblem, the optimal coordinated placement (COP) for BESS and CB, simultaneously. The distribution system daily loss minimization (DSDLM) is used as the objectives of COP problem. The proposed method was tested with the IEEE 33-bus radial distribution test system. The results demonstrated that the proposed method is successful and robust in minimizing system losses, which saves losses of 35.12% when compared with and without COP.

4.2 Capacitor bank modeling

CB is installed for mitigation of voltage drop, and also can potentially reduce energy loss. The reactive power generation of CB can be represented as,

$$\mathbf{CBS} = [cbs_1, cbs_2, \ldots, cbs_i, \ldots, cbs_{NCB}], \text{ for } i = 1, \ldots, NCB. \quad (4.1)$$

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[2] Part of this work is a paper published at the "International Journal of Intelligent Engineering & Systems (IJIES), 2022.

4.3 COPP problem formulation

The objective function for distribution system daily loss minimization can be expressed as Eq. (3.1), subject to the power balance constraints Eq. (3.2) - (3.8), and energy storage modeling obtain by Eq. (3.9) – (3.17).

The objective function COPP is formulated as follows:

Minimize

$$ADL = \sum_{h=1}^{24} P^{h}_{loss,total}(C^{h}_{bess}, \mathbf{CBS}, \mathbf{B}), \tag{4.2}$$

for BESS and CB connected to bus B with state of charge $C^{h}{}_{bess}$ and compensated from **CBS**.

From Eq. (3.4), the power balance constraints with capacitor bank was added cbs_i in Eq. (4.1), as shown in Eq. (4.3)

$$Q^{h}_{Gi} - (Q^{h}_{Di} - cbs_i) = -\sum_{j=1}^{NB} |V^{h}_{i}||V^{h}_{j}||y_{ij}|\sin(\theta_{ij} - \delta^{h}_{ij}),$$

$$\text{for } i = 1,\ldots,NB, h = 1,\ldots,24, \tag{4.3}$$

4.4 Round-off technique for DSDLM

In this chapter, the optimal allocation of BESS is solved by Rounding-off technique using PSO. The approximate computing is one of the most efficient data processing methods for signal and image processing, computer vision, machine learning, and data mining, among others (P. Lohray, et al, 2019). In this section, the rounding technique is introduced as an efficient method for finding location of BESS. If b_i is position of particle placement, each particle will be rounded during the iteration process. If b_i has a decimal point more than 5, this will increase by one, and particle is equal to b_i if b_i has less than 5 decimal points, as follows:

$$b_i = \begin{cases} b_i^{\max}, if \; b_i + 0.5 \geq b_i^{\max} \\ b_i^{\min}, if \; b_i - 0.5 < b_i^{\min} \end{cases}, \tag{4.4}$$

$$b_i^{\max}, b_i^{\min} \in \{\text{integer}\}. \tag{4.5}$$

4.5 MIPSO based COPP for DSDLM

In this section, coordinated optimal placement problem (COPP) of BESS and CB considering optimal BESS scheduling (OBESSS) for distribution system daily loss minimization (DSDLM) is proposed. The proposed method used the mixed-integer particle swarm optimization (MIPSO) to optimal placement of BESS and CBs, while OBESSS is solved by PSO. Thailand's power system load profile was used to verify the proposed method in the radial IEEE 33-bus radial distribution test system.

The structure of a distribution grid typically includes active and reactive resources such as, bulk power systems, BESS, CB, and load demand, as shown in Fig. 4.1.

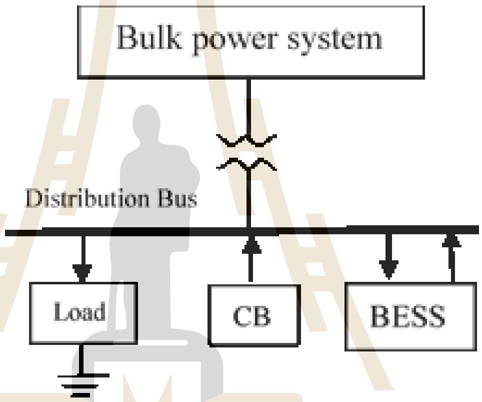

Figure 4.1 A structure of distribution system with CB and BESS

The schedule of $C^{h}{}_{bess}$ in Eq. (3.11) is obtained by PSO. $C^{h}{}_{bess}$ and **CBS** in Eq. (4.1) are used for obtain ADL in Eq. (4.2), the scheduling and placement were update position by PSO. The daily loss is utilized as the objective function in Eq. (3.1), which is based on the load flow analysis. The minimum value of ADL among all particles is called $gbest$, and the minimum ADL of individual *ith* particle is called $pbest$.

The proposed method has 6 computational steps as follows,

Step 1 : Initial set of particles for bus that connected with BESS as,

$$\mathbf{B}=\left[b_1,\ldots,b_i,\ldots,b_{NBESS+NCB}\right]^T \quad \text{, for } 1\le b_i\le NB, \tag{4.6}$$

Where, $\mathbf{B}$ is the matrix representing bus number with BESS and CB, b_i is the bus number connected with BESS.

The rounding technique is introduced as an efficient method for finding location of BESS. If b_i is position of particle representing the bus number for BESS placement, each particle will be rounded during the iteration process, as follow,

$$b_i = \begin{cases} b_i^{\max}, if \ b_i + 0.5 \geq b_i^{\max} \\ b_i^{\min}, if \ b_i - 0.5 < b_i^{\min} \end{cases}, \tag{4.7}$$

$$b_i^{\max}, b_i^{\min} \in \{\text{integer}\}, i = 1, \ldots, NBESS + NCB. \tag{4.8}$$

The set of particles for bus number connected with BESS and CB (*B*) in Eq. (4.6) was rounded to identify the location of BESS using Eq. (4.7) and (4.8). Subsequently, initial set of particles for schedule is obtained by Eq. (3.9) - (3.17). if *p* is the particle of the schedule, p is $C^h{}_{bess,1}$,and if p is the particle of bus number connected with BESS and CB, p are b_i .

Step 2 : Compute minimum daily loss of ADL by the DSDLM in Eq. (3.1), using PSO.

Step 3 : Evaluate the fitness function of each particle and determine the initial $pbest$ and $gbest$ are obtain by Eq. (4.2).

Step 4 : Compute velocity of particle and update position of particle to obtain DSDLM. The schedule $C_{bess,i}{}^h$ in Eq.(3.9) is used for obtain ADL in Eq. (4.2), the scheduling and placement were update position by Eq. (3.18) and (3.19). The load flow analysis is preformed and the daily loss is used as the objective function in Eq. (3.1). The best value of ADL is call $gbest$, and the best value of location and scheduling of BESS are call $pbest$. Update position of particle. In order to obtain DSDLM,

Step 5 : If computation reach maximum number of iterations, go to 7, else go to 2.

Step 6 : Stop.

The COPP computational procedure as shown is Fig. 4.2.

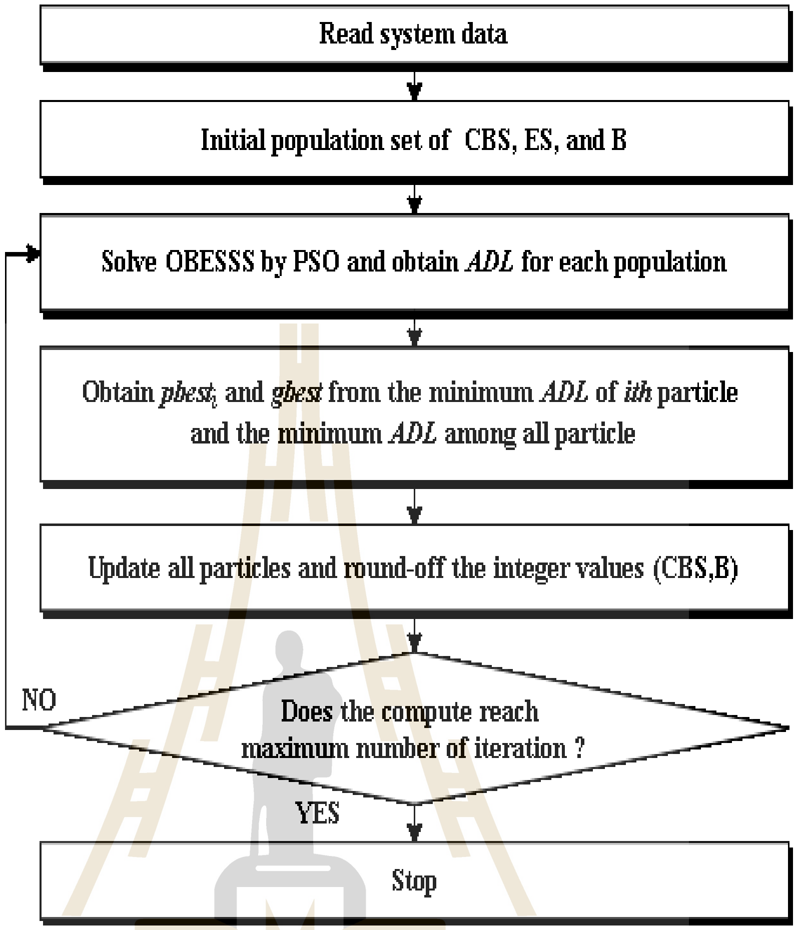

Figure 4.2 The COPP computational procedure

4.6 Simulation Results

The MIPSO based COPP for DSDLM, to validate on the radial distribution IEEE 33 buses has been utilized as a case study, the provided data as shown in Fig 3.8.

The simulation study includes,

Case 1: Reference case (without BESS and CBs),

Case 2: Optimal placement of BESS,

Case 3: Optimal placement of CBs,

Case 4: COPP of BESS and CBs.

4.6.1 Reference case (without BESS and CBs)

In this case, the IEEE 33-bus radial distribution test system without battery energy storage system and capacitor bank was solved by Newton-Raphson power flow for obtain ADL. The result illustrates the system average daily loss without capacitor bank and battery energy storage system is 129.78 kWh. The result ADL in this case used to compare with other cases.

4.6.2 Optimal Placement of BESS

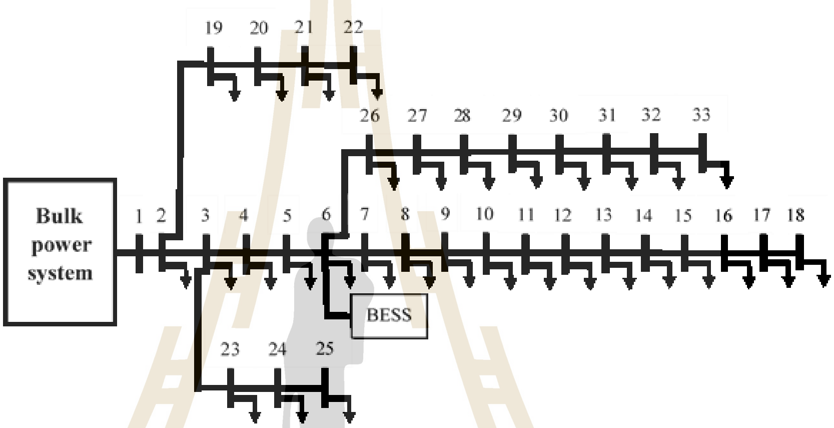

Figure 4.3 The modified IEEE 33-bus radial distribution test system with BESS

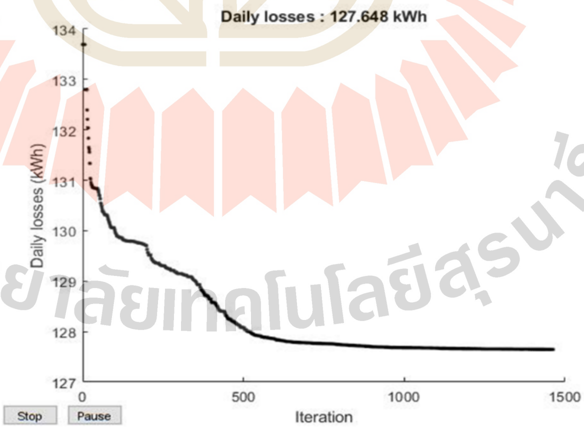

Figure 4.4 Daily loss in each iteration

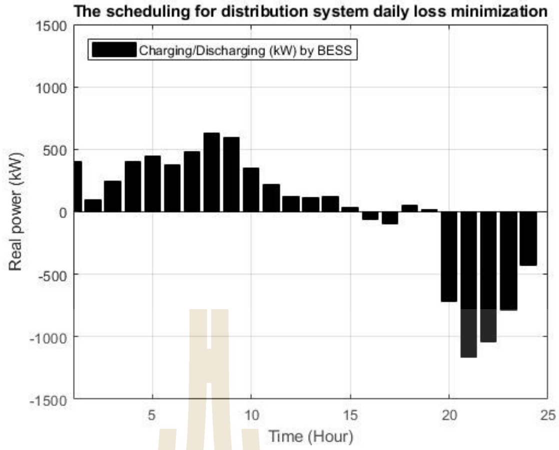

Figure 4.5 The scheduling for distribution system daily loss minimization

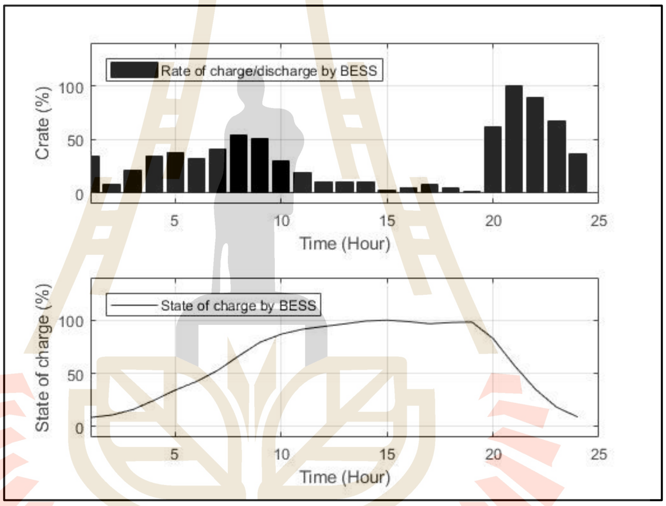

Figure 4.6 The rate of charge and the state of charge by BESS

In this case, the size 1.25 MW/10 MWh BESS is used to test the propose algorithm. The BESS efficiency of charge and discharge are 95%. The optimal BESS was investigated by the proposed MIPSO considering OESSS. As shown in Fig. 4.3, bus number 6 was chosen for install the BESS. In this case, the *ADL* with OPBESS is 127.65 kWh, Fig. 4.4 shows the convergence plot of solution. The rate of charge and the state of charge by BESS are shown in Fig. 4.6.

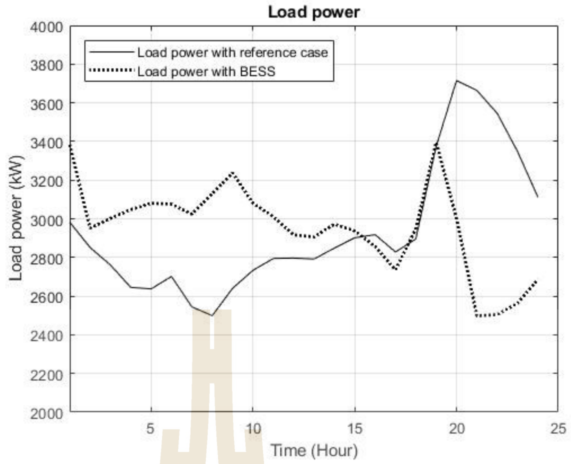

Figure 4.7 The comparison of power load with and without BESS

The scheduling of BESS is shown in Fig. 4.5. Due to BESS is charging when off-peak and discharging when peak load, so peak power load with BESS was decease at 21.00 o'clock, as shown in Fig. 4.7. BESS is possible to handle high peak demand loads. However, it is still significantly unable to compensate for the system loss and voltage decrease. As a result, CB can assist in the solution of this problem.

4.6.3 Optimal Placement of CBs

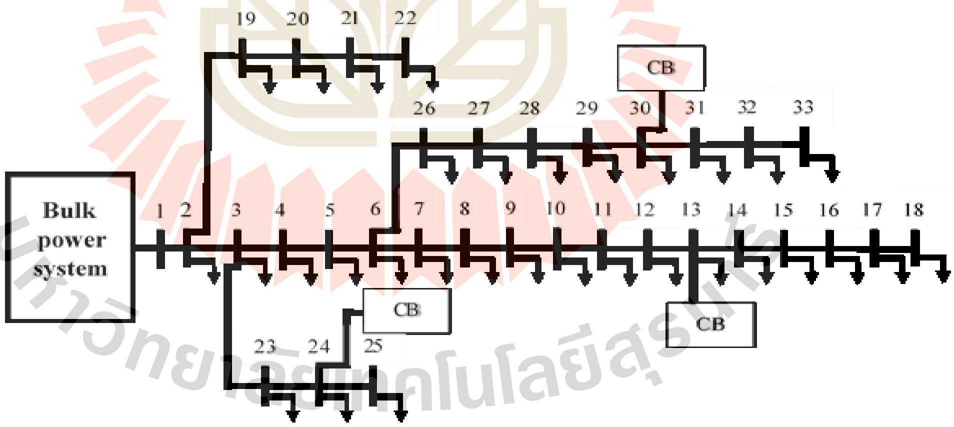

Figure 4.8 The modified IEEE 33-bus radial distribution test system with optimal placement CBs

The optimal CB placement in the IEEE 33-bus radial distribution test system by the proposed method was compared to other previous published research, with the aim of minimizing total loss and operation cost (P. Diaz, etal.,2017). Table 4.1 shows that the proposed method resulted in the same solution with (P. Diaz, etal.,2017) for conventional problem formulation. However, the daily load profile (DLP) was not considered in (P. Diaz, etal.,2017).

Table 4.1 Comparison method to minimize total loss in optimal CB placement

Solver		LS (P. Diaz, etal.,2017)	MIPSO	
Case	Ref.	Without DLP	Without DLP	With DLP
Total Loss(kWh)	210.98	139.23	139.23	86.01
MaximumV(p.u.)	1.0000	1.0000	1.0000	1.0000
MinimumV(p.u.)	0.9038	0.9291	0.9291	0.9423
Loss Saving(%)	0.00	34.01	34.01	59.23

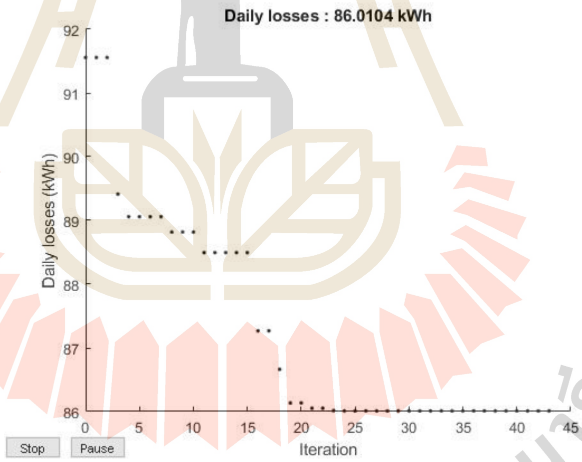

Figure 4.9 Daily loss in each iteration

Therefore, in this section, the DLP was considered to solve for the ADL. The 350, 600, and 1050 kvar CBs are used for optimal placement. From the propose method, CB was installed at bus 13,24 and 30, as shown in Fig. 4.8. The ADL of this case is 86.0104 kWh, which loss saving of 59.23% (saving more than without DLP case). Fig. 4.9 shows that the algorithm convergence to minimum loss in 43 iterations.

The voltage profile in each bus was compensated condition by MIPSO. The voltage drop in this case is lower than in the reference case and BESS case, as shown in Fig. 4.16.

4.6.4 COPP of BESS and CBs

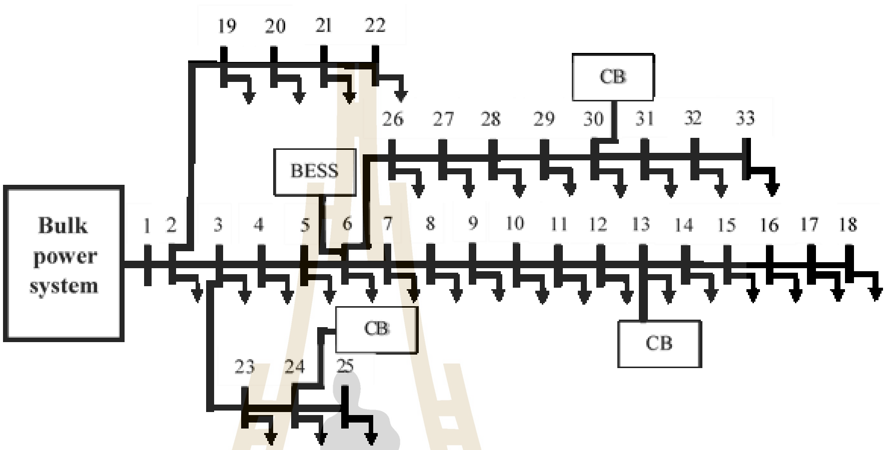

Figure 4.10 The modified IEEE 33-bus radial distribution test system with optimal placement BESS and CBs

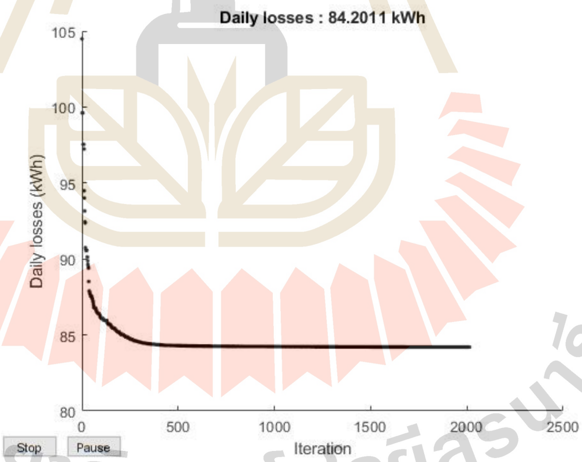

Figure 4.11 Daily loss in each iteration

With the proposed MIPSO based. Fig. 4.10. shows that bus number 6 was chosen to install 1.25 MW/10 MWh of BESS and buses numbers 13, 24, and 30 were placed by CBs, with the sizes of 350, 600, and 1050, respectively.

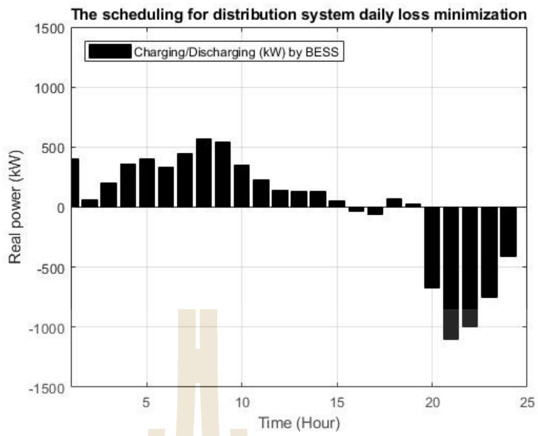

Figure 4.12 The scheduling for distribution system daily loss minimization

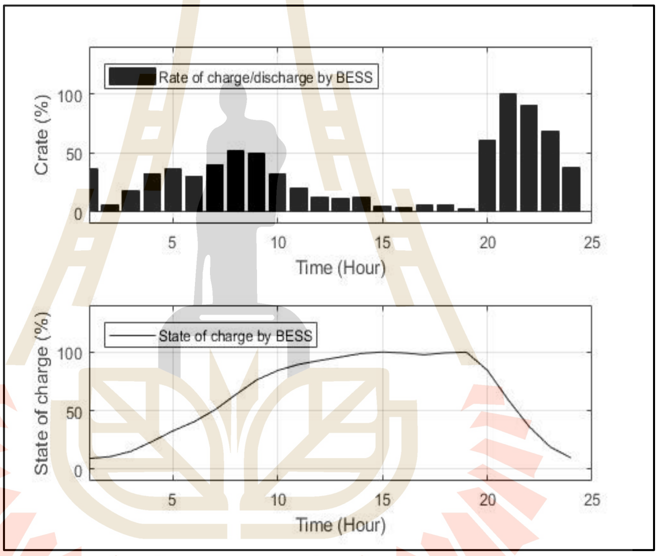

Figure 4.13 The rate of charge and the state of charge by BESS

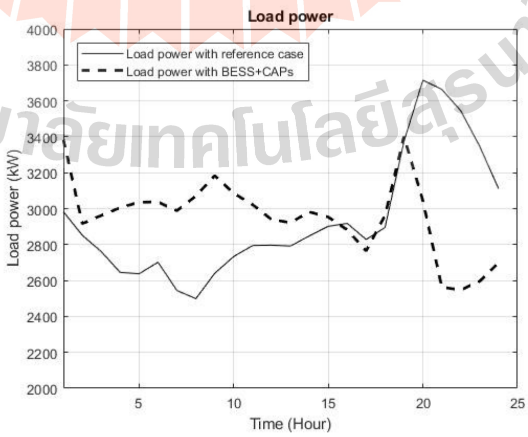

Figure 4.14 The comparison of power load with and without optimal placement BESS and CBs

Table 4.2 Hourly loss of IEEE 33-bus radial distribution test system

Time	Case 1	Case 2	Case 3	Case 4
	Hourly losses (kW)	Hourly losses (kW)	Hourly losses (kW)	Hourly losses (kW)
1	131.7409	156.1866	87.3708	110.6394
2	119.7343	126.0988	79.5606	83.7840
3	111.8022	125.7058	74.3875	85.4428
4	102.1437	125.5076	68.0735	87.8815
5	101.4991	125.5794	67.6515	88.1850
6	106.8218	124.8462	71.1337	86.4586
7	94.1166	126.1528	62.8132	90.7851
8	90.5947	127.0256	60.5014	91.7468
9	101.7402	124.4514	67.8094	87.4914
10	109.4596	121.0148	72.8576	84.8111
11	114.7226	121.4062	76.2933	83.6642
12	114.8860	121.1142	76.4000	83.5383
13	114.4751	120.9067	76.1319	83.0816
14	119.4523	121.2097	79.3769	81.8394
15	124.2406	121.5404	82.4947	81.0080
16	125.7144	121.1590	83.4536	80.3963
17	117.6576	120.1695	78.2073	81.7191
18	123.6554	120.8485	82.1139	80.4152
19	171.3835	131.7973	112.9943	77.5112
20	210.9875	144.9729	138.3603	79.3673
21	204.7166	142.5138	134.3585	78.8940

Table 4.2 Hourly loss of IEEE 33-bus radial distribution test system (Cont.)

Time	Case 1	Case 2	Case 3	Case 4
	Hourly losses (kW)	Hourly losses (kW)	Hourly losses (kW)	Hourly losses (kW)
22	190.6568	137.9043	125.3664	77.6928
23	168.5288	130.8732	111.1571	77.0083
24	144.0933	124.5576	95.3812	77.4656
ADL	129.78	127.65	86.01	84.20

Table 4.2. illustrated *ADL* of the modified IEEE 33-bus radial distribution test system with BESS and CBs is reduced to 84.20 kWh, lower than those case 1-3. In addition, the proposed method has been solved by GA for comparison with the PSO method. The results shown that the PSO based COPP was able to provide more efficient findings than GA when considering minimizing total loss, as shown in Table 4.3.

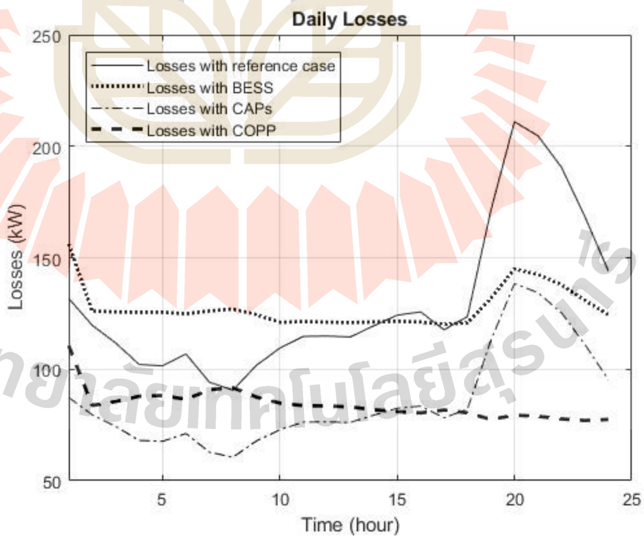

Figure 4.15 The comparison of daily losses

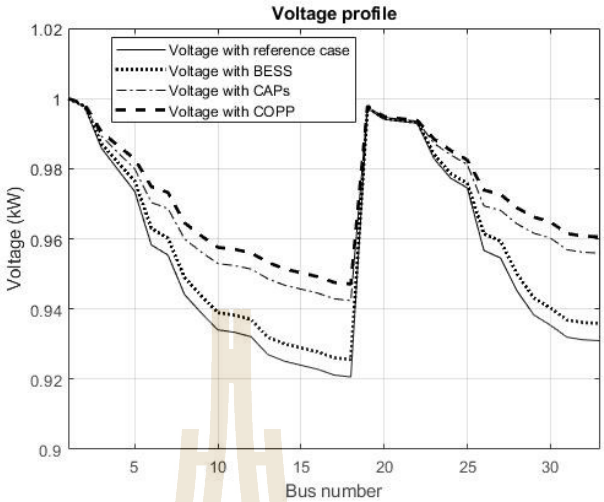

Figure 4.16 The comparison of voltage profile

From Fig. 4.11, the convergence of *ADL* is 2000 iterations. The scheduling of ESS in Fig. 4.12, shows that state of charge of this case is similar to case 3. The rate of charge and the state of charge by BESS are shown in Fig. 4.13. Similarly, the peak power load with BESS and CBs was decease at 21.00 o'clock shown as Fig. 4.14.

Table 4.3 Simulation results with IEEE 33-bus radial distribution test system

Case	1	2	3	4	
Solver	-	MIPSO	MIPSO	GA	MIPSO
OPBESS(NO.)	-	6	-	6	6
OPCB(NO.)	-	-	13,24,30	13,24,30	13,24,30
ADL (kWh)	129.78	127.64	86.01	84.82	84.20
MaximumV(p.u.)	1.0000	1.0000	1.0000	1.0000	1.0000
MinimumV(p.u.)	0.9206	0.9256	0.9423	0.9511	0.9470
ADL Saving (%)	0.00	1.65	33.73	34.64	35.12

In this case, the curve of hourly loss was leveled smoother than BESS in case 2, as shown in Fig. 4.15. Meanwhile, Fig. 4.16. shows the voltage profiles for case 1-4. The results show that when BESS and CBs are placed optimally, significant improvements in bus voltage can be achieved when compared to other cases. Finally, the proposed method is efficiency minimize the ADL by the optimal placement BESS and CBs, considering the optimal scheduling BESS.

4.7 Conclusion

In Chapter 4, the COPP with DSDLM sub problem is proposed, using MIPSO. The proposed method was evaluated using a modified IEEE 33-bus radial distribution test system with the load profile of the Thai power system during the summer season. When properly allocated by MIPSO, CBs can better compensate for reactive power. Meanwhile, the bus with the BESS installed can effectively determine the power consumption schedule with the PSO. The results show that, the proposed method is efficient and dependable for coordinated allocation BESS and CB in minimizing system losses from comparison with and without COP by considering BESS scheduling.

CHAPTER 5
OPTIMAL BATTERY ENERGY STORAGE ALLOCATION CONSIDERING OPTIMAL DAILY SCHEDULING USING MIXED-INTEGER PARTICLE SWARM OPTIMIZATION

5.1 Introduction

Nowadays, PV station installation is becoming extremely prevalent, because it is an environmentally friendly source of energy It may also assist in reducing the price of generating electricity from other resources. Due to various factors, including location, temperature, and illuminance. As a result, it is difficult to predict the power generated by PV stations. Thereby, BESS appear to be an important part of future smart grids and can play a critical role in overcoming these problems. When properly allocated, BESS provides a benefit in power system with PV station was connected. the most of research about optimal placement of BESS and PV station is solved without optimal scheduling.

Therefore, this chapter proposes a MIPSO, including particle swarm optimization (PSO) and rounding particle swarm optimization (RPSO) approach for optimal scheduling and placement for battery energy storage system (BESS), in EDNs to minimizing daily loss, considering renewable energy. The Newton-Raphson load flow is used to determine the daily loss in RDN. In the proposed method, the distribution system annual loss minimization (DSALM) for optimal BESS daily scheduling is solved by PSO. Meanwhile, the optimal battery energy storage allocation (OBESA) is solved by RPSO, incorporating the result from DSALM. The proposed OBESA and DSALM algorithm had been tested with IEEE 33-bus radial distribution test system, using load profile of Thailand power system. The simulation result shown that the proposed method can efficiently minimize the total daily loss by BESS scheduling. Moreover, the proposed MIPSO algorithm can achieve the optimal placement of BESS considering optimal daily scheduling.

5.2 PV stations modeling

Photovoltaic cells are semiconductor-based *pn* junction devices. In PV manufacture, silicon is the most used semiconductor material. The light is instantly converted to energy by the PV cell. When exposed to sunlight, PV cells generate DC electricity. PV cells have a very low output voltage. As a consequence, the PV module is produced by joining a sequence of PV cells. Depending on the requirements, the PV modules are connected in series or series-parallel configurations. PV generates power in the daytime. Figure 5.1. shows the actual power output of single PV module. The power generation of PV power plant can be represented as,

$$P_{PV,i}^{h} = [P_{PV,i}^{1},...,P_{PV,i}^{h},...,P_{PV,i}^{24}], \text{ for } i = 1,...,NPV. \tag{5.1}$$

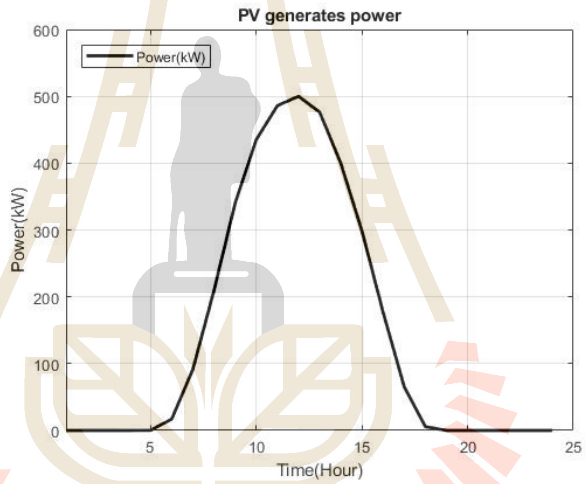

Figure 5.1 The typical real power output of PV module

5.3 OBESA problem formulation

In this section, an optimal battery energy storage allocation considering optimal daily scheduling incorporating DSALM is proposing. The proposed OBESA is solved by RPSO coordinately with the DSALM which is solved by PSO. The proposed method was tested with the radial IEEE 33-bus distribution test system using Thailand's power system load profile.

The modern distribution grid is usually including active resources, such as renewable power stations, BESS, and load demand as shown in Fig 5.2.

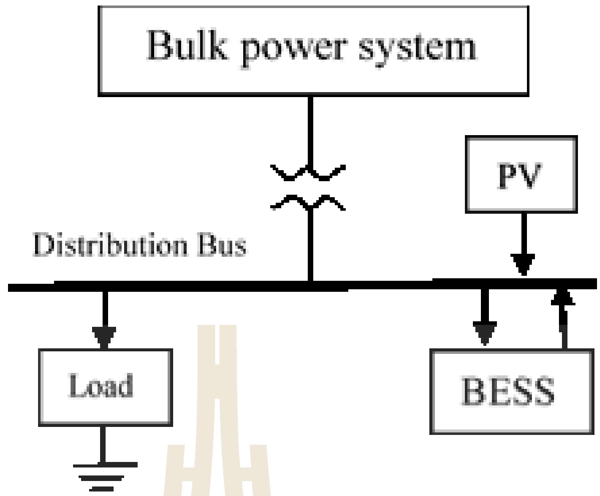

Figure 5.2 A structure of distribution system with PV and BESS

The proposed method includes DSALM problem formulation for obtain daily scheduling of BESS, and OBESA problem formulation that uses DSALM as subproblem for optimal placement of BESS by MIPSO algorithm.

In this section, an OBESA for DSALM is proposed. The objective function of OBESA is

Minimize $$TAL = D^{s} P^{s}_{loss,total} + D^{r} P^{r}_{loss,total} + D^{w} P^{w}_{loss,total}. \qquad (5.2)$$

From Eq. (3.3), the power balance constraints with PV stations was added P^{h}_{PV} in Eq. (5.1),

$$P^{h}_{Gi} - (P^{h}_{Di} \pm (C^{h}_{bess,i} \cdot (\eta_c / \eta_d)) - P^{h}_{PV,i}) = \sum_{j=1}^{NB} |V^{h}_{i}||V^{h}_{j}||y_{ij}|\cos(\theta_{ij} - \delta^{h}_{ij}),$$

$$\text{for } i = 1, \ldots, NB, h = 1, \ldots, 24, \qquad (5.3)$$

5.4 MIPSO based OBESA for DSALM

The OBESA computation procedure as shown in Fig. 5.3. The proposed method has 6 computational steps as follows,

Step 1 : Initial set of particles for bus that connected with only BESS as,

$$\mathbf{B_{bess}} = \left[b_{bess,1}, \ldots, b_{bess,i}, \ldots, b_{bess,NBESS} \right]^{T}, \ 1 \le x_i \le NB. \qquad (5.4)$$

Where, $\mathbf{B_{bess}}$ is the matrix representing bus number with BESS, $b_{bess,i}$ is the bus number connected with BESS.

In this case, the rounding technique is similar Chapter 4. If $b_{bess,i}$ is position of particle representing the bus number for BESS placement, each particle will be rounded by Eq. (4.7). Moreover, Eq. (4.8) in Section 4.5 was considered BESS only, as shown in Eq. (5.5),

$$b_i^{\max}, b_i^{\min} \in \{\text{integer}\}, i = 1, \ldots, NBESS. \tag{5.5}$$

The set of particles for bus number connected with BESS ($\mathbf{B_{bess}}$) in Eq. (5.4) was rounded to identify the location of BESS using Eq. (4.7) and (5.5). Subsequently, initial set of particles for schedule is obtained by Eq. (3.9) - (3.17). if p is the particle of the schedule, p is $C^h{}_{bess,i}$,and if p is the particle of bus number connected with BESS, p is $b_{bess,i}$.

Step 2 : Compute minimum daily loss of $P^s{}_{loss,total}$, $P^r{}_{loss,total}$, and $P^w{}_{loss,total}$ by the DSDLM in section 3.1, using PSO.

Step 3 : Evaluate the fitness function of each particle and determine the initial $pbest$ and $gbest$ are obtain by Eq. (5.2).

Step 4 : Compute velocity of particle and update position of particle to obtain DSALM. The schedule $C_{bess,i}{}^h$ in Eq.(3.11) is used for obtain $P^s{}_{loss,total}$, $P^r{}_{loss,total}$, and $P^w{}_{loss,total}$ in Eq.(5.2), the scheduling and placement were update position by Eq. (3.18) and (3.19). The load flow analysis is preformed and the daily loss is used as the objective function in Eq. (3.1). The value is a TAL is call $gbest$, and the best value is a scheduling of BESS is call $pbest$.

Step 5 : If computation reach maximum number of iterations, go to 7, else go to 2.

Step 6 : Stop.

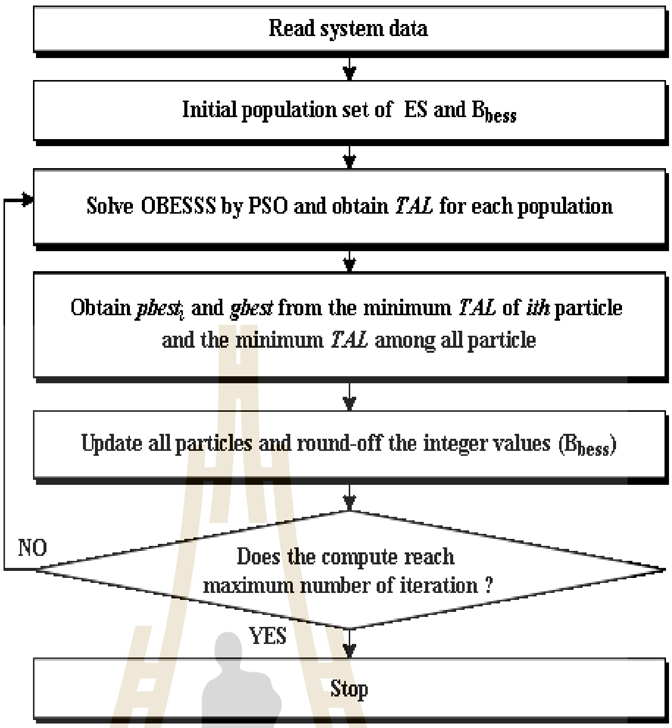

Figure 5.3 The OBESA computational procedure

5.5 Simulation Results

In this section, the simulation results of OBESA considering DSALM are presented. The proposed method was tested with IEEE 33-bus radial distribution test system with some modification for cases study, the IEEE 33-bus radial distribution test system, as shown in Figure 3.8.

This test system is composed of 33 buses and 32 lines, with the point of connection to bulk power system at bus 1. The voltage supplied by certain substation is 12.66 kV, while the remaining 32 load buses consume a total active and reactive power of 3,715.00 kW and 2,300.00 kVAR, respectively. In this thesis, six PV stations, each rated of 500 kW, are mounted at bus number 3,8,14,25,30 and 31, to provide active power. The modified IEEE 33 system was considered by two applications, which are the high penetration of photovoltaics model and BESS that effect to the load profile.

The Thailand daily load curve, is used as the system load profile including summer season (April 14th, 2018), rainy season (September 9th, 2018) and winter season (January 1st, 2018). Daily load curves of the test system are shown in Figures 3.3-3.5.

The simulation study includes,

1. Reference case: the original IEEE 33-bus radial distribution test system,

2. PV case: the modified IEEE 33-bus radial distribution test system with PV stations,

3. BESS+PV case: the modified IEEE 33-bus radial distribution test system with single BESS and PV stations, and

4. 2BESS+PV case: the modified IEEE 33-bus radial distribution test system with multiple BESS and PV stations.

5.5.1 Reference case

In this section, from Eq. (3.16) and Eq. (3.17), the LF^h is used to calculate 24 hour demands at each bus of the IEEE-33 bus system using load profile of Thailand. In next step, Newton-Raphson load flow is used to calculate daily loss by Eq. (3.1). The system daily loss without PV stations and BESS is 3114.82 kWh in summer season, 3648.86 kWh in rainy season and 2877.70 kWh in winter season.

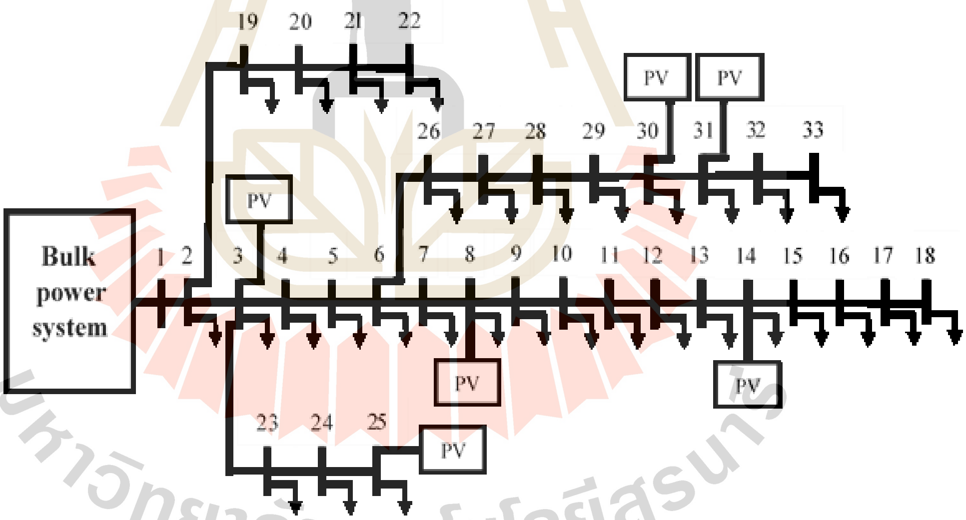

Figure 5.4 The modified IEEE 33-bus radial distribution test system with PV stations

5.5.2 PV case

In this case, the IEEE 33-bus radial distribution test system considers only PV stations, a total of six PV stations have been added at buses 3, 8, 14, 25, 30, and 31, as shown in Fig. 5.4 (A. Alzahrani, et al, 2019).

In this case, the PVs maximum output power is 500 kW. The PV power generation profile is based on the solar irradiance of Thailand as shown in Table A.3.

The result show that PV stations can reduce daily loss from the reference case. Moreover, PV stations reduce the consumption from utility. Therefore, daily loss is decreased due to the load profile. The system daily loss with PV stations are 2470.48 kWh in summer season, 2845.82 kWh in rainy season and 2346.35 kWh in winter season.

From Figure 3.3-3.5, it is noticeable that load profile has maximum output power is not synonymous to the PV model (load profile has maximum power output at hours 19-21 but PV model has maximum power output at hours 12). The improvement can be achieved by the BESS application.

5.5.3 BESS+PV case

The BESS is commonly employed in the distribution system to assist with energy management. This application is possible to store power when demand is low and then supply back when demand is high. When used appropriately, BESS provides benefit in significant reduction on annual loss. The IEEE 33-bus radial distribution test system with six solar PV stations installed at buses 3, 8, 14, 25, 30, 31 is used for optimal BESS placement. The PV stations placement in this situation is similar to that in PV case.

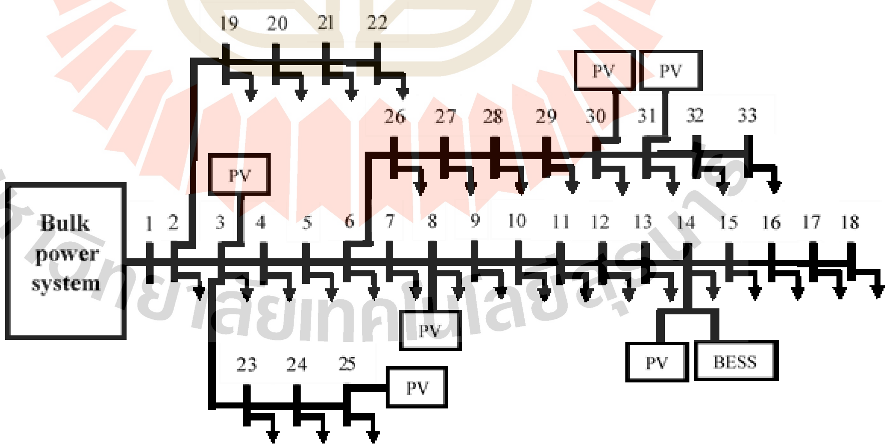

Figure 5.5 The modified IEEE 33-bus radial distribution test system with PV stations and single BESS

In this case, the optimal placement of the single BESS was investigated by solving for minimum daily loss. The 3000 kWh BESS is used to test the proposed MIPSO based OBESA for DSALM. The charging and discharging efficiency of BESS, in this thesis are 95%. The result shown that the optimal location for BESS is at bus 14, shown in Fig. 5.5.

Fig. 5.6 shows the proposed method converged to the best value, in approximately 540 iterations. The daily losses with PV stations and single BESS, are 2288.76 kWh in summer season, 2669.08 kWh in rainy season and 2155.30 kWh in winter season. The schedules of BESS are shown in Figs. 5.7-5.9. The rate of charge and the state of charge by BESS as shown in Figs. 5.10-5.12.

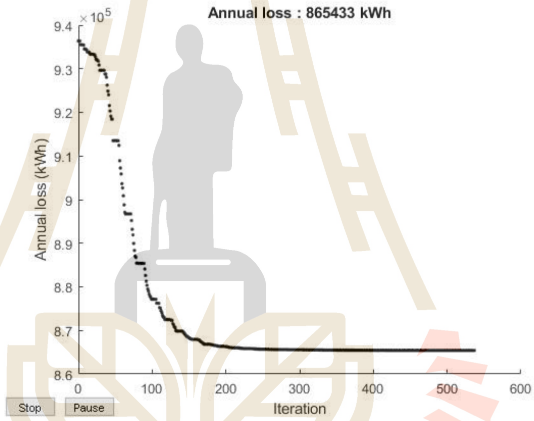

Figure 5.6 Annual loss in each iteration

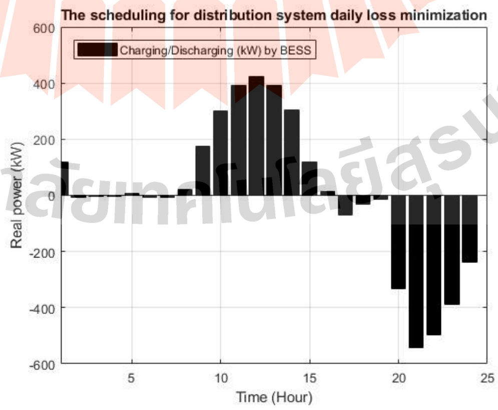

Figure 5.7 The scheduling for distribution system daily loss minimization in summer

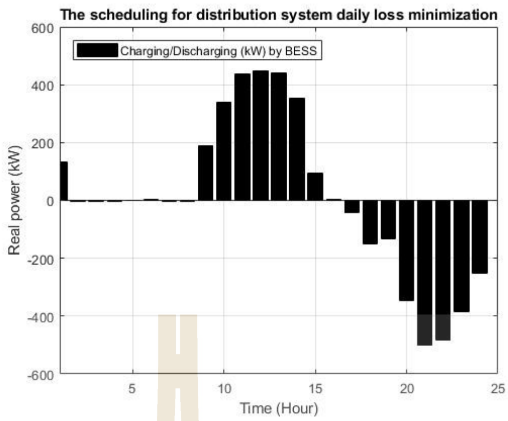

Figure 5.8 The scheduling for distribution system daily loss minimization in rainy

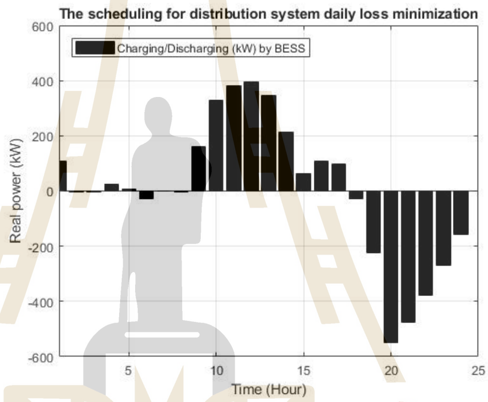

Figure 5.9 The scheduling for distribution system daily loss minimization in winter

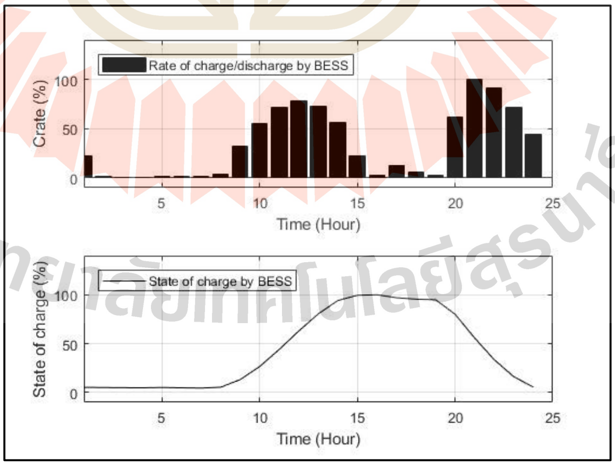

Figure 5.10 The rate of charge and the state of charge by BESS in summer

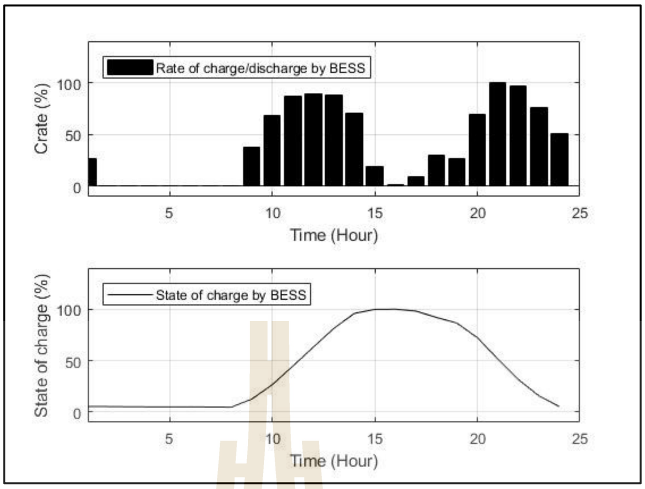

Figure 5.11 The rate of charge and the state of charge by BESS in rainy

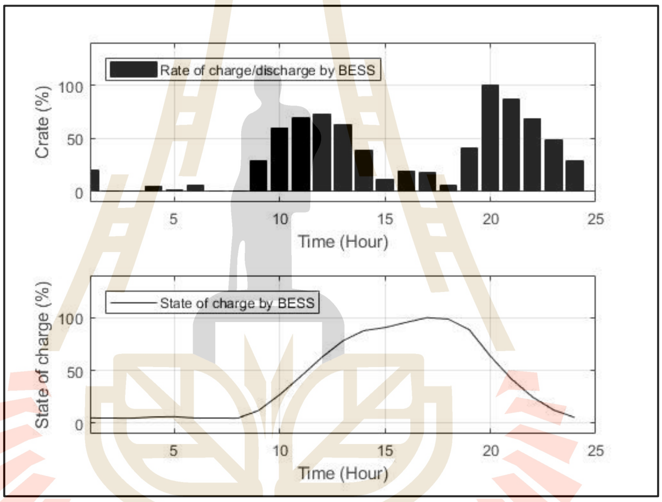

Figure 5.12 The rate of charge and the state of charge by BESS in winter

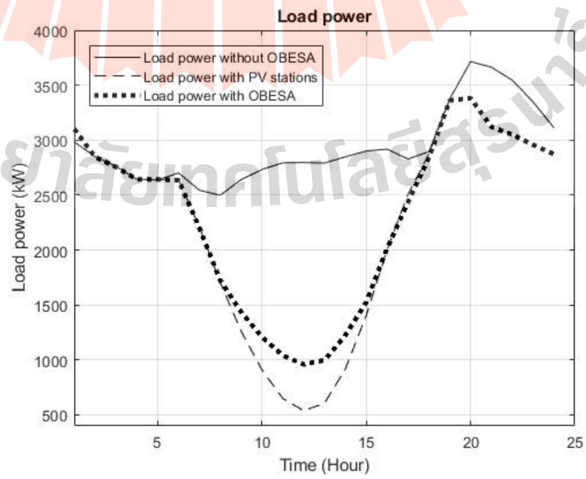

Figure 5.13 The comparison of power load with and without OBESA in summer

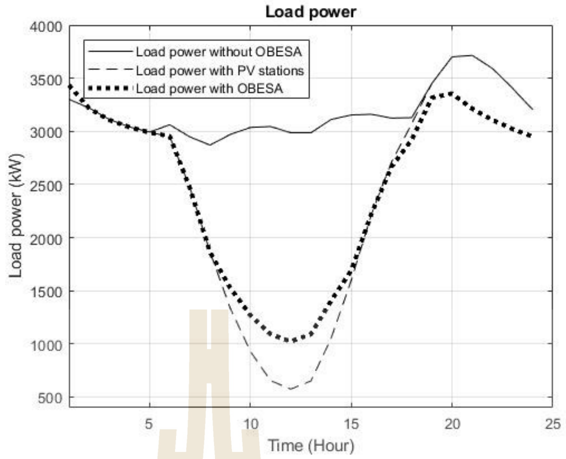

Figure 5.14 The comparison of power load with and without OBESA method in rainy

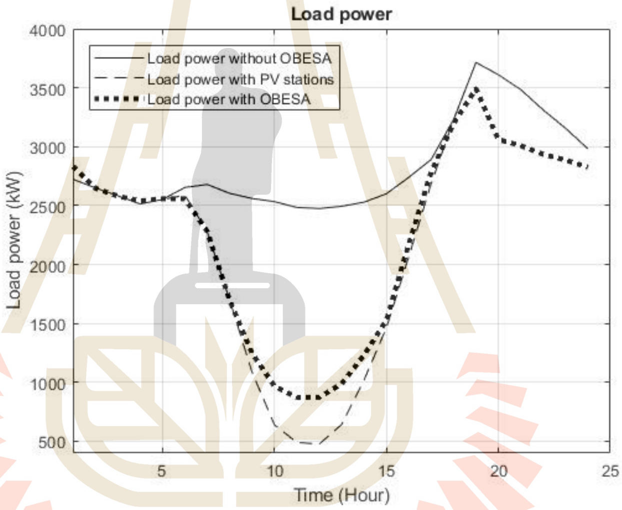

Figure 5.15 The comparison of power load with and without OBESA in winter

Figs. 5.13-5.15 demonstrate the distribution system load profile comparison of IEEE 33 buses system with and without PV stations and single BESS. The case with battery energy storage system can reduce daily loss from the reference case and PV case.

5.5.4 2ESS+PV case

In This case, the optimal placement for multiple BESSs for minimum annual loss using the proposed method had been investigated. The two sets of 1500 kWh BESS is used in this case. The propose MIPSO based OBESA is used to optimally scheduling of energy storage system for allocate the ESSs in the IEEE 33-bus radial distribution test system with PVs.

From Fig. 5.16, the IEEE 33-bus radial distribution test system as shown are six PVs installed in buses 3, 8, 14, 25, 30, 31 and a distribution BESSs, The PVs placement in this situation is similar to PVs case. Bus14 and Bus 31 were resulted for optimal placement of BESS. The daily losses of IEEE 33 bus test system are reduced to 2259.21 kWh in summer season, 2635.59 kWh in rainy season and 2131.12 kWh in winter season.

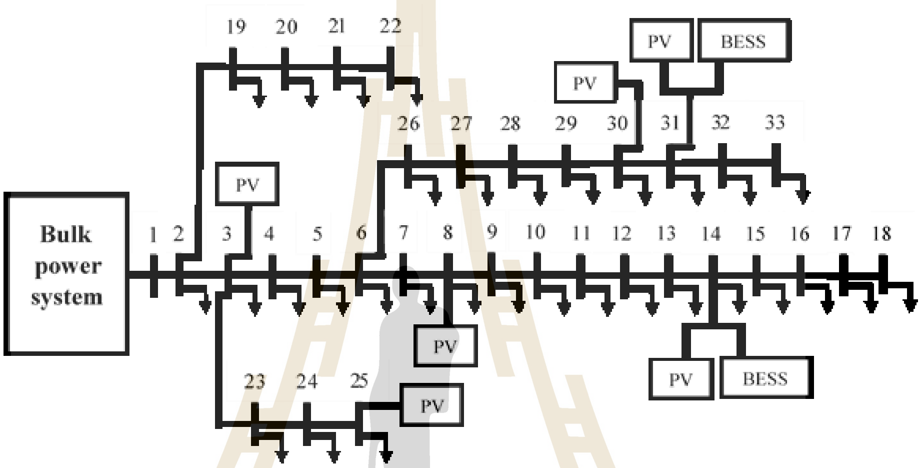

Figure 5.16 The modified IEEE 33-bus radial distribution test system with distributed BESS and PV station

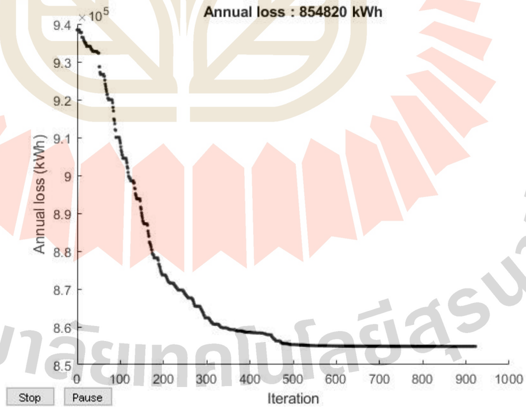

Figure 5.17 Annual loss in each iteration

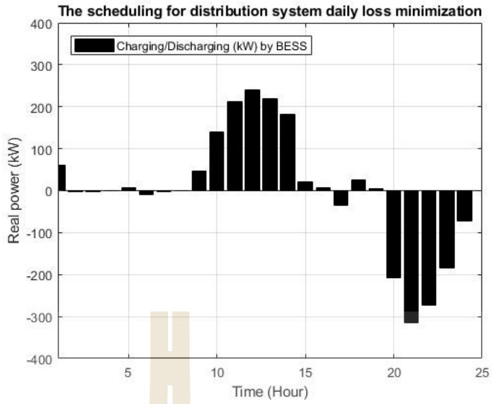

Figure 5.18 The scheduling for distribution system daily loss minimization of BESS at bus 14 in summer

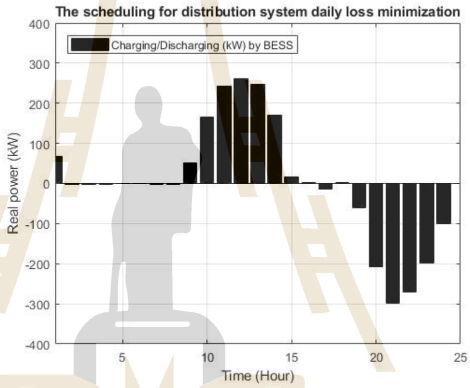

Figure 5.19 The scheduling for distribution system daily loss minimization of BESS at bus 14 in rainy

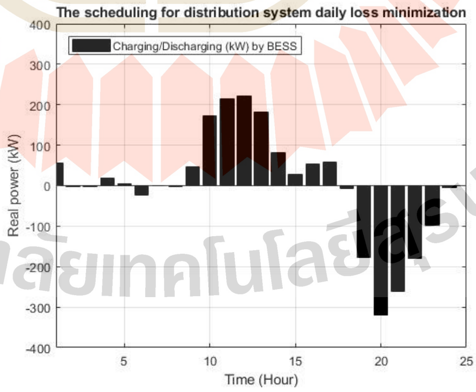

Figure 5.20 The scheduling for distribution system daily loss minimization of BESS at bus 14 in winter

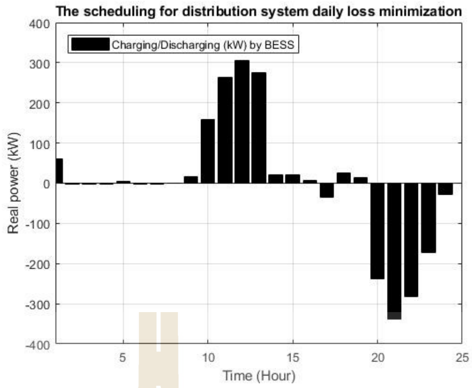

Figure 5.21 The scheduling for distribution system daily loss minimization of BESS at bus 31 in summer

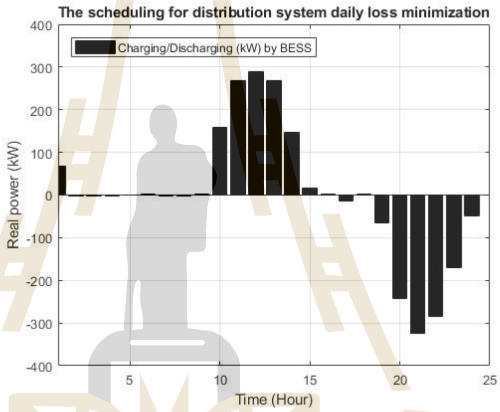

Figure 5.22 The scheduling for distribution system daily loss minimization of BESS at bus 31 in rainy

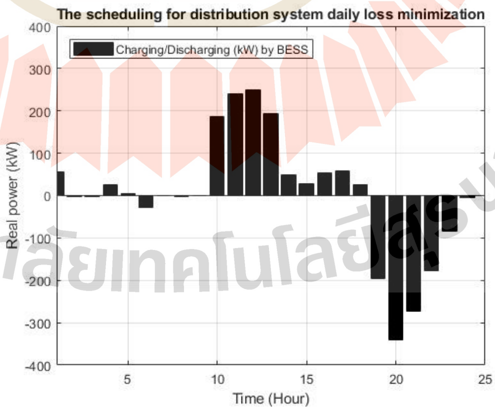

Figure 5.23 The scheduling for distribution system daily loss minimization of BESS at bus 31 in winter

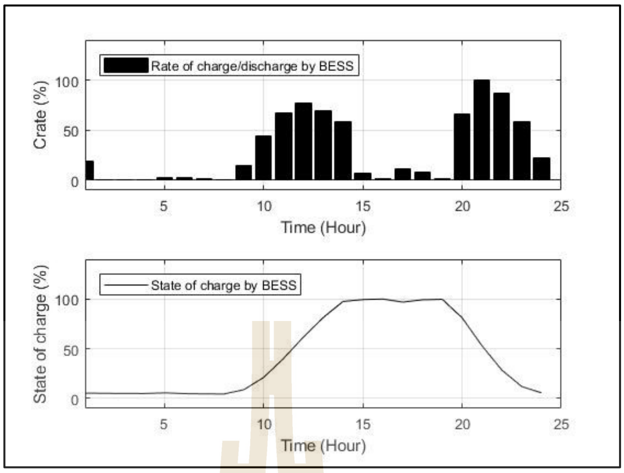

Figure 5.24 The rate of charge and the state of charge by BESS at bus 14 in summer

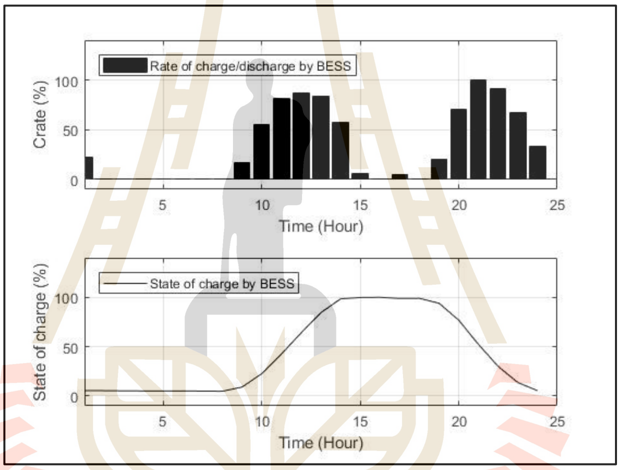

Figure 5.25 The rate of charge and the state of charge by BESS at bus 14 in rainy

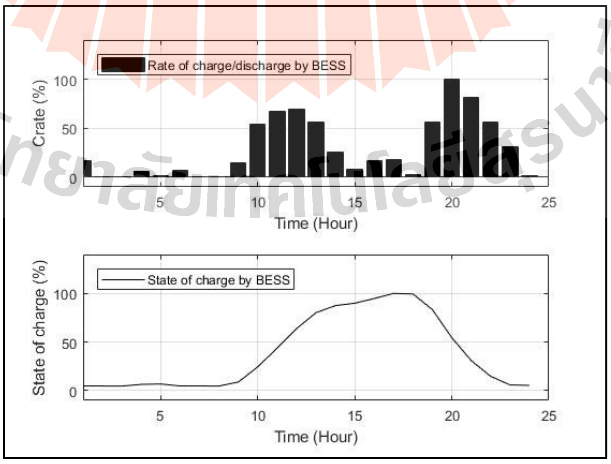

Figure 5.26 The rate of charge and the state of charge by BESS at bus 14 in winter

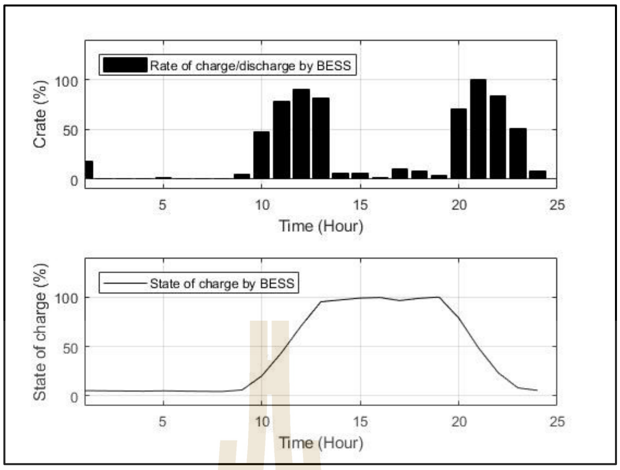

Figure 5.27 The rate of charge and the state of charge by BESS at bus 31 in summer

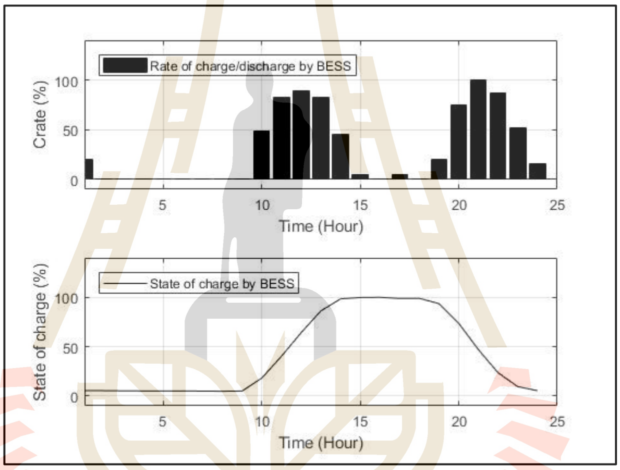

Figure 5.28 The rate of charge and the state of charge by BESS at bus 31 in rainy

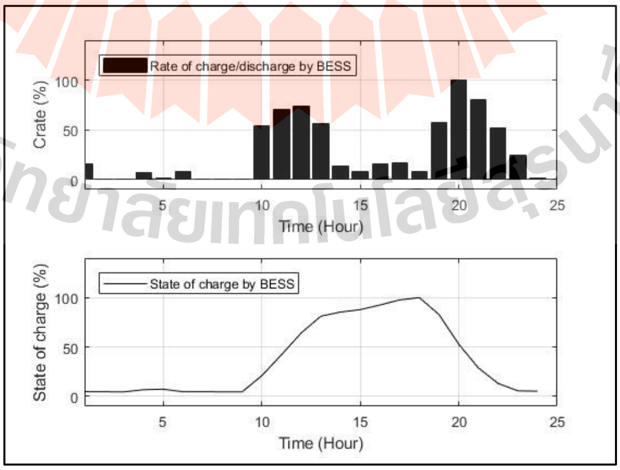

Figure 5.29 The rate of charge and the state of charge by BESS at bus 31 in winter

Fig. 5.17 shows the convergence of PSO-RPSO algorithm, in 920 iterations. The BESSs are placed near the location where the PV stations is installed, because BESSs can charge when PV stations are over supply to load. The distribution BESSs can reduce annual losses lower than those of without PV stations and BESSs and with PV stations and single BESSs. The scheduling of distributed BESSs are shown in Figs. 5.18-5.23.

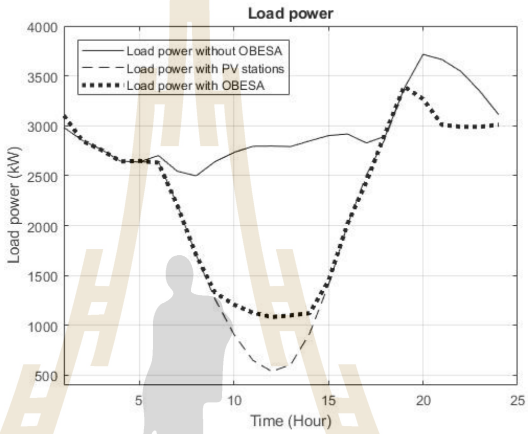

Figure 5.30 The comparison of power load with and without OBESA in summer

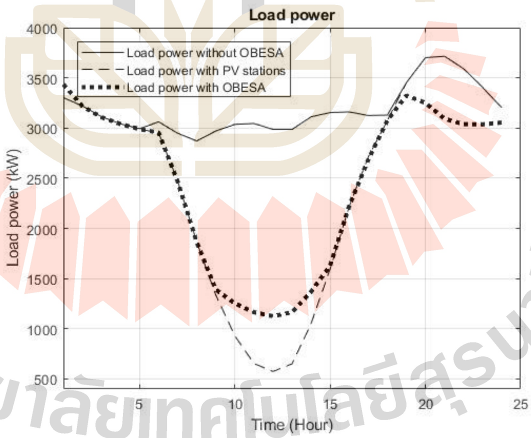

Figure 5.31 The comparison of power load with and without OBESA in rainy

From scheduling of BESSs, the BESSs charge the energy during minimal load requirements (PV stations supply more power than necessary) and discharge the energy back to the system during peak hours, with the best location of BESSs at bus 14 and 31. Therefore, the proposed method is efficiency minimize the daily loss at distribution system by scheduling the BESSs. The rate of charge and the state of charge by BESS as shown in Figs. 5.24-5.29. The comparison on load profile of IEEE 33-bus radial distribution test system with and without PV stations and BESSs are shown in Figs. 5.30-5.32. for summer, rainy, and winter seasons, respectively.

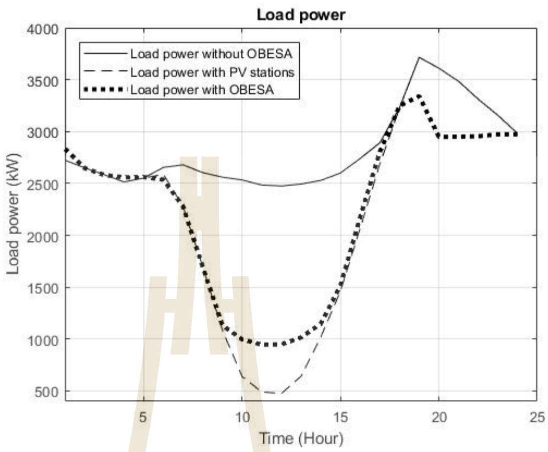

Figure 5.32 The comparison of power load with and without OBESA in winter

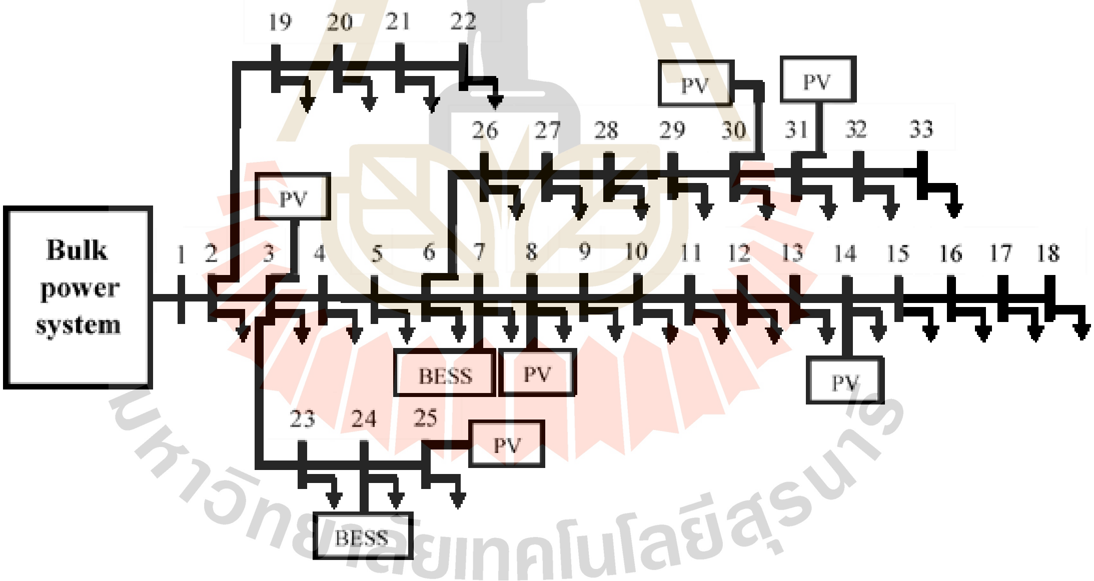

Figure 5.33 The modified IEEE 33-bus radial distribution test system with distributed BESS and PV station

In addition, the proposed method has been solved by MIGA for comparison with the MIPSO method. The results shown that the MIPSO based OBESA was able to provide more efficient findings than GA when considering minimizing total loss, as shown in Table 5.1.

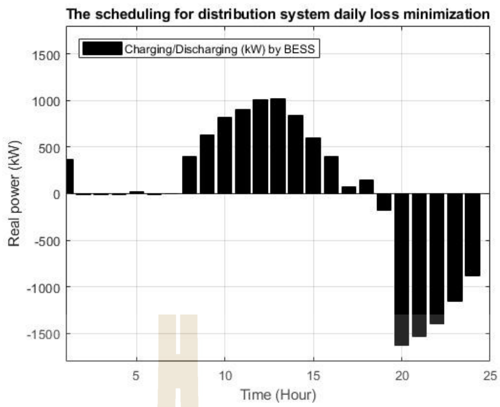

Figure 5.34 The scheduling for distribution system daily loss minimization of BESS at bus 7 in summer

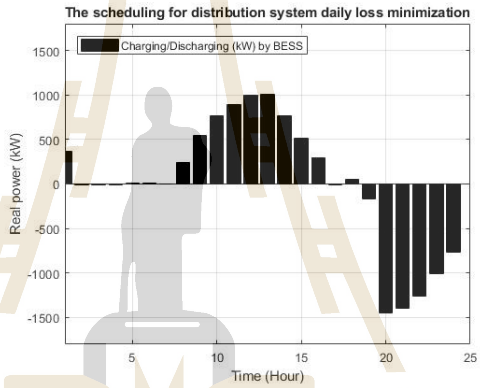

Figure 5.35 The scheduling for distribution system daily loss minimization of BESS at bus 7 in rainy

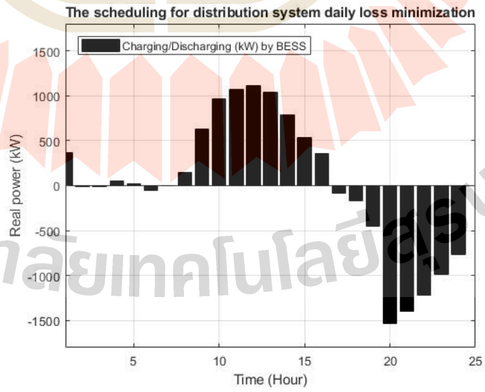

Figure 5.36 The scheduling for distribution system daily loss minimization of BESS at bus 7 in winter

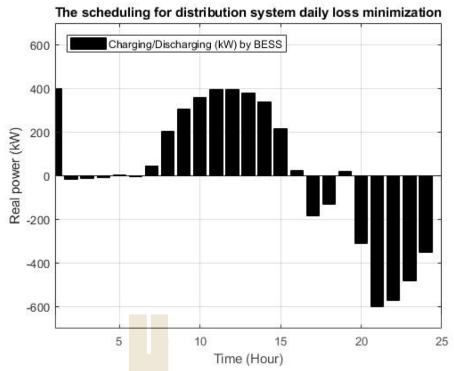

Figure 5.37 The scheduling for distribution system daily loss minimization of BESS at bus 24 in summer

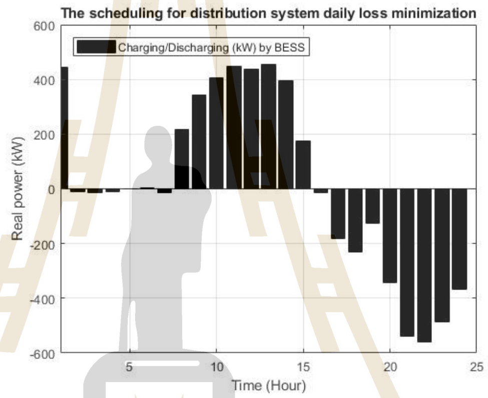

Figure 5.38 The scheduling for distribution system daily loss minimization of BESS at bus 24 in rainy

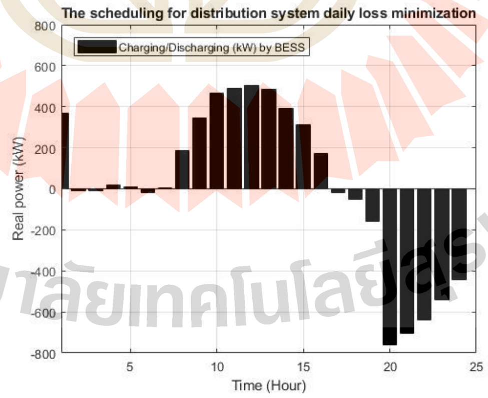

Figure 5.39 The scheduling for distribution system daily loss minimization of BESS at bus 24 in winter

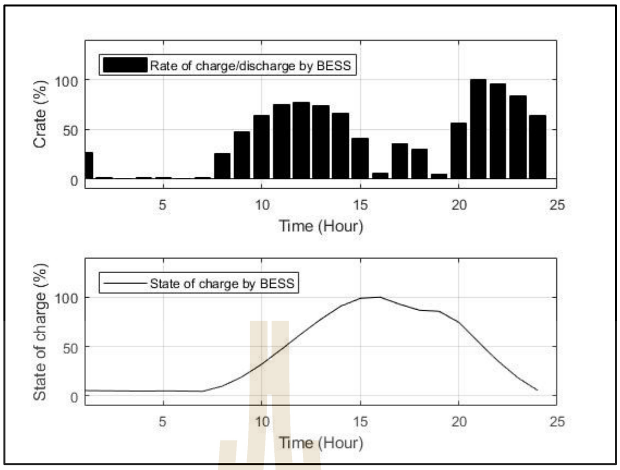

Figure 5.40 The rate of charge and the state of charge by BESS at bus 7 in summer

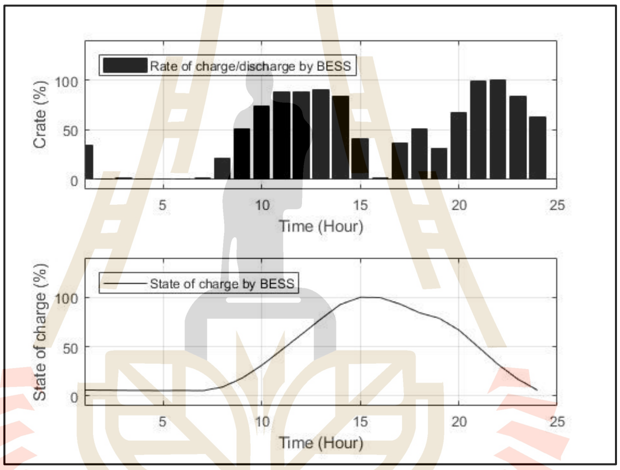

Figure 5.41 The rate of charge and the state of charge by BESS at bus 7 in rainy

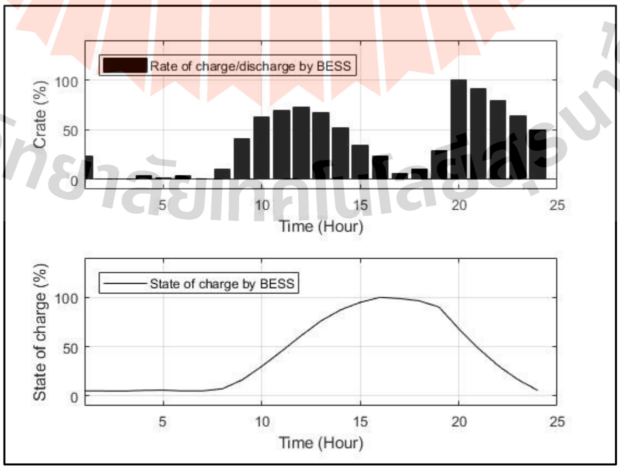

Figure 5.42 The rate of charge and the state of charge by BESS at bus 7 in winter

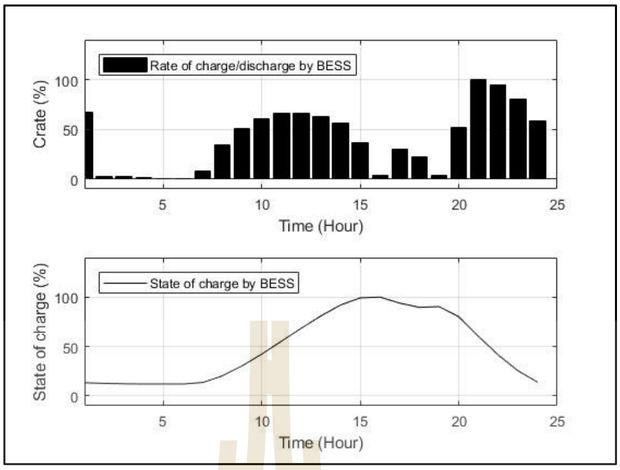

Figure 5.43 The rate of charge and the state of charge by BESS at bus 24 in summer

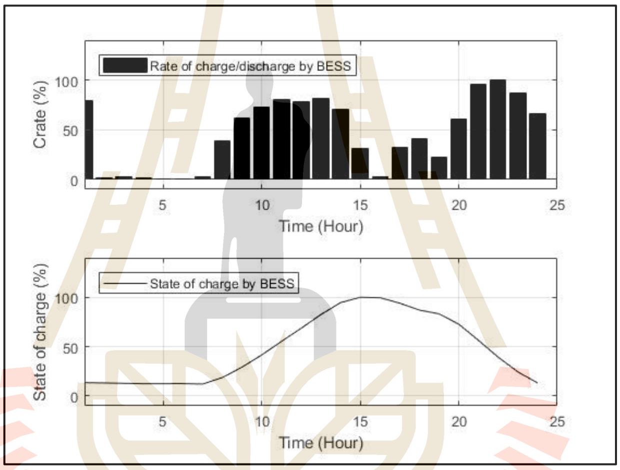

Figure 5.44 The rate of charge and the state of charge by BESS at bus 24 in rainy

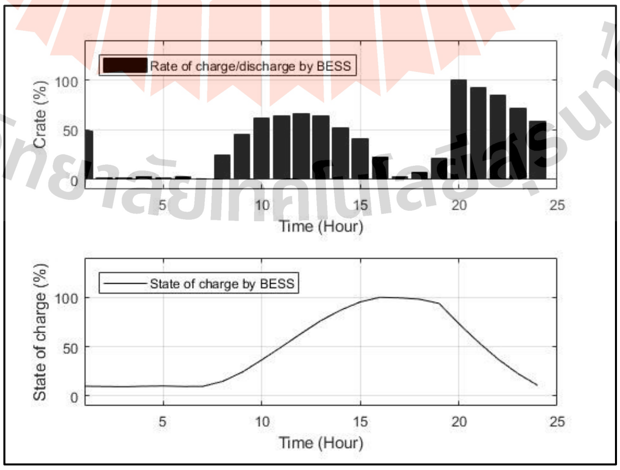

Figure 5.45 The rate of charge and the state of charge by BESS at bus 24 in winter

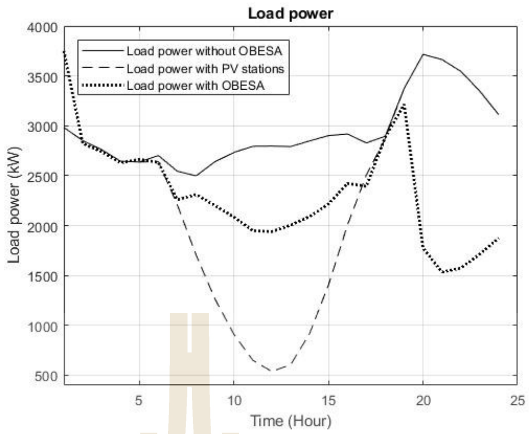

Figure 5.46 The comparison of power load with and without OBESA in summer

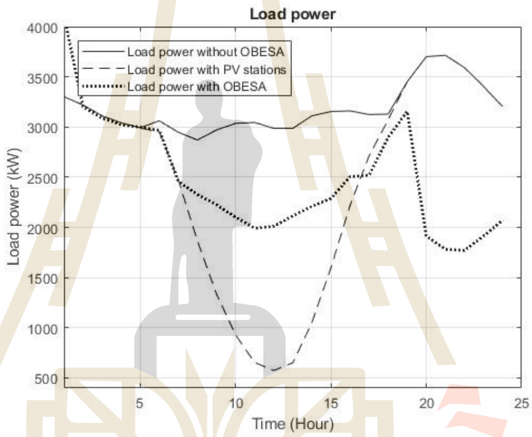

Figure 5.47 The comparison of power load with and without OBESA in rainy

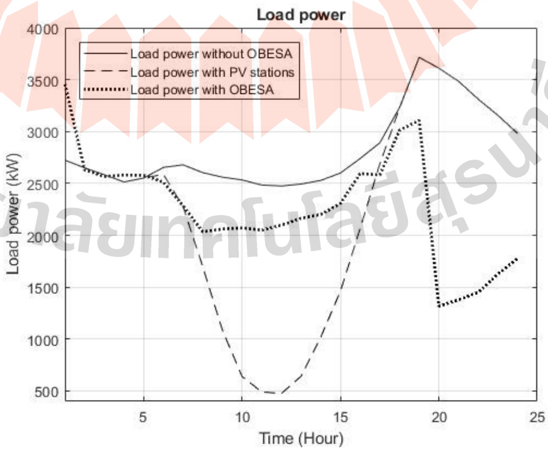

Figure 5.48 The comparison of power load with and without OBESA in winter

Finally, BESSs size of 10000 kWh are used to increase efficient of the proposed method for minimizing total loss. The results shown that bus 7 and bus 24 were chosen for install BESS as shown in Fig.5.33. Therefore, the size of BESS is effect to optimal placement problem. The scheduling of BESS demonstrates in Figs. 5.34-5.39. The rate of charge and the state of charge by BESS as shown in Figs. 5.40-5.45. Finally, the comparisons of power load with and without OBESA as shown in Fig.5.46-5.48.

Table 5.1 Results of the Reference, PV, BESS+PV, and 2BESS+PV cases

Case	Solver	Annual loss (kwh)	Summer (kwh/day)	Rainy (kwh/day)	Winter (kwh/day)	Loss reduce (%)
Reference	-	1173034.83	3114.82	3648.86	2877.70	**0.00**
PV case	-	932288.37	2470.48	2845.82	2346.35	**20.52**
BESS+PV case	MIPSO	865433.06	2288.76	2669.08	2155.30	**26.22**
2BESS+PV case (BESS 1500 kWh)	MIPSO	854820.04	2259.21	2635.59	2131.12	**27.13**
2BESS+PV case (BESS 1500 kWh)	MIGA	893743.74	2370.90	2739.29	2235.64	**23.81**
2BESS+PV case (BESS 10000 kWh)	MIPSO	840785.61	2223.77	2624.98	2061.82	**28.32**

5.6 Conclusion

In Chapter 5, the OBESA considering DSALM is proposed. The optimization techniques use in this paper is MIPSO. The proposed method had been tested with the modified IEEE 33-bus radial distribution test system, with PV stations and BESS using load profile of Thailand power system. The results shown that the proposed DSALM can successfully minimize the annual loss by BESS optimal scheduling. Meanwhile, the proposed OBESA can provide the optimal placement for BESSs, considering the DSALM form DSDLM in each season. Therefore, the proposed DSALM can potentially be used for optimal daily scheduling of BESSs. In addition, the optimal location of BESSs can be obtained by the proposed OBESA.

CHAPTER 6
CONCLUSION AND RECOMMENDATION

6.1 Introduction

This chapter concludes by giving summary of the main contributions of research work, recommendations, and a scope of further research work which may improve the performance of OBESA.

6.2 Summary

In this thesis, the optimization technique is MIPSO. In Chapter 3, the simple BESS operation, which fixed time charging during light-load period and discharging during peak-load period was compared to optimal scheduling of BESS. The proposed method had been tested with the modified IEEE 33-bus radial distribution. The result show that efficiency minimize the daily loss at distribution system by scheduling BESS by PSO. Then, the COPP with DSDLM sub problem is proposed in Chapter 4. The proposed method was evaluated using a modified IEEE 33-bus radial distribution test system with the load profile of the Thai power system during the summer season. The optimal placement of BESS and CBs are solved by integer of PSO. Meanwhile, BESS is scheduled by the PSO. The results showed that, the proposed method is efficient and dependable for coordinated allocation BESS and CB in minimizing system losses, which *ADL* saving of 35.12 % when compare to the based case.

In addition, Chapter 5 has been updated with PV stations connected to the IEEE 33-bus radial distribution test system. When comparing the annual load profile with the operation of PV stations, it is observed that the generation power of PV stations is not synonymous with load demand. Therefore, BESS can be achieved to solve this problem. The proposed method used Thailand's power system load profile, which is considered an annual load profile. The rounding PSO technique is used for optimal allocation of BESS. Meanwhile, BESS scheduling was obtained by PSO. The results show that the proposed DSALM can successfully minimize the annual loss by BESS optimal allocation and scheduling.

6.3 Recommendation

Renewable energy is becoming increasingly significant on today's electricity grid. Because these numerous energies fluctuate in power generation and are unpredictably unpredictable. As a result, developing a framework for managing these uncertain energies is essential. The proposed method can be applied to the task of planning, allocating, and scheduling BESS.

This method used daily load profile data input to the MIPSO algorithm, from which daily energy consumption data is obtained from popular methods such as load usage forecasts. Statistical data collection methods, etc. The proposed method requires 3-6 hours to plan the BESS's daily schedule. For OBESA problems, this method requires 3-6 days to prepare optimal placement of BESS by considering BESS annual scheduling.

By incorporating Thailand's daily energy usage statistics into the proposed software, the proposed method can be implemented. Taking into consideration the following elements :

6.3.1 What is the maximum wattage load used per day for daily power requirements? This information is used to design the size of the BESS.

6.3.2 The type of data utilized in the computation must only originate from the daily load profile (24 hours).

6.3.3 The cost-effectiveness of the installation of a battery energy storage system should be considered to determine the amount of BESS in electrical system.

6.3.4 From III, the proposed method is applied to identify the best optimal location for an electrical system has limited costs in installing BESS. The proposed method can locate the most appropriate installation site of BESS.

6.3.5 The proposed method is suitable for planning an energy management system, which takes quite a long time to find the answer. Therefore, the proposed method is not suitable for use in the operation.

From the presentation of various methods in this thesis, the proposed mixed-integer particle swarm optimization for DSDLM can successfully identify optimal placement and scheduling of BESS. the break-even analysis of installing BESS has not been considered get in this investigation. Therefore, the finding a better way to get answers is challenging.

The optimal sizing using MIPSO will be added to this further work. Therefore, the installing and operation cost of BESS will be considered. The high cost of BESS necessitates the development of a techno-economic solution. The proposed method will factor in the cost of installing BESS as well as system daily loss reduction, which this investigate be used in the future development of smart grid systems.

From the scheduling of this thesis, we observe that the charging behavior of a battery energy storage system either stores energy or releases energy depending on the daily load usage, as well as considering the power generation of solar energy is managed every hour (24 hours). In fact, if the battery energy storage system is operated too often, it will affect the life cycle of BESS. As a consequence, recommendations for further research into this problem are offered. A BESS daily charge and discharge limits must be considered. In order to extend the life of BESS.

For other possible further researches, The MIPSO techniques for scheduling BESS will searched additional methods that can leveling load curve to be as smooth as possible. To give more credibility, this approach will be applying other systems, such as IEEE distribution 10 bus system, IEEE distribution 69 bus system, Thailand power system.

Finally, in this thesis, the BESS can effectively reduce the energy losses in the electrical system. In addition, other benefits of BESS have several advantages, such as helping increase the minimum voltage profile of each bus, decreasing energy demand during peak periods, reducing the effects of pressure ripples in renewable energy systems, and reducing the cost of power generation for other fuel energy. Therefore, further research related to energy storage systems can use these benefits to determine a problem in making assumptions. Finally, this proposed method can be developed and used in the study for the maximum benefit of these problems.

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APPENDIX A : Parameter Data

APPENDIX A : Parameter Data

A.1 IEEE 33 bus radial distribution test system

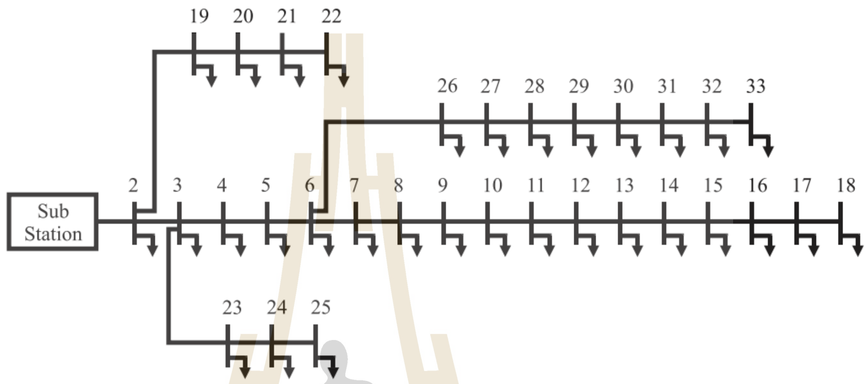

Figure A.1 The IEEE 33 bus system network diagram

Table A.1 Transmission line data

Line No.	Line Bus	Line Bus i+1	Line Resistance R(Ω)	Line Reactance R(Ω)	Real Load Power (kW)	Reactive Load Power (kvar)
1	1	2	0.0922	0.0477	100	60
2	2	3	0.4930	0.2511	90	40
3	3	4	0.3660	0.1864	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.8190	0.7070	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	1.7114	1.2351	200	100
8	8	9	1.0300	0.7400	60	20
9	9	10	1.0400	0.7400	60	20
10	10	11	0.1966	0.0650	45	30

Table A.1 Transmission line data (Cont.)

Line No.	Line Bus	Line Bus i+1	Line Resistance R(Ω)	Line Reactance R(Ω)	Real Load Power (kW)	Reactive Load Power (kvar)
11	11	12	0.3744	0.1238	60	35
12	12	13	1.4680	0.1550	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.5910	0.5260	60	10
15	15	16	0.7463	0.5450	60	20
16	16	17	1.2890	1.7210	60	20
17	17	18	0.7320	0.5740	90	40
18	2	19	0.1640	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	50
23	23	24	0.8980	0.7091	420	200
24	24	25	0.8960	0.7011	420	200
25	6	26	0.2030	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.0590	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.9630	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.3410	0.5302	60	40

A.2 The objective function is used to compare results in Chapter 4

Minimize:

$$C(Q) = K_p \times t \times P_{Loss}(Q) + K_{ic} \times N_q + \sum_{j=1}^{n} Q_j \times k(Q_j) \qquad \text{(A.1)}$$

Subject to $Q_j \in \{350, 600, 1050\}$

Where

$C(Q)$ is the total cost (\$),

K_p is cost for unit of power loss (\$/kW),

t is the time per hour,

$P_{Loss}(Q)$ is the total power loss (kW),

K_{ic} is installation cost of CB (\$),

N_q is the number of compensation capacitors to install,

Q_j is the size of the shunt capacitor (kvar),

$k(Q_j)$ is cost per unit of reactive power (\$/kvar).

Table A.2 Parameter for objective function

Parameters	
Kp	\$0.06
kc	-
t	8760 h
Kic	\$1,000
Kc	\$3,000

Table A.3 Parameter of PV stations

Time (Hr)	Irradiance(W/m2)			PV Generation(kW)		
	Summer	Rainy	Winter	Summer	Rainy	Winter
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0.54	2.49	0.54	0.10	0.50	0.11
6	77.30	110.44	75.86	13.76	22.30	15.42
7	458.69	495.53	455.90	81.67	100.08	92.64
8	1105.71	1073.61	1058.93	196.88	216.82	215.18
9	1814.34	1687.10	1753.86	323.05	340.72	356.39
10	2319.94	2127.65	2277.43	413.07	429.69	462.78
11	2668.50	2406.99	2445.47	475.14	486.11	496.92
12	2808.15	2475.77	2460.62	500.00	500.00	500.00
13	2721.61	2397.90	2262.18	484.59	484.27	459.68
14	2356.11	2030.01	1819.18	419.51	409.98	369.66
15	1792.96	1513.48	1332.67	319.24	305.66	270.80
16	1089.99	913.52	749.63	194.08	184.49	152.33
17	396.65	405.18	214.69	70.62	81.83	43.63
18	26.88	56.09	4.33	4.79	11.33	0.88
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0

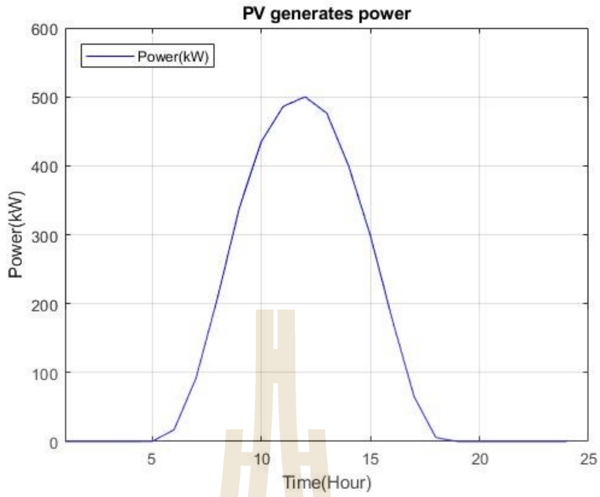

Figure A.2 The PV station output power

A.4 Thailand daily load profile

Table A.4 Summer Load Profile (14 APR 18)

Hour	Thailand Requirement in Summer Season			
	North	Northeastern	Central	South
1	1593.62	1880.87	11278.98	1579.15
2	1507.27	1750.59	10831.72	1524.33
3	1424.87	1675.18	10532.93	1483.69
4	1359.70	1596.66	10078.84	1448.61
5	1371.89	1613.14	10001.64	1453.75
6	1488.18	1772.07	10026.40	1507.66
7	1350.28	1639.03	9406.19	1536.55
8	1263.90	1534.57	9361.09	1522.21
9	1319.50	1532.03	10067.87	1537.27
10	1364.26	1544.57	10504.09	1553.15
11	1396.73	1552.49	10806.21	1546.54
12	1409.52	1591.26	10777.75	1533.73
13	1444.37	1643.73	10682.74	1515.53
14	1494.47	1694.42	10878.81	1528.86
15	1535.29	1760.31	11066.34	1526.26
16	1550.05	1787.08	11105.43	1534.13
17	1536.37	1784.87	10609.08	1555.24
18	1555.67	1902.98	10758.23	1636.02
19	1888.74	2651.18	11968.33	1963.81
20	2254.55	2985.31	13084.23	2016.62
21	2269.22	2894.84	12937.24	1958.00
22	2156.07	2744.23	12641.72	1867.55
23	2009.34	2525.21	12040.17	1753.39
24	1820.74	2289.32	11285.25	1639.10

Table A.5 Rainy Load Profile (9 Sep 18)

Hour	Thailand Requirement in Rainy Season			
	North	Northeastern	Central	South
1	1933.78	2160.38	14664.72	2020.68
2	1861.56	2096.96	14364.83	1939.07
3	1809.93	2018.99	13876.79	1876.22
4	1748.46	1957.19	13609.82	1827.51
5	1768.71	1960.82	13271.60	1835.42
6	1935.97	2112.11	13317.12	1903.94
7	1874.19	1982.91	12862.19	1827.27
8	1765.97	1945.16	12551.86	1801.04
9	1835.87	1961.27	12963.85	1933.05
10	1877.09	1973.50	13232.26	2027.92
11	1878.91	2002.63	13201.59	2081.10
12	1906.25	1960.74	12855.26	2073.37
13	1972.71	1938.48	12823.84	2058.35
14	2035.56	2007.37	13429.37	2107.78
15	2109.41	2045.12	13571.37	2122.55
16	2061.53	2073.29	13657.42	2096.86
17	1997.21	2094.57	13536.75	2034.79
18	2045.05	2188.66	13537.63	1917.05
19	2341.68	2721.68	14443.86	2207.69
20	2698.54	2998.86	15185.15	2407.51
21	2655.23	2870.52	15463.69	2388.21
22	2440.53	2669.00	15189.12	2307.97
23	2184.39	2415.89	14632.31	2191.48
24	1994.56	2217.87	13909.41	2040.70

Table A.6 Winter Load Profile (1 Jan 18)

Hour	Thailand Requirement in Winter Season			
	North	Northeastern	Central	South
1	874.60	1273.41	8892.85	1556.95
2	899.71	1143.61	8709.99	1502.85
3	865.94	1093.95	8531.20	1456.55
4	841.67	1094.84	8260.11	1429.90
5	941.62	1164.12	8261.01	1433.50
6	1035.45	1413.53	8334.40	1491.00
7	1110.04	1458.50	8283.36	1537.70
8	1025.53	1282.06	8239.78	1495.20
9	902.29	1042.54	8364.72	1529.85
10	885.23	975.12	8290.25	1565.50
11	902.00	956.11	8061.55	1569.00
12	959.99	979.44	7967.02	1540.55
13	977.71	1003.30	8026.34	1526.40
14	978.83	1021.54	8172.78	1523.00
15	986.57	1172.97	8343.47	1521.65
16	1111.31	1296.23	8735.01	1529.65
17	1308.14	1450.17	9077.30	1535.80
18	1564.07	1927.89	9821.21	1628.00
19	1906.80	2281.48	10965.55	2025.10
20	1829.91	2127.46	10730.70	2007.00
21	1663.43	1871.83	10635.05	1941.25
22	1414.44	1681.00	10364.48	1854.75
23	1248.48	1504.94	10087.38	1754.65
24	1109.74	1354.05	9705.36	1616.90

APPENDIX B : List of Publications

List of Publications

K. Kaiyawong and K. Chayakulkheeree (2020), Optimal Energy Storage System Scheduling for Distribution System Daily Loss Minimization Using Particle Swarm Optimization, **The 43rd Electrical Engineering Conference (EECON-43)**, Phitsanulok, Thailand, pp 57-60.

K. Kaiyawong and K. Chayakulkheeree (2022), Coordinated Optimal Placement of Energy Storage System and Capacitor Bank Considering Optimal Energy Storage Scheduling for Distribution System Using Mixed-Integer Particle Swarm Optimization, **International Journal of Intelligent Engineering and Systems**, pp 329-337.

Optimal Energy Storage System Scheduling for Distribution System Daily Loss Minimization Using Particle Swarm Optimization

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Abstract

This paper proposes a particle swarm optimization (PSO) approach for optimal scheduling energy storage system (ESS) in electrical distribution network (EDNs) for minimizing power loss. The continued development in ESS technologies has introduced new possible applications for EDNs. The distribution system daily loss minimization (DSDLM) algorithm had been tested with IEEE 33 buses system. The simulation result shown that the proposed algorithm can efficiently minimize the total daily loss by considering ESS scheduling.

Keywords: particle swarm optimization, daily loss minimization, energy storage system.

1. Introduction

Nowadays, the demand for electricity is increasing day by day, there are fluctuations in energy consumption in power delivery during the day. Therefore, the reduction in power loss is very important for the system to operate economically and reliably. Thereby, energy storage system (ESS) can play a vital role in overcoming these problems and appears to be a crucial part of the future smart grids. When properly allocated, ESS provide benefit in significant reductions on power loss.

Many researches have been done under the objective of minimizing power loss in power delivery. Many methods have been proposed, such as, Particle Swarm Optimization (PSO) [1-4], STATCOM [5], Soft Open Point (SOP) [6], Locust Search (LS) [7], Fuzzy Multi-objective Formulation and Genetic Algorithm (GA) [8] to obtain the power system real power loss minimization. Among these stochastic optimization methods, PSO is a famous stochastic base optimization technique [9], inspired by social of behavior of bird flocking or fish schooling. PSO was proven to be one of the best stochastic optimization method for several problems. The research investigation for optimal ESS scheduling using PSO is, therefore, benefit to power distribution system operation.

In this paper, an optimal energy storage system scheduling (OESSS) for distribution system daily loss minimization (DSDLM) is proposed. The proposed OESSS is solved by PSO and tested with the 33 bus distribution test system. The propose method resulted in the minimal daily loss of distribution system with OESSS.

The organization of this paper is as follows. Section 2. addresses the DSDLM problem formulation. PSO for solving the DSDLM problem is given in Section 3. The simulation result on the radial distribution IEEE 33 bus system are illustrated in Section 4. Lastly, the conclusion is given in Section 5.

2. Problem Formulation

In the problem formulation, the objective function distribution system daily loss minimization (DSDLM) problem is formulated as,

minimize $$P_{loss,Total} = \sum_{h=1}^{24} P_{loss}^h, \quad (1)$$

where,

$$P_{loss}^h = \sum_{i=1}^{NB} \sum_{\substack{j=1 \\ j \neq i}}^{NB} G_{ij} \left[\left(V_i^h\right)^2 + \left(V_j^h\right)^2 - 2V_i^h V_j^h \cos(\delta_i^h - \delta_j^h) \right],$$
$$h = 1,...,24, \quad (2)$$

subject to the power balance constraints,

$$P_{Gi}^h - P_{Di}^h + C_{ess,i}^h = \sum_{j=1}^{NB} |V_i^h||V_j^h||y_{ij}| \cos(\theta_{ij} - \delta_{ij}^h), \quad (3)$$

$i = 1,..., NB, h = 1,..., 24,$

$$Q_{Gi}^h - Q_{Di}^h + C_{ess,i}^h = -\sum_{j=1}^{NB} |V_i^h||V_j^h||y_{ij}| \sin(\theta_{ij} - \delta_{ij}^h), \quad (4)$$

$i = 1,.., NB, h = 1,..., 24,$

and line flow limit constraints,

$$|f_i^h| \le f_i^{h,\max}, \text{for } i = 1,...NL,\ h = 1,\ldots,24, \quad (5)$$

and real power generation constraint,

$$P_{Gi}^{h,\min} \le P_{Gi}^h \le P_{Gi}^{h,\max}, \text{ for } i = 1,...,NL,\ h = 1,\ldots,24, \quad (6)$$

and reactive power generation constraints,

$$Q_{Gi}^{h,\min} \le Q_{Gi}^h \le Q_{Gi}^{h,\max}, \text{ for } i = 1,...,NL,\ h = 1,\ldots,24, \quad (7)$$

and bus voltage limit constraint,

$$\left|V_i^{h,\min}\right| \le \left|V_i^h\right| \le \left|V_i^{h,\max}\right|, \text{ for } i = 1,...,NL,\ h = 1,\ldots,24, \quad (8)$$

and power factor load curve calculator,

$$(P.F.)^h = \frac{P_{loadth}^h}{P_{loadth,\max}^h}, \text{ for } h = 1,\ldots,24, \quad (9)$$

and new load curve calculator,

$$P_{load}^{h,new} = P_{load}^{h} \times (P.F.)^{h}, \text{ for } h = 1,\ldots,24, \quad (10)$$

and capacity of energy storage system limit constraint,

$$ES_i^h = \left[ES_i^1, \ldots, ES_i^h, \ldots, ES_i^{24}\right], h = 1,\ldots,24, i = 1,\ldots,NL, \quad (11)$$

$$0 \le ES_i^h \le ES_i^{h,\max}, h = 1,\ldots,24, i = 1,\ldots,NL, \quad (12)$$

$$C_{ess,i}^h = \left[C_{ess,i}^1, \ldots, C_{ess,i}^h, \ldots, C_{ess,i}^{24}\right], h = 1,\ldots,24, i = 1,\ldots,NL, \quad (13)$$

$$0 \le C_{ess,i}^h \le C_{ess,i}^{h,\max}, h = 1,\ldots,24, \; i = 1,\ldots,NL, \quad (14)$$

$$C_{ess,i}^h = \begin{cases} ES_i^1, & h=1 \\ ES_i^h - ES_i^{h-1}, & h=2,\ldots,24 \end{cases}, i = 1,\ldots,NL. \quad (15)$$

Therefore, if $C_{ess,i}^h < 0$, the ESS is in discharging condition, if $C_{ess,i}^h > 0$, the ESS is in charging condition.

Where,

P_{loss} is the daily loss (kWh),
P_{loss}^h is the hourly loss in each hour (kW),
f_i^{max} is the limit of line flow (MVA),
f_i^h is the MVA flow of line i (MVA) in each hour,
G_{ij} is the conductance of the lines between bus i and bus j for $j \neq i$,
NG is total number of generators,
NB is the total number of buses,
P_{Di}^h is real power at bus i (kW) in each hour,
P_{Gi}^h is the real of power generator connected bus i (kW) in each hour,
P_{Gi}^{max} is the maximum real power generation at bus i (kW) in each hour,
Q_{Gi}^h is the reactive power generator at bus i (kVAR) in each hour,
Q_{Di}^h is the reactive power demand at bus i (kVAR),
$|V_i|^h$ is the voltage magnitude of bus i (p.u.) ,
V_i^h is the voltage of bus i (p.u.) in each hour,
$|y_{ij}|$ is the magnitude of the y_{ij} element of Y_{bus} (mho),
θ_{ij} is the angle of the y_{ij} element of Y_{bus} (radian),
δ_{ij}^h is the voltage angle difference between bus i and j (radian) in each hour ,
$P.F.$ is power facter load curve ,
P^h_{load} is real power of distribution system (kW),
P^h_{loadth} is real power from the Electricity Generating Authority of Thailand data in each hour (kW),
ES_i^h is capacity of ESS in each hour (kW), and
$C_{ess,i}^h$ is scheduling of ESS in each hour (kW).

3. PSO based OESSS for DSDLM

In the proposed method, the OESSS for DSDLM is solved by PSO. In PSO system, the computation can be explain as follow, [9],

$$v_i^{t+1} = wv_i^t + c_1r_1(pbest_i^t - p_i^t) + c_2r_2(gbest^t - p_i^t), \quad (16)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1}, \quad (17)$$

where,

w is the inertia weight factor,
c_1,c_2 are the acceleration constants,
r_1,r_2 are the uniform random values,
t is the number of iteration,
v is the velocity of particle,
x is the position of particle,
$pbest$ is the best particle position,
$gbest$ is the best group position, and
p is the particle.

In order to obtain DSDLM, The $C_{ess,i}^h$ in Eq.(13) is used as each particle in Eq.(16), the best value is a scheduling of ESS is call *gbest*. The load flow analysis is preform and the daily loss is used as the objective function in Eq.(1), the best value is a daily loss minimize best is call *pbest*. The DSDLM problem computational procedure can be illustrated as in Fig1.

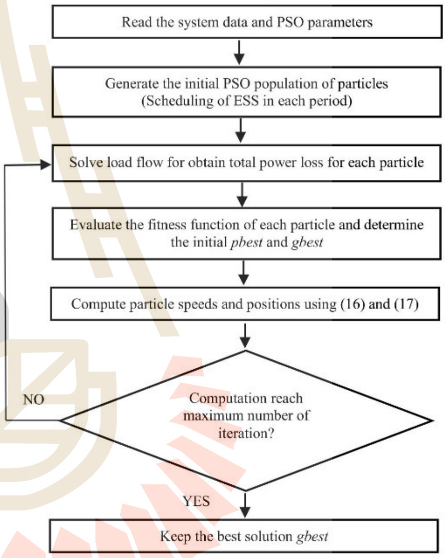

Fig 1. The DSDLM problem Computational Procedure

4. Simulation Results

The proposed PSO based DSDLM has been verified on the radial distribution IEEE 33 buses shown in Fig 2. The system line data and bus data were obtained from [7], The Thailand daily load curve on 14 April 2018, which is annual peak day, is used as the system load profile. The result are shown in Tables 1 and 2 and Figs 3-6. The simulation study includes,

Case 1: Without ESS,
Case 2: The simple ESS operation, and
Case 3: PSO based OESSS for DSDLM.

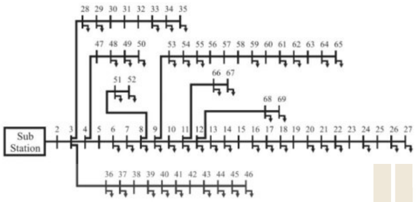

Fig 2.Radial distribution IEEE 33 buses test system

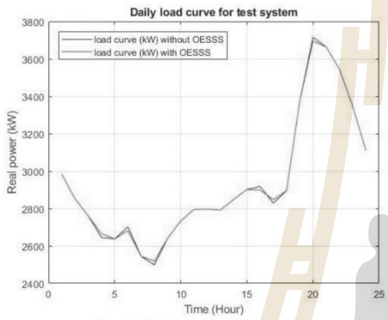

Fig 3. Daily load curve for test system

Table 1 The hourly loss of IEEE 33 bus system for Cases 1-3

Time(Hr)	Ploss(kW)			Time(Hr)	Ploss(kW)		
	Case 1	Case 2	Case 3		Case 1	Case 2	Case 3
01:00	131.7	131.7	131.7	13:00	114.5	114.5	114.5
02:00	119.7	119.7	119.7	14:00	119.5	119.5	119.5
03:00	111.8	111.8	111.8	15:00	124.2	124.2	124.2
04:00	102.1	102.1	104.6	16:00	125.7	125.7	122.9
05:00	101.5	101.5	101.5	17:00	117.7	117.7	120.4
06:00	106.8	106.8	104.3	18:00	123.7	123.7	123.7
07:00	94.1	94.1	94.1	19:00	171.4	171.4	171.4
08:00	90.6	92.8	92.8	20:00	211.0	205.9	205.9
09:00	101.7	101.7	101.7	21:00	204.7	204.7	204.7
10:00	109.5	109.5	109.5	22:00	190.7	190.7	190.7
11:00	114.7	114.7	114.7	23:00	168.5	168.5	168.5
12:00	114.9	114.9	114.9	24:00	144.1	144.1	144.1

Table 2 The daily loss when install ESS at each bus using simple ESS operation of IEEE 33 bus system

From Bus	Ploss (kWh)	From Bus	Ploss (kWh)	From Bus	Ploss (kWh)
1	3114.8	12	3112.3	23	3114.2
2	3114.7	13	3112.1	24	3114.0
3	3114.3	14	3112.0	25	3114.6
4	3114.1	15	3112.0	26	3113.2
5	3113.8	16	3112.0	27	3113.1
6	3113.3	17	3112.0	28	3112.8
7	3113.2	18	3111.9	29	3112.5
8	3112.8	19	3114.7	30	3112.4
9	3112.6	20	3114.7	31	3112.2
10	3112.4	21	3114.6	32	3112.2
11	3112.4	22	3114.6	33	3112.2

Table 1 illustrates the hourly loss, the result shown the system daily loss without energy storage system (Case 1) is 3114.8 kWh.

The simple ESS operation (Case 2), sets the period for the energy storage system to charge energy during specific periods of time during minimal load requirements and discharge the energy back to the system during peak hour.

In this paper, the 20 kW ESS is used to test the proposed algorithm. The location of the ESS was investigated by solving for minimum daily loss as shown in Table 2. Bus number 18 was chosen for install the ESS, due to minimum daily loss with simple ESS operation, of 3111.9 kWh.

The PSO parameters, are as follow,

$c_1 = 2$,
$c_2 = 2$,
$w_{min} = 0.9$,
$w_{max} = 0.4$,
population size = 600, and
maximum iteration = 20.

The best OESSS for DSDLM using PSO solution are shown in Figs 4-6.

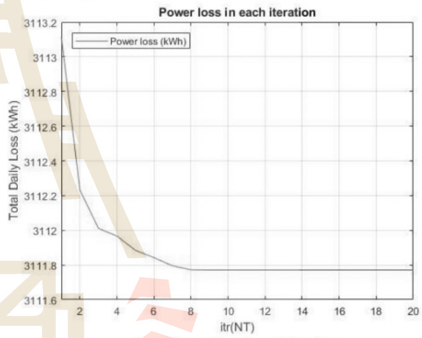

Fig 4. Power loss in each iteration

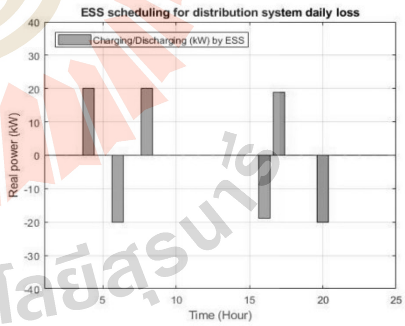

Fig 5. ESS scheduling for distribution system daily loss

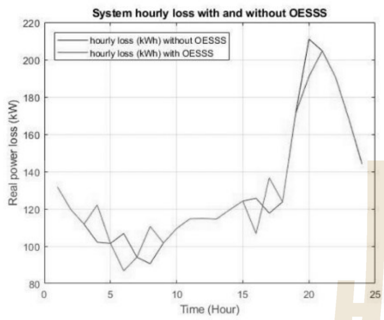

Fig 6. System hourly loss with and without OESSS

With the proposed PSO based OESSS for DSDLM (Case 3), the daily loss of IEEE 33 bus test system is reduced to 3111.77 kWh, lower than that of without ESS (Case 1) and the simple ESS operation (Case 2).

Therefore, the proposed method is efficiency minimize the daily loss at distribution system by scheduling the ESS.

5. Conclusion

In this paper, the PSO based OESSS for DSDLM is proposed and investigated. The total real power loss can be minimized successfully. The results have shown that distribution system daily loss minimization problem can be efficiently solved, the results reveal the scheduling of energy storage to supply the prosumers during peak load that lead to energy savings because energy is not supplied from the system and the losses are reduced. Therefore, the energy storage system can be an option to be installed in the system in order to help save energy in the long run.

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Biography

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Coordinated Optimal Placement of Energy Storage System and Capacitor Bank Considering Optimal Energy Storage Scheduling for Distribution System Using Mixed-Integer Particle Swarm Optimization

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Abstract: This paper proposes a mixed-integer particle swarm optimization (MIPSO) for coordinated optimal placement of energy storage system (ESS) and capacitor bank (CB). In the propose method, optimal ESS scheduling (OESSS) is solved by particle swarm optimization (PSO), as a subproblem, the optimal coordinated placement (COP) for ESS and CB, simultaneously. The distribution system annual loss minimization (DSALM) is used as the objectives of COP problem. The proposed method was tested with the IEEE 33-bus radial distribution test system. The results demonstrated that the proposed method is successful and robust in minimizing system losses, which loss saving of 35.12% when compare to the based case, which is the best solution among other existing methods.

Keywords: Optimal placement, Optimal scheduling, Minimize power loss, Energy storage system, Capacitor bank.

1. Introduction

Nowadays, in distribution system, day-to-day fluctuations in power consumption. distributed high, resulting in significant power loss in the system. Therefore, a reduction in power loss and improved voltage are very important for the electrical distribution power systems (EDPs) to reduce energy consumption and operating costs. This problem can be solved by installing capacitor bank (CB) to compensate for reactive power and power consumption variations that can be managed with an energy storage system (ESS).

A number of methods have been presented with the purpose of reducing power loss and improving voltage in electrical power systems. such as, distribution system reconfiguration using modified particle swarm optimization (MPSO) [1], Soft Open Point (SOP) which is a type of power electrical component which can be used to replace traditional switches or normally open points (NOP) in network distribution was proposed in [2]. In [3], parameter improved particle swarm optimization (PIPSO) is solver for optimal sizing and placement of a distributed generation (DG), this paper integrating real power supporting of DG with IEEE 33 bus and 69 bus radial distribution network. CB has been used to solve optimal dispatch problem for reactive power in [4]. Particle swarm optimization (PSO) was utilized to test a power system to reduction in a power loss in [5]. In other system of this challenge, [6] calculated the operation of CB and tap-changing transformer using the Newton-Raphson load flow technique. When minimizing power loss is integrated with other aims, such as controlling voltage drop in the electrical system, fuzzy multi-objective optimization has been used genetic algorithms (GA) for control device in power system [7]. These methods, aimed at minimizing real power loss.

Optimal placement of CB is a method of locating the proper CB installation for the electrical system's best benefit. The capacitor placement challenge is a very well-known topic that has been discussed by a number of authors in the past, such as, genetic algorithm method [8, 9], the sperm whale algorithm (SWA) [10], moth-flame optimization algorithm [11] and complex calculation methods like fuzzy logic

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control (FLC) [12], these methods are used for reduce power loss, improve the voltage profile but not considering operation cost. In addition to other considerations, the cost of installing and operating capacitors will be considered, such as cuckoo search algorithm (CSA) [13], locust search method (LS) [14], particle swarm optimization (PSO) [15, 16], genetic algorithm (GA) [17], and hybrid approach of PSO-GA [18]. All the above methods can efficiently reduce the operating cost of the installed capacitor bank in the distribution system. [19] determining the size and location of reactive power compensation integrated with hydro power distributed generation into the power system. In the presence of distributed solar power generation (PV), [20] develop a model of a specific distribution system to select the appropriate capacity and location sets of newly installed CB, these prove that capacitors can be used in conjunction with EDPs for minimize power loss.

Similar to other resources, ESS can be solved in a multitude of situations, including optimizing capacity, increasing stability, balancing supply fluctuations, satisfying a load demand. However, under or over-voltage in the distribution system can be caused by inappropriate ESS allocation and sizing. Therefore, optimal placement of ESS (OPESS) is important for planning location and sizing of ESS, to maximize the benefits from ESS. Many research's used OPESS for integrating renewable energy sources (RER). For examples, [21] propose a wind generator with ESS to improve voltage profile and system loss using the PSO algorithm for optimal placement in the 34-bus unbalanced system. Some researches focus on integrating ESS with power PV station, such as, the optimal siting of battery energy storage system (BESS) in distribution network is solved by PSO to minimize the energy losses of the system [22, 23]. With similar objective function, [24-26] developed the GA optimization method to reduce daily loss and peak demand by PV stations while deploying ESS, but the cost of installing ESS is not considered. With the same concept, [27] developed a GA optimization approach for minimizing voltage fluctuations induced by PV penetration by distributing BESS across permitted nodes of a distribution system while considering for capital, land-of-use, and installation costs with a qualitative cost model. Therefore, OPESS can efficiently locate and install ESS to benefit the system.

In addition to finding the proper installation location for ESS, optimal scheduling of energy storage systems is also important for day-to-day operation. [28] presented a model based on LaGrange relaxation and tests with the IEEE 37 bus considering reshaping the load curve when using ESS. [29] used the exchange market algorithm (EMA), when ESS is installed with RER uncertainty. The 24-hour optimal scheduling for ESS using load forecasting and RER is developed in [30, 31] with prediction of the load forecast and operation time of PV in the short term. All of the above method confirms that ESS can manage energy allocation at various periods of the day to reduce power loss or peak demand load. However, the break-even point of today's ESS deployments isn't worth contemplating. Thereby, the high cost of ESS poses severe concerns, necessitating the development of cost-effective alternatives [32]. In addition, the optimal placement of ESS can be gain more benefit when incorporation the problem with CB placement.

Most of researches on optimal CB placement solve the total loss minimization using single loading condition. Meanwhile, the optimal scheduling of ESS is solved without optimal allocation. Therefore, this paper proposed the method for solving the optimal placement of CB and ESS, simultaneously, considering optimal scheduling of ESS.

In this paper, coordinated optimal placement problem (COPP) of ESS and CB considering optimal ESS scheduling (OESSS) for distribution system annual loss minimization (DSALM) is proposed. The proposed method used the mixed-integer particle swarm optimization (MIPSO) to optimal placement of ESS and CBs, while OESSS is solved by PSO [33]. Thailand's power system load profile was used to verify the proposed method in the radial IEEE 33-bus distribution test system. The results shown that the proposed method can successfully provide optimal ESS and CB allocation.

In this paper, the COPP formulation is addressed in Section 2. Section 3 presents a MIPSO approach to the COPP. Section 4 shows the results of the radial distribution IEEE-33 bus test system. Lastly, Section 5 address the conclusion.

2. Problem formulation

The proposed method includes coordinated optimal placement problem (COPP) formulations considering daily ESS scheduling using MIPSO algorithm. The structure of a distribution grid typically includes active and reactive resources such as, bulk power systems, ESS, CB, and load demand, as shown in Fig. 1.

The objective function of COPP is formulated as follows:

Minimize

$$AAL = DP_{loss,total}(\boldsymbol{C_{ess}^{h}}, \boldsymbol{CBS}, \boldsymbol{B}), \qquad (1)$$

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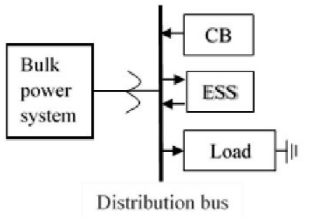

Figure. 1 A structure of distribution system with CB and ESS

for ESS and CB connected to bus **B** with state of charge $\mathbf{C}^h_{ess}$ and compensated from **CBS**.

The considered time interval is one day (24 hour),

$$P_{loss,total} = \sum_{h=1}^{24} P_{loss}^h, \quad (2)$$

where,

$$P_{loss}^h = \sum_{i=1}^{NB} \sum_{\substack{j=1 \\ j \neq i}}^{NB} G_{ij} \left[\left(V_i^h\right)^2 + \left(V_j^h\right)^2 - 2V_i^h V_j^h \cos(\delta_i^h - \delta_j^h) \right],$$
$$\text{for } i,j = 1, \ldots, NB, h = 1, \ldots, 24, \quad (3)$$

Subject to the power balance constraints,

$$P_{Gi}^h - P_{Di}^h + \left(C_{ess,i}^h \times \left(\frac{\eta_c}{\eta_d} \right) \right) = \sum_{j=1}^{NB} |V_i^h||V_j^h||y_{ij}| \cos(\theta_{ij} - \delta_{ij}^h),$$
$$\text{for } i = 1, \ldots, NB, h = 1, \ldots, 24, \quad (4)$$

$$Q_{Gi}^h - Q_{Di}^h - cbs_i = -\sum_{j=1}^{NB} |V_i^h||V_j^h||y_{ij}| \sin(\theta_{ij} - \delta_{ij}^h), \text{for } i = 1, \ldots, NB, h = 1, \ldots, 24, \quad (5)$$

Line flow limit constraints,

$$|f_i^h| \leq f_i^{max} \quad , \text{for } i = 1, \ldots, NL, h = 1, \ldots, 24, \quad (6)$$

Power generation constraint,

$$P_{Gi}^{min} \leq P_{Gi}^h \leq P_{Gi}^{max} \quad ,$$
$$\text{for } i = 1, \ldots, NG, h = 1, \ldots, 24, \quad (7)$$

$$Q_{Gi}^{min} \leq Q_{Gi}^h \leq Q_{Gi}^{max} \quad ,$$
$$\text{for } i = 1, \ldots, NG, h = 1, \ldots, 24, \quad (8)$$

Bus voltage limit constraint,

$$|V_i^{min}| \leq |V_i^h| \leq |V_i^{max}|,$$
$$\text{for } i = 1, \ldots, NB, h = 1, \ldots, 24. \quad (9)$$

The reactive power generation of CB can be represented as,

$$\boldsymbol{CBS} = [cbs_1, cbs_2, \ldots, cbs_i, \ldots, cbs_{NCB}],$$
$$\text{for } i = 1, \ldots, NCB. \quad (10)$$

The energy capacity, as well as the capacity for power charging and discharging, are all included in this paper's ESS model. [31] shows the efficiency of charging and discharging represented by [34],

$$\boldsymbol{ES} = [ES_i^1, \ldots, ES_i^h, \ldots. ES_i^{24}],$$
$$\text{for } i = 1, \ldots, NESS, h = 1, \ldots, 24, \quad (11)$$

$$0 \leq ES_i^h \leq ES_i^{h,max}$$
$$\text{for } i = 1, \ldots, NESS, h = 1, \ldots, 24, \quad (12)$$

$$\boldsymbol{C_{ess}} = \left[C_{ess,i}^1, \ldots, C_{ess,i}^h, \ldots C_{ess,i}^{24}\right]$$
$$\text{for } i = 1, \ldots, NESS, h = 1, \ldots, 24, \quad (13)$$

$$C_{ess,i}^{h,min} \leq C_{ess,i}^h \leq C_{ess,i}^{h,max}$$
$$\text{for } i = 1, \ldots, NESS, h = 1, \ldots, 24, \quad (14)$$

$$C_{ess,i}^h = \begin{cases} ES_i^1, h=1 \\ ES_i^h - ES_i^{h-1}, h=2,\ldots,24 \end{cases}$$
$$\text{for } i = 1, \ldots, NESS, h = 1, \ldots, 24. \quad (15)$$

In this paper, if $C^h_{ess,i} < 0$, the ESS is in discharging condition, if $C^h_{ess,i} > 0$, the ESS is in charging condition.

The initial set of particles for bus that connected with ESS and CB as,

$$\boldsymbol{B} = [b_1, \ldots, b_i, \ldots, b_{NESS+NCB}]^T,$$
$$\text{for } 1 \leq b_i \leq NB, \quad (16)$$

$$b_i \in \{\text{integer}\},$$
$$i = 1, \ldots, (NESS + NCB). \quad (17)$$

where,

AAL is average annual loss (kWh),
D is number of days,
$P_{loss,total}$ is the total daily loss,
$P_{loss}{}^h$ is the hourly loss in each hour,
G_{ij} is the conductance of the lines between bus i and bus j for $j \neq i$,
$V_{ij}{}^h$ is the voltage of bus i,j in each hour,
$\delta_{ij}{}^h$ is the voltage angle difference between bus i and j in each hour,
$P_{Gi}{}^h$ is active power of generator connected bus i in each hour,
$P_{Gi}{}^{min}$ is minimize active power generation,
$P_{Gi}{}^{max}$ is maximum active power generation,

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Q_{Gi}^{h} is reactive power of generator connected bus i in each hour,
Q_{Gi}^{min} is minimize reactive power generation,
Q_{Gi}^{max} is maximum reactive power generation,
f_i is the MVA flow of line i in each hour is f_i^{h},
f_i^{max} is the limit of line flow (MVA),
$|V_i|^{h}$ is the voltage magnitude of bus i,
$|V_i|^{min}$ is minimum voltage magnitude for bus i,
$|V_i|^{max}$ is maximum voltage magnitude for bus i,
$|y_{ij}|$ is the magnitude of the y_{ij} element of Y_{bus}.,
θ_{ij} is the angle of the y_{ij} element of Y_{bus},
NB is the total number of buses,
NG is the total number of generators,
NL is the total number of lines,
CBS is the matrix representing size of CB,
cbs_i is the size of CB to be installed,
NCB is the total number of CB in the system,
ES is the matrix representing capacity of ESS,
ES_i^{h} is the capacity of i^{th} ESS at hour h,
$\mathbf{C}_{ess}$ is the matrix of charge/discharge by ESS,
$C^{h}_{ess,i}$ is charge/discharge of i^{th} ESS at hour h,
η_c, η_d are the charging and discharging efficiency,
$NESS$ is the total number of ESS in the system,
B is the matrix representing bus number with ESS and CB,
b_i is the bus number connected ESS and CB.

3. MIPSO based COPP algorithm

In this paper, the set of particles for bus number connected with ESS (**B**) in Eq. (16) was rounded to identify the location of ESS and CBs using Eq. (17). Subsequently, initial set of particles for schedule is obtained by Eqs. (11) to (15).

The schedule of $\mathbf{C}^{h}_{ess}$ in Eq. (15) is obtained by PSO. $\mathbf{C}^{h}_{ess}$ and **CBS** in Eq. (10) are used for obtain *AAL* in Eq. (1), the scheduling and placement were update position by PSO [33]. The annual loss is utilized as the objective function in Eq. (1), which is based on the load flow analysis. The minimum value of *AAL* among all particles is called *gbest*, and the minimum *AAL* of individual *ith* particle is called *pbest*. The COPP computational procedure as shown is Fig. 2.

4. Result and discussion

The proposed MIRPSO based COPP has been verified on the IEEE 33-bus radial distribution test system shown in Fig. 3. The system line data and bus data were obtained from [14].

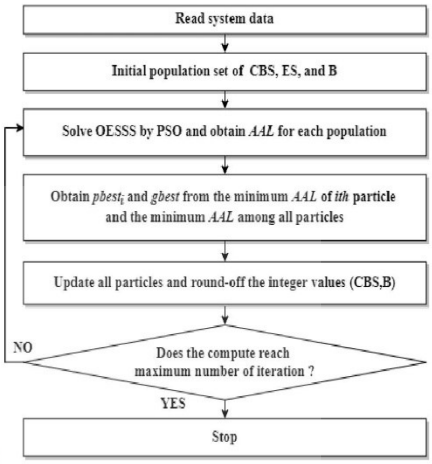

Figure. 2 The COPP computational procedure

The Thailand daily load curve on 14 April 2018, shown in Fig. 4. which is annual peak day, is used as the system load profile.

The simulation study includes,
Case 1: Reference case (without ESS and CBs),
Case 2: Optimal placement of ESS,
Case 3: Optimal placement of CBs,
Case 4: COPP of ESS and CBs.

4.1 Reference case (without ESS and CBs)

In this case, the IEEE 33-bus radial distribution test system without energy storage system and capacitor bank was solved by Newton-Raphson power flow for obtain *AAL*. The result illustrates the system average annual loss without capacitor bank and energy storage system is 129.78 kWh. The result *AAL* in this case used to compare with other cases.

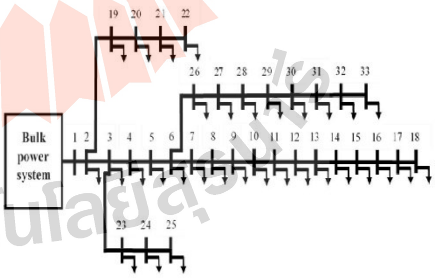

Figure. 3 IEEE 33-bus radial distribution test system

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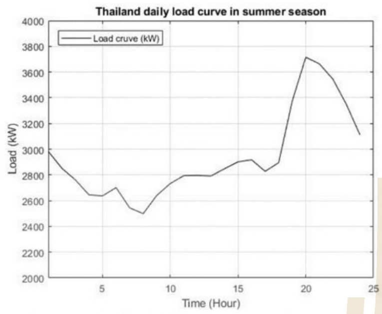

Figure. 4 Thailand daily load curve for test system

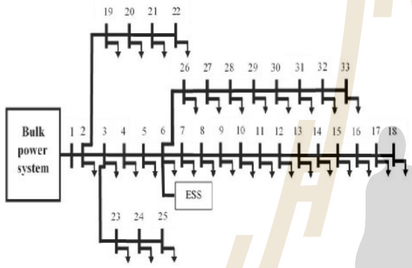

Figure. 5 The modified IEEE 33-bus radial distribution test system with ESS

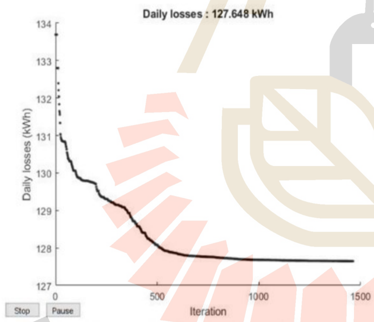

Figure. 6 Daily loss in each iteration

4.2 Optimal placement of ESS

In this case, the size 1.5 MW/10 MWh ESS is used to test the propose algorithm. The optimal ESS was investigated by the proposed MIPSO considering OESSS. As shown in Fig. 5, bus number 6 was chosen for install the ESS. In this case, the *AAL* with OPESS is 127.65 kWh, Fig. 6 shows the convergence plot of solution.

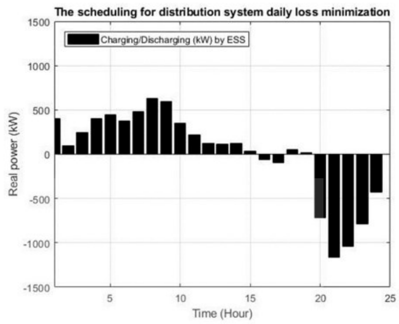

Figure. 7 The scheduling for distribution system daily loss minimization

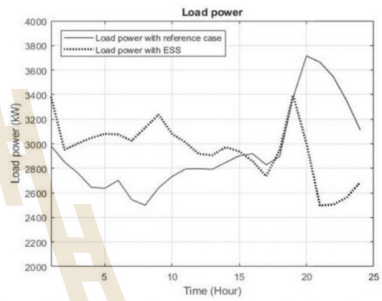

Figure. 8 The comparison of power load with and without ESS

The scheduling of ESS is shown in Fig. 7. Due to ESS is charging when off-peak and discharging when peak load, so peak power load with ESS was decease at 21.00 o'clock, as shown in Fig. 8. ESS is possible to handle high peak demand loads. However, it is still significantly unable to compensate for the system loss and voltage decrease. As a result, CB can assist in the solution of this problem.

4.3 Optimal placement of CBs

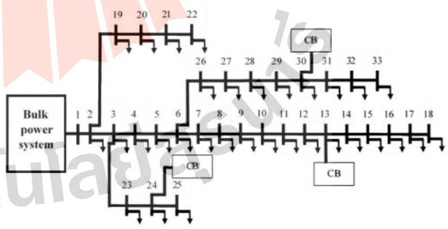

Figure. 9 The modified IEEE 33-bus radial distribution test system with optimal placement CBs

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Table 1. Comparison method to minimize total loss in optimal CB placement

Solver	-	LS [14]	MIPSO	
Case	Ref.	Without DLP	Without DLP	With DLP
Total Loss(kWh)	210.98	139.23	139.23	86.01
MaximumV(p.u.)	1.0000	1.0000	1.0000	1.0000
MinimumV(p.u.)	0.9038	0.9291	0.9291	0.9423
Loss Saving(%)	**0.00**	**34.01**	**34.01**	**59.23**

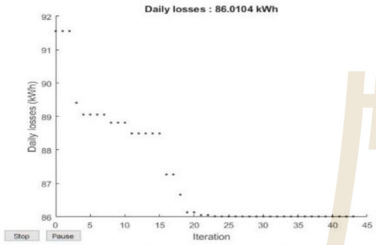

Figure. 10 Daily loss in each iteration

The optimal CB placement in the IEEE 33-bus radial distribution test system by the proposed method was compared to other previous published research, with the aim of minimizing total loss and operation cost [14]. Table 1 shows that the proposed method resulted in the same solution with [14] for conventional problem formulation. However, the daily load profile (DLP) was not considered in [14].

Therefore, in this paper, the DLP was considered to solve for the *AAL*. The 350, 600, and 1050 kVAR CBs are used for optimal placement. From the propose method, CB was installed at bus 13,24 and 30, as shown in Fig. 9. The *AAL* of this case is 86.0104 kWh, which loss saving of 59.23% (saving more than without DLP case). Fig. 10 shows that the algorithm convergence to minimum loss in 43 iterations. The voltage profile in each bus was compensated condition by MIPSO. The voltage drop in this case is lower than in the reference case and ESS case, as shown in Fig. 16.

4.4 COPP of ESS and CBs

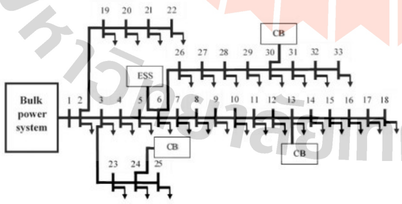

Figure. 11 The modified IEEE 33-bus radial distribution test system with optimal placement ESS and CBs

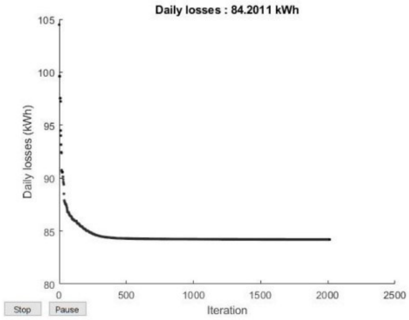

Figure. 12 Daily loss in each iteration

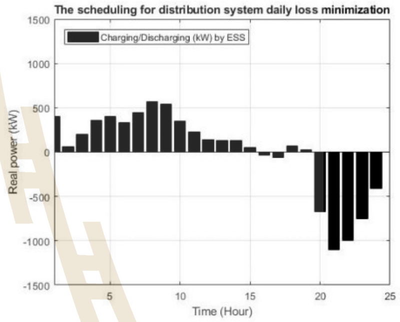

Figure. 13 The scheduling for distribution system daily loss minimization

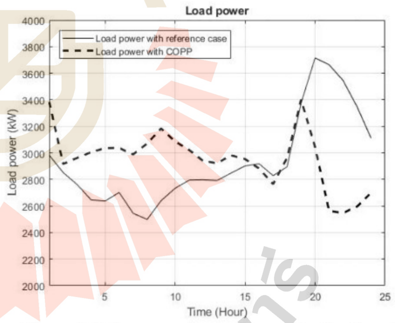

Figure. 14 The comparison of power load with and without optimal placement ESS and CBs

With the proposed MIPSO based. Fig. 11. shows that bus number 6 was chosen to install 1.5 MW/10 MWh of ESS and buses numbers 13, 24, and 30 were placed by CBs, with the sizes of 350, 600, and 1050, respectively.

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Table 2. Hourly loss of IEEE 33-bus radial distribution test system for cases 1-4

Time	Case 1 Hourly losses (kW)	Case 2 Hourly losses (kW)	Case 3 Hourly losses (kW)	Case 4 Hourly losses (kW)
1	131.7409	156.1866	87.3708	110.6394
2	119.7343	126.0988	79.5606	83.7840
3	111.8022	125.7058	74.3875	85.4428
4	102.1437	125.5076	68.0735	87.8815
5	101.4991	125.5794	67.6515	88.1850
6	106.8221	124.8462	71.1337	86.4586
7	94.1166	126.1528	62.8132	90.7851
8	90.5947	127.0256	60.5014	91.7468
9	101.7402	124.4514	67.8094	87.4914
10	109.4596	121.0148	72.8576	84.8111
11	114.7226	121.4062	76.2933	83.6642
12	114.8860	121.1142	76.4000	83.5383
13	114.4751	120.9067	76.1319	83.0816
14	119.4523	121.2097	79.3769	81.8394
15	124.2406	121.5404	82.4947	81.0080
16	125.7144	121.1590	83.4536	80.3963
17	117.6576	120.1695	78.2073	81.7191
18	123.6554	120.8485	82.1139	80.4152
19	171.3835	131.7973	112.9943	77.5112
20	210.9875	144.9729	138.3603	79.3673
21	204.7166	142.5138	134.3585	78.8940
22	190.6568	137.9043	125.3664	77.6928
23	168.5288	130.8732	111.1571	77.0083
24	144.0933	124.5576	95.3812	77.4656
AAL	**129.78**	**127.65**	**86.01**	**84.20**

Table 2 illustrated *AAL* of the modified IEEE 33-bus radial distribution test system with ESS and CBs is reduced to 84.20 kWh, lower than those case 1-3. In addition, the proposed method has been solved by GA for comparison with the PSO method. The results shown that the PSO based COPP was able to provide more efficient findings than GA when considering minimizing total loss, as shown in Table 3.

From Fig. 12, the convergence of *AAL* is 2000 iterations. The scheduling of ESS in Fig. 13, shows that state of charge of this case is similar to case 3. Similarly, the peak power load with ESS and CBs was decease at 21.00 o'clock shown as Fig. 14.

In this case, the curve of hourly loss was leveled smoother than ESS in case 2, as shown in Fig. 15. Meanwhile, Fig. 16. shows the voltage profiles for case 1-4. The results show that when ESS and CBs are placed optimally, significant improvements in bus voltage can be achieved when compared to other cases. Finally, the proposed method is efficiency minimize the *AAL* by the optimal placement ESS and CBs, considering the optimal scheduling ESS.

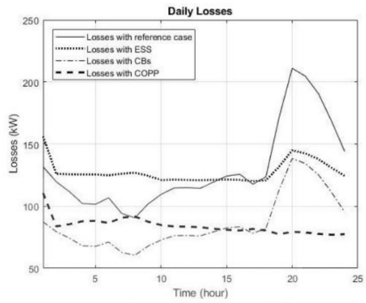

Figure. 15 The comparison of daily losses

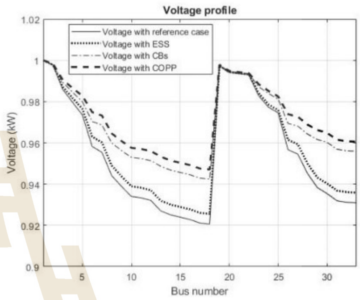

Figure. 16 The comparison of voltage profile (average from 24 hour)

Table 3. Simulation results with IEEE 33-bus radial distribution test system for cases 1-4

Case	1	2	3	4	
Solver	-	MIPSO	MIPSO	GA	MIPSO
OPESS(NO.)	-	6	-	6	6
OPCB(NO.)	-	-	13,24,30	13,24,30	13,24,30
AAL (kWh)	129.78	127.64	86.01	84.82	84.20
MaximumV(p.u.)	1.0000	1.0000	1.0000	1.0000	1.0000
MinimumV(p.u.)	0.9206	0.9256	0.9423	0.9511	0.9470
AAL Saving (%)	**0.00**	**1.65**	**33.73**	**34.64**	**35.12**

5. Conclusion

In this paper, the COPP with DSALM sub problem is proposed, using MIPSO. The proposed method was evaluated using a modified IEEE 33-bus radial distribution test system with the load profile of the Thai power system during the summer season. When properly allocated by MIPSO, CBs can better compensate for reactive power. Meanwhile, the bus with the ESS installed can effectively determine the power consumption schedule with the PSO. The results show that, the proposed method is efficient and dependable for coordinated allocation ESS and CB in minimizing system losses, which *AAL* saving of 35.12 % when compare to the based case.

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Conflicts of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, K. Kaiyawong and K. Chayakulkheeree; methodology, K. Kaiyawong and K. Chayakulkheeree; software, K. Kaiyawong; validation, K. Kaiyawong and K. Chayakulkheeree; formal analysis, K. Kaiyawong and K. Chayakulkheeree; investigation, K. Kaiyawong and K. Chayakulkheeree; resources, K. Kaiyawong; data curation, K. Kaiyawong; writing—original draft preparation, K. Kaiyawong; writing—review and editing, K. Chayakulkheeree; visualization, K. Kaiyawong; supervision, K. Chayakulkheeree;.

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VITAE

Korawitch Kaiyawong received his B. Eng. in EE from Suranaree University of Technology in 2020. He is currently a graduate student in power system program at Suranaree University of Technology (SUT). His current interests are in power system optimization algorithms and researching about energy storage system.

When I was studying for my bachelor's degree at Suranaree University of Technology, I interned at AKA Company. I have experience in many electrical systems, such as building automation systems, fire alarm systems, and high-voltage systems.

After I graduated with a bachelor's degree, I immediately studied for a master's degree at Suranaree University of Technology. I am so proud of my teacher assistant position duty to teach laboratory for students. I also accepted paper and participated in EE-Conference 41, and accept journal in International journal of intelligent and systems (IJIES) about energy storage problem.

Moreover, I have experience in consult assistance of PV power plant, my duty is analyzing and energy management systems for the installation of PV power plants in power system.

Finally, I have experience as a project engineer for induction motor work at Suranaree University of Technology. This work helps me develop my electrical engineering skills.