MINISTRY OF EDUCATION AND TRAINING
UNIVERSITY OF TECHNICAL EDUCATION - HO CHI MINH CITY

TON NGOC TRIEU

EXPANDING THE DISTRIBUTION GENERATION AND ENERGY STORAGE SYSTEM ON THE DISTRIBUTION NETWORK

Specialization: Electrical Engineering
Professional code: 9520201

SUMMARY OF THESIS

HO CHI MINH CITY – 2023

The work was completed at **Ho Chi Minh City University of Technology and Education**

Scientific instructor 1: Assoc. Dr. TRUONG VIET ANH

Scientific instructor 2: Assoc. Dr. VU PHAN TU

Review 1:
Review 2:
Review 3:

The thesis will be defended before the Grassroots Thesis Evaluation Council meeting at
Ho Chi Minh City University of Technology and Education
on ……………………

LIST OF RESEARCH PUBLICATIONS

1. Anh Viet Truong, **Trieu Ngoc Ton,** Thuan Thanh Nguyen and Thanh Long Duong, ‘Two states for optimal position and capacity of distributed generators considering network reconfiguration for power loss minimization based on runner root algorithm’, *Energies*, vol. 12, no. 1, p. 106, 2019 (SCIE – Q2, IF = 3.343).
2. **Trieu Ngoc Ton,** Thuan Thanh Nguyen, Viet Anh Truong, and Tu Phan Vu, ‘Optimal Location and Size of Distributed Generators in an Electric Distribution System based on a Novel Metaheuristic Algorithm’, *Eng. Technol. Appl. Sci. Res.*, vol. 10, no. 1, pp. 5325–5329, 2020, doi: 10.48084/etasr.3372 (ESCI).
3. Anh Viet Truong, **Trieu Ngoc Ton,** Thanh Long Duong, and Phan-Tu Vu, ‘Reconfigure the Distribution Network With Photovoltaic Connection to Minimize Energy Loss Based on Average Branch Power and an Advanced Branch Exchange Algorithm’, *IEEE Access*, vol. 9, pp. 104572–104581, 2021, doi: 10.1109/access.2021.3098902 (SCIE – Q1, IF = 3.557).
4. **Trieu Ngoc Ton,** Thuan Thanh Nguyen, Viet Anh Truong, and Phan-Tu Vu, ‘Optimal location and operation of battery energy storage system in the distribution system for reducing energy cost in 24-hour period’, *Int Trans Electr Energ Syst,* Vol. e12861, No. February, pp. 1–17, 2021 (SCIE – Q2, IF = 2.860).
5. **Tôn Ngọc Triều,** Nguyễn Tùng Linh, Trương Việt Anh và Phạm Văn Lới, “Nâng cao công suất của hệ thống pin lưu trữ trên lưới điện phân phối có kết nối năng lượng mặt trời nhằm giảm chi phí,” *TNU J. Sci. Technol.*, vol. 226, no. 16, pp. 11–19, 2021 (Thai Nguyen University).
6. **Tôn Ngọc Triều,** Trương Việt Anh, Vũ Phan Tú, ‘Áp dụng phương pháp Backward / Forward cải tiến trong bài toán tối ưu lưới điện phân phối có kết nối nguồn điện phân tán’, *Tạp chí phát triển KH&CN*, vol. 2, no. 2, 2019 (National University of Ho Chi Minh City).
7. Nguyễn Tùng Linh, Nguyễn Thanh Thuận, **Tôn Ngọc Triều**, Trương Việt Anh, Nguyễn Anh Xuân, ‘Tối ưu vị trí và công suất nguồn điện phân tán có xét đến tái hình cấu hình lưới điện phân phối’, *Tạp chí phát triển KH&CN,* vol. 20, no. K7, pp. 5–14, 2017 (National University of Ho Chi Minh City).
8. Thuan Thanh Nguyen, **Trieu Ngoc Ton,** Thang Trung Nguyen, Thanh-Phuc Nguyen, and Ngoc Au Nguyen, ‘*Optimization* of location and size of distributed generations for maximizing their capacity and minimizing power loss of distribution system based on cuckoo search algorithm’, *Bull. Electr. Eng. Informatics*, vol. 10, no. 4, pp. 1769–1776, 2021, doi: 10.11591/eei.v10i4.2278 (SCOPUS – Q3, IF = 1.87).
9. **Tôn Ngọc Triều,** Nguyễn Tùng Linh, Trương Việt Anh, Hoàng Ngọc Tuyến, ‘Tối ưu vị trí và công suất nguồn điện *phân* tán cho hệ thống điện phân phối hình tia không cân bằng sử dụng whale optimization algorithm’, *Tạp Chí Khoa Học Và Công Nghệ Năng Lượng - Trường Đại Học Điện Lực*, vol. 27, pp. 1–13, 2021 (Electric Power University).
10. N. T. Thuan, **T. N. Trieu**, T. V. Anh, and D. T. Long, ‘Service restoration in radial distribution system using continuous genetic algorithm’, *Proceeding 2016 Int. Conf. advanved Technol. Sustain. Dev. ICATSD2016*, pp. 619–628, 2016 (Conference).

CHAPTER 1: INTRODUCTION

1.1. Introduce

Electricity plays an increasingly important role in ensuring stability and development in each country. Distribution network (DN) and loads will change in the coming years with new requirements. To expand, DN can upgrade the system, build wiring, install substations, expand substations, install distributed generation (DG) and energy storage system (ESS) [1]. Currently, the expansion of DN through the installation of DG or ESS is an inevitable trend [2]. Current and future energy strategies focus on exploiting renewable energy sources (RES) and natural gas, saving energy, storing energy and attracting policies in private investment. RES is popular because of its sharply reduced costs and many supportive policies [3], [4].

ESS is currently being developed and used more and more with different benefits. In particular, there are great benefits from solving the problem during peak hours that the system does not meet the demand or the high cost of buying energy. Excess energy is stored by ESS at times of low demand and emitted when there is high demand [5]. Therefore, it is necessary to optimize the installation of ESS for distribution network to improve operational efficiency and other benefits. In fact, photovoltaic (PV) batteries have been installed according to existing investment conditions and will continue to expand more capacity. Therefore, distribution network needs to operate with the most efficient grid configuration.

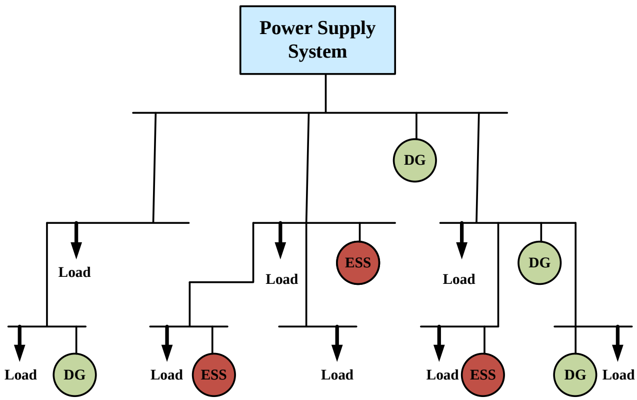

Figure 1.1. Distribution network that connects DGs and ESSs

DG and ESS attract a lot of research for the optimization of the distribution network expansion problem [6], [7]. When there is DG or ESS, the distribution network will work more efficiently and control the price of electricity [8], [9]. Therefore, the problem for the current distribution network is:

- For distribution networks without DG: The expansion of distribution network through locating and improving the capacity of DG participating in the system to improve operational efficiency for distribution network.
- For distribution network with DG connection: Continue to expand DG capacity according to investment time, incentive policies, installation location and environmental factors.

- For distribution network with high purchasing cost, it is necessary to reduce costs and stabilize the capacity of RES. Installing ESS, in addition to reducing electricity prices and supporting RES, reducing energy loss, time shifting and reducing peak loads are also considered.
- For distribution network that need to exploit local energy sources: The expansion of distribution network needs to maximize the participation rate of DG and reduce investment costs. One of the technical issues to reduce operating costs is minimizing power loss [10].

The topic "Expanding the distribution generation and energy storage system on the distribution network" with the goal of solving the following problem:

- Expand distribution network through installation of transformers to reduce power loss.
- Define distribution network configuration as PV expands capacity with the goal of minimizing energy loss.
- Expand distribution network through installation of ESS to reduce electricity purchase costs.
- Maximize the capacity of DG to participate in the distribution network.

1.2. Object and scope of the study

- Theoretical research on distribution network, DG and ESS.
- Researching problems of expanding distribution network through connecting DG and ESS.
- Simulate, test on the sample distribution network and compare with other announcements.

1.3. Research goals and tasks

- Expand distribution network through DG installation to minimize power loss.
- Define distribution network configuration when expanding PV capacity to minimize energy loss.
- DG capacity expansion plan joins the distribution network to minimize power loss.
- Optimized installation of ESS on the distribution side to reduce energy purchase costs and reduce energy loss.

1.4. Research Methods

- Theoretical research: Understanding, analyzing and synthesizing a number of documents.
- Simulation on MATLAB , PSS-ADEPT.

1.5. Dissertation contribution

The thesis analyzes and proposes the problem of expanding the distribution network, expanding the capacity of DG and the operating capacity of ESS to improve the operational efficiency of the distribution network. The thesis proposes three new problems and one applied to the distribution network in Vietnam, the problems are as follows:

Problem 1: Expanding the power grid through determining the optimal location and capacity of the DG with consideration of distribution network reconfiguration (DNR). The thesis presents a new problem to solve the problem of optimal position and capacity of DG through two stages. Phase I - optimal installation of DG in closed loop (design phase) and phase II – open switching optimization for open-operated distribution networks (operation phase). The problem proposes to optimize the installation of DG with consideration of reconfiguration with the objective function of minimizing the power loss of the system. The two-stage proposed problem is a new type of optimization problem in DG installation optimization with reconfiguration when considering other types of DNRs as published DG installation optimization problems . The common optimization problems used today such as the problem of location, capacity and reconfiguration concurrency (concurrency problem); position optimization problem first, then power optimization and reconfiguration (VT-CS and DNR problem). The proposed problem with two optimization stages has the advantage of providing a globally optimal solution to the DG installation problem with consideration of reconfiguration. The two-stage problem shows that the number of variables decreases for each stage of the optimization algorithm by dividing it into two stages. In addition, the proposed two-phase problem also shows that it is suitable for long-term DG installation (design phase) to be given priority and DNR to be short-term (operating phase). The 33-node distribution networkand the 69-node distribution network were tested and showed the effectiveness of the proposed problem. The proposed problem uses Runner Root Algorithm (RRA) to perform and compare with Coyote Algorithm (COA) and Genetic Algorithm (GA). In terms of algorithms, the results show that RRA, COA and GA algorithms are effective algorithms to optimize DG installation for distribution grid with reconfiguration consideration. The proposed problem is also compared with the concurrent problems and the VT - CS and DNR problems with different algorithms also show the efficiency of the two-phase separation problem. The simulation results of the proposed problem show that the power loss of the whole system is similar to the concurrency problem and better than that of the VT - CS and DNR problems. The proposed problem is implemented and published in [1], [5] and [7].

Problem 2: Determine the configuration of the distribution grid when expanding the capacity of photovoltaic (PV). The thesis proposes an improved branch exchange algorithm with Average Branch Capacity (CSNTB) to determine the operating configuration of the distribution network when PV is expanded with the goal of minimizing energy loss. The advantage of the proposed problem is that it is simple, easy to implement and accurate in determining the configuration of the distribution network when the PV is expanded to the installed capacity. The 18-node distribution network and 33-node distribution network have been tested, showing that the proposed method is simple, quickly determines the grid configuration and has high accuracy when compared to the problem of determining the configuration. Distribution grid according to the method of using average branch capacity (CSNTB) and the method of using load graph by optimization algorithms. The proposed problem is implemented and published in [2] and [10].

Problem 3: Applying to expand the distribution network of Chu Prong - Gia Lai in Vietnam. Chu Prong distribution network is applied to expand through DG installation in order to maximize the penetration capacity and minimize the power loss of the system. The problem proposes three stages of DG installation, corresponding to three locations and feasible capacity that can be installed in the Chu Prong distribution network. Runner Root Algorithm (RRA), Coyote Algorithm (COA) and Genetic Algorithm (GA) algorithms are effectively used for problem 1 and are applied to test the problem of installing three DGs for Chu Prong distribution network. From the results of three optimized DGs, the thesis proposes a plan to expand DG installation for Chu Prong distribution network through three phases in order to suit the investment and installation of DG in the shortest time. The proposed problem is implemented and published in [3] and [8].

Problem 4: Expanding the distribution network through the installation of a Battery Energy Storage System (BESS) to reduce the cost of purchasing energy. The thesis presents the problem of determining the location and capacity of BESS on the distribution network in order to reduce the cost of purchasing electricity as well as the cost of energy loss. The proposed problem with a new point is to give an objective function that is to minimize the cost of purchasing energy and the CSA algorithm is applied for the first time to the problem of optimizing the location and capacity of BESS. Optimizing the installation of BESS into the system not only reduces the cost of purchasing electricity, but also reduces energy loss and effectively exploits Renewable Energy Systems (RES). The 18-node distribution network and the 33-node distribution network with PV were tested for the BESS installation optimization problem and showed the effectiveness of BESS when participating in the distribution network. The proposed problem is implemented and published in [4] and [6].

The problems in the thesis propose to expand the distribution network through the installation and capacity expansion of DG and BESS in order to improve the operational efficiency of the distribution network. For DG has shown a reduction in system power loss and for BESS has shown a huge reduction in purchasing power costs.

1.6. Dissertation layout

Chapter 1: Introduction

Chapter 2: Overview

Chapter 3: Expanding the penetration of distributed generation on distributed power systems

Chapter 4: Expanding the penetration of energy storage systems on distributed power systems

Chapter 5: Conclusion

CHAPTER 2: OVERVIEW

2.1. Distribution network (DN)

The traditional structure of the power system is vertical. Therefore, the transmission from the power source to the electricity user will cause large capacity loss. To improve reliability, it is necessary to plan the construction of the distribution network according to the ring structure and operate in the ray structure. The new structure of the power system is horizontal because there is DG or ESS and the system will perform the task better.

2.2. Distributed Generation (DG)

2.2.1. Introduce

DG is now integrated into DN is very popular because of the great benefits [2], [11]. The DGs with large capacity are RES often connected to the transmission grid. Because of unfavorable environmental conditions, there may be a shortage of electricity. To make up for this shortfall, the solution to install small capacity DG is effective and reasonable cost [12], [13]. Therefore, distribution network needs to plan the capacity and location of DG with appropriate goals, in which power loss is the top goal because it evaluates the effectiveness of DGs entering the system [14].

2.2.2. Technology

The DG technology is depicted as Figure 2.1 [11].

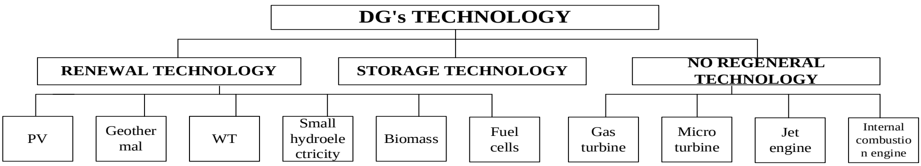

Figure 2.1. DG technologies [11]

2.2.3. Benefits

DG connected to the system has many advantages and benefits as shown in Table 2.1.

Table 2.1. Benefits of connecting DG to distribution network

Technique	Economy	Environment
• Reduced power loss. • Improve the quality. • Increased reliability and security. • Autonomous power supply. • Increased energy efficiency.	• Deferred investment deferred • Reduce all kinds of expenses. • Enhanced performance. • Reduced reserve requirements. • Reduce investment risk.	• Reduce emissions. • Reduce environmental impact. • Encourage RES.

2.2.4. Installation target of DG

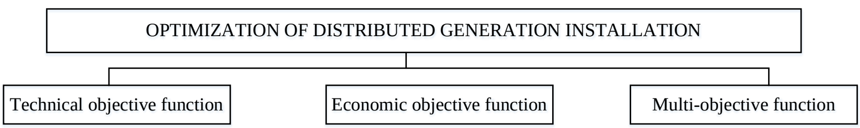

Figure 2.2. Objectives when optimizing DG installation

Most of the DG installation optimization studies with the goal of minimizing power loss are basic and other goals use support as shown in Figure 2.2.

2.3. Energy Storage System (ESS)

2.3.1. Introduce

ESSs have applications in most of the stages of generation - transmission - distribution - DG (RES) - customers. ESS helps to keep the power balance in the system. ESS is imperative for the electricity industry [16] and creates new business opportunities as well as new connections between sellers and buyers [17]. Currently, ESS technology has the advantage of meeting new requirements with decreasing investment costs and profitability [18]. ESS is a sustainable, reliable, efficient and friendly solution [5]. Figure 2.3 shows charge/discharge time and flattening graph with ESS [5], [19].

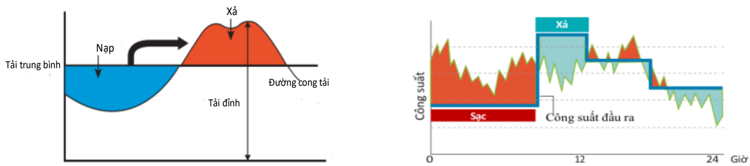

Figure 2.3. Load/discharge and leveling graph with ESS [5]

2.3.2. Technology

Currently, there are various ESS technologies such as mechanical, magnetic, thermal, electrochemical, electrostatic, chemical and mixed [18].

2.3.3. Benefit

The traditional electricity value chain has five links: fuel - generation - transmission - distribution - service, then ESS becomes the sixth link that is responsive. Table 2.2 shows the benefits of connecting the ESS to the system.

Table 2.2. Benefits of connecting ESS to system

Transmission and distribution company	Electricity users	RES
• Defer the upgrade and stabilize the system. • Flatten load peaks, reduce redundancy. • Replace traditional energy. • Adjust frequency/voltage. • Respond to non-contractual requirements.	• Increase power quality. • Time shift. • Exploit RES. • Price difference.	• RES max. • Adjust voltage/frequency. • Avoid fines. • Load balancing.

2.3.4. Installation target of ESS

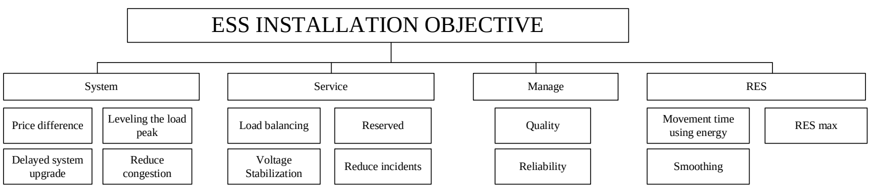

Figure 2.4. ESS installation objective

Figure 2.4 shows the ESS installation objectives. When the distribution network has ESSs, the customer controls the cost of purchasing electricity and can switch the connected power source so that the purchase cost is the lowest [20].

2.4. Optimization method and algorithm for installing DG and ESS

Algorithms used in DG and ESS installation optimization have two basic groups: classical algorithms and artificial intelligence algorithms [8].

2.5. Distribution network expansion

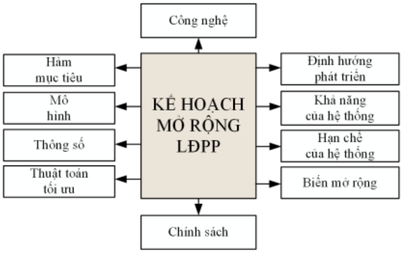

Figure 2.5. Distribution network expansion plan

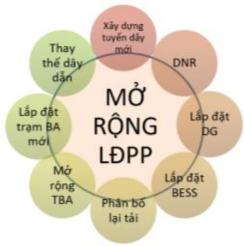

Figure 2.6. Extended variable distribution network

DN and loads will change dramatically with new requirements such as reliability, service expectations, investment costs, energy prices and the environment. Therefore, a distribution network expansion plan (DEP) is needed. DEP needs to consider new load characteristics, cost, DG and ESS, supplier, line, substation extension. Recently, a number of DEP studies have adopted effective installation of DG/ESS as the dominant factor [1]. Expanding distribution network through the installation of DG/ESS for efficient distribution network is an important and urgent need [21].

2.5.1. Expanding DG's penetration into DN

- Expanding DN through the new installation of DG into distribution network:

Different combinations of capacity, location, number and type of DG will have different advantages [1], [12]. distribution network optimization planning is a process that supports energy supply through DG in order to achieve maximum benefits of DG at minimal cost [24]. The most interested benefit today is the installation of DG with the goal of minimizing power loss. Because, this represents the evaluation of the effectiveness of the DG participating in the distribution network [25], [26]. Studies on optimal integration of DNR with DG installation to enhance the performance of distribution network are studied a lot. Although, both techniques contribute to loss reduction. The optimal implementation of the concurrent combination, the parameters of the algorithm will be more complicated than solving it individually. When combined simultaneously, the control variables will be longer, take more time and number of iterations for the optimal solution. Therefore, the problem is divided into two stages with phase I is to optimize the installation of DG in closed loop and phase II is to optimize open switch for open operation.

- Expanding the capacity of DG installed in the distribution network:

Connecting PVs to the distribution network with the number, capacity and location as originally designed is very difficult. Distribution network with PV will continue to expand capacity but not on the optimal mode of operation. At this point, it is very important to determine the operating configuration to reduce power loss. In which, DNR is an effective method for this problem. The problem of minimizing energy loss is replaced by the problem of minimizing power loss for different reasons [27], [28]. Current studies do not consider the effect of DG power on the branch capacity of distribution network. This can lead to configurations with zero energy loss. When the power of the DG participates in the distribution network with a large capacity, at some point in time, the direction of power transmission of some branches may be changed. Therefore, it is necessary to consider the influence of DG capacity on branches of distribution network to determine a simple, fast and accurate configuration of DN when expanding PV capacity.

2.5.2. Expanding ESS's penetration into distribution network

When there is ESS, the distribution network is easy to control, flexibly and improve the system [29]. When ESS determines the optimal, it will be effective, otherwise, ESS will adversely affect the system [30]. Depending on the operator's point of view (independent power supply, expansion of distribution network, energy exploitation) or investor's point of view (stabilizing RES, avoiding contract penalties or energy price differences) there will be specific goals. body. Optimizing ESS needs to consider the profit based on arbitrage and improve the system.

2.6. Conclusion of chapter 2

Chapter 2 presents an overview of distribution network, distributed generation (DG), energy storage (ESS) and DG/ESS integration to expand distribution network. In Chapter 3, the problem of expanding the penetration capacity of DG on the distribution network through the installation of DG to minimize power loss and the problem of determining the operating configuration of the distribution network when expanding the maximum capacity of DG to minimize the power loss. In addition, chapter 3 also proposes a plan to expand the penetration of DG for the Chu Prong distribution network. Chapter 4 presents the problem of expanding the penetration of ESS on the distribution network to minimize the cost of electricity. Chapter 5 presents the conclusion and development direction of the thesis.

CHAPTER 3: EXPANDING THE PREPARATION OF THE DISTRIBUTION GENERATION ON THE DISTRIBUTION NETWORK

3.1. Introduce

The DG optimization problem on distribution network with the objective function is mainly to minimize the power loss [31], [32]. ΔP and ΔQ of branch x are shown as (3.1) and (3.2).

$$\Delta P_x = \left(\frac{P_x^2 + Q_x^2}{|V_x|^2}\right) R_x \tag{3.1}$$

$$\Delta Q_x = \left(\frac{P_x^2 + Q_x^2}{|V_x|^2}\right) X_x \tag{3.2}$$

Chapter 3 presents three problems to expand the penetration of DG on DN:

- Problem 1 in section 3.2 will present the problem of expanding DN through DG installation with consideration of distribution network reconfiguration (DNR) with the objective function of minimizing power loss. The problem proposes to solve the problem in two stages. Phase I - optimize installation of DG in closed loop and phase II - optimize open switch for open operation.

- Problem 2 in section 3.3 will present the problem of determining distribution network configuration when expanding the capacity of photovoltaic (PV). The problem proposes to use an improved branch exchange algorithm with average branch capacity (CSNTB) to determine the distribution network operation configuration when PV expands capacity with the goal of minimizing energy loss.

- Problem 3 in section 3.4, this part will present the problem of extended application to Chu Prong distribution networks through the installation of DG in order to maximize the participating power of the DG and minimize the power loss of the system.

3.2. Distribution network expansion through installation of DG with DNR consideration

3.2.1. Description of the problem

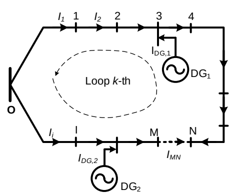

Figure 3. 1. Simple one-loop distribution network

Closed-loop power loss ($\Delta P^{kín}$) and open loop ($\Delta P^{hở}$) as (3.3) and (3.4).

$$\Delta P^{kín} = \sum_{i \in OM}^{nbr} R_i I_i^2 + R_{MN} I_{MN}^2 + \sum_{i \in ON}^{nbr} (-I_i)^2 R_i \tag{3.3}$$

$$\Delta P^{hở} = \sum_{i \in OM}^{nbr} R_i (I_i - I_{MN})^2 + \sum_{i \in ON}^{nbr} R_i (I_i + I_{MN})^2 \tag{3.4}$$

Đặt $R_{Loop} = \sum_{i \in OM}^{nbr} R_i + R_{MN} + \sum_{i \in ON}^{nbr} R_i$

$$\Delta P^{hở} - \Delta P^{kín} = I_{MN}^2 R_{Loop} \tag{3.5}$$

Objective function: $\Delta P = \sum_{i=1}^{nbr} R_i \times \left(\frac{P_i^2 + Q_i^2}{V_i^2}\right)$ (3.6)

3.2.2. Optimizing capacity and DG position on distribution network considering DNR

In this part, the problem of expanding distribution network only focuses on studying the problem of optimizing the installation of position and capacity of DG considering DNR with the objective function of minimizing power loss. Because minimizing power loss will evaluate the efficiency of DG participating in distribution network [25], [26]. Currently, the researches on optimizing the installation of DG on distribution network with the objective function of minimizing power loss are quite popular and most of them are optimization algorithms [33]. However, these studies focus on optimizing DG installation without considering DNR. Meanwhile, DNR is an effective technique to reduce power loss. When the DGs are integrated into the DN, the optimal operating configuration will change, the previous operating configuration may no longer be appropriate. Therefore, it is necessary to comprehensively consider installing DG in combination with DNR for effective operation. Currently, the DG installation optimization problem considering DNR has a lot of research, but mainly focuses on the metaheuristic algorithm because it effectively solves the complexity and gives the globally optimal solution to the problem [34]. There are two types of problems as follows:

- The first form is position optimization first, then DG and DNR power. Studies [35], [36] are typical for this problem. However, this is DNR mounting and DG mounting. The position and power of the DG will depend on the initial configuration but when DNR the position and power of the optimized DG may not be suitable to minimize the power loss. Therefore, this form easily falls into local extremes.

- The second form is the simultaneous optimization of position, power and DNR. The studies [37], [38] are typical of the concurrency problem. Problems of this kind often have a global maxima. However, it is not necessary to solve both problems at the same time because the optimized DG installation will no longer be the best when the position of the opening switchs changes. Simultaneous optimization, the parameter of the complex algorithm with the control variable is larger than that of solving the individual problem to find the optimal solution.

Therefore, the problem needs to be separated into two phases: phase I - optimizing the installation of DG in closed loop and phase II - optimizing open switch for open operation. At this time, the proposed problem will be simple, fast, convergent and globally optimal solution with lower input parameters for each optimization stage and this is also suitable for the design and development stages. operating phase of the distribution network.

3.2.3. Test results

3.2.3.1. Distributed network system 33 nodes

Distributed network system 33 nodes has 37 branches and 5 open switchs {33; 34; 35; 36; 37} as shown in Figure 3.2 [39]. Table 3.1 and Table 3.2 show the results of the proposed problem.

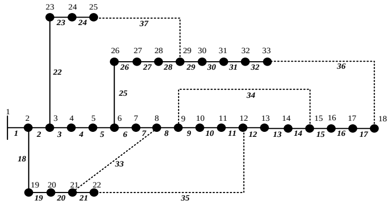

Figure 3.2. Distributed network system 33 nodes [39]

Table 3.1. Results of the two-stage problem-distributed network system 33 nodes

Parameter	Initial	Proposed problem (Two-stage problem)					
		RRA – Stage		COA – Stage		GA - Stage [40]	
		I	II	I	II	I	II
Open switch	33; 34; 35; 36; 37	-	33; 34; 11; 30; 28	-	33; 34; 11; 30; 28	-	33, 34, 11, 30, 28
PDG - MW (node)	-	1.133(25) 0.815(32) 1.101(8)	1.133(25) 0.815(32) 1.101(8)	1.172(30) 0.754(14) 1.146(24)	1.172(30) 0.754(14) 1.146(24)	1.107(25) 0.823(32) 1.105(8)	1.107(25) 0.823(32) 1.105(8)
ΔP (kW)	202.68	41.905	53.313	42.342	54.035	41.9082	53.4274
% Reduce ΔP	-	79.32	73.70	79.11	73.34	79.32	73.64
T (s)	-	25.078	9.316	25.078	9.316	130.49	39.54
Number of iterations	-	245.2	18.50	284.6	28.56	260.4	25.5

Table 3.2. Optimal results of the problems - distributed network system 33 nodes

Parameter	Problem				
	Two stages (RRA)	Simultaneously (RRA)	Simultaneously (CSA) [33]	VT-CS and DNR (FWA) [41]	VT-CS and DNR (HSA) [42]
Open switch	33; 34; 11; 30; 28	33; 34; 11; 30; 28	33; 34; 11; 31; 28	7; 14; 11; 32; 28	7; 14; 10; 32; 28
PDG - MW (node)	1.1326 (25) 0.8146 (32) 1.1011 (8)	1.12095 (25) 0.87689 (18) 0.96971 (7)	0.8968 (18) 1.4381 (25) 0.9646 (7)	0.5367 (32) 0.6158 (29) 0.5315 (18)	0.5258 (32); 0.5586 (31); 0.5840 (33)
ΔP (kW)	53.3129	50.825	53.21	67.11	73.05
% Reduce ΔP	73.70	74.92	73.75	66.89	63.95
Number of iterations	63.7	751.9	724.6	668.4	704.5
T (s)	34.39	46.39	52.4	64.3	74.8

Table 3.1 shows that the initial power loss of 202.68 kW reduced to 41,905 kW in phase I and phase II to 53.313 kW. The phase I results show that the power loss is minimal because it is the loss of the closed loop distribution network. In phase I, the results find the position and capacity of the DGs in the closed-loop network. Phase II, find open switches for the distribution network to operate open with open switches of {33; 34; 11; 30; 28}. Therefore, in phase II, the power loss increases to 53.313 kW compared to 41.905 kW in phase I. The results of the two-stage problem by RRA algorithm are similar to the results of COA and GA algorithms. This shows that the

proposed problem is performed with different algorithms with similar results. Table 3.2 shows the results of different problems and algorithms

3.2.3.2. Distributed network system 69 nodes

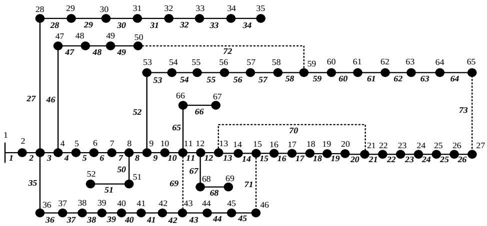

Figure 3. 3. Single-line diagram of 69-node system [39]

Distributed network system 69 nodes as shown in Figure 3.3 have 73 branches and 5 open switchs {69; 70; 71; 72; 73} [43]. The optimal results are shown in Table 3.3 and Table 3.4.

Table 3.3. Results of the two-stage problem - Distributed network system 69 nodes

Parameter	Initial	Proposed problem (Two-stage problem)					
		RRA – Stage		COA – Stage		GA - Stage [40]	
		I	II	I	I	II	I
Open switch	69; 70; 71; 72; 73	-	69; 70; 12; 55; 63	-	69; 70; 12; 55; 63	-	69; 70; 12; 55; 62
PDG - MW (node)	-	1.618(61) 0.771(50) 0.675(21)	1.618(61) 0.771(50) 0.675(21)	1.554(62) 0.824(50) 0.735(21)	1.618(62) 0.771(50) 0.675(21)	1.622(61) 0.743(50) 0.678(21)	1.622(61) 0.743(50) 0.678(21)
ΔP (kW)	224.89	28.89	39.31	29.32	40.02	28.89	39.33
% Reduce ΔP	-	87.15	82.52	85.53	80.25	85.75	80.60
T (s)	-	32.97	27.26	34.67	29.35	35.43	28.31
Number of iterations	-	240.15	71.05	252.04	75.09	242.22	74.25

Table 3.4. Optimal results of the problems - 69 nodes system

Parameter	**Problem**				
	Two stages (RRA)	Simultaneously (RRA)	Simultaneously (CSA) [33]	VT-CS and DNR (FWA) [41]	VT-CS and DNR (HSA) [42]
Open switch	69; 70; 12; 55; 63	69; 70; 14; 55; 61	69; 70; 14; 58; 61	69; 70; 13; 55; 63	69; 17; 13; 58; 61
PDG - MW (node)	1.6175 (61) 0.7710 (50) 0.6752 (21)	0.5161 (64) 1.45167 (61) 0.53696 (11)	0.5413 (11) 0.5536 (65) 1.7240 (61)	1.1272 (61) 0.2750 (62) 0.4159 (65)	1.0666 (61) 0.3525 (60) 0.4257 (62)
ΔP (kW)	39.31	35.193	37.02	39.25	40.3
% Reduce ΔP	82.52	84.35	83.54	82.55	82.08
Number of iterations	311.15	807.15	796.9	840.6	860.2
T (s)	60.23	184.26	186.9	203.2	235.7

The results of the two-stage problem at distribution network 69 nodes are shown in Table 3.3. With an initial power loss of 224.89 kW reduced to 28.89 kW in phase I and 39.31 kW in phase II. The results of the two-stage problem by the RRA algorithm are similar to the results of the COA and GA algorithms. This shows that the proposed problem is performed with different algorithms giving similar results. Table 3.4 shows the results of different problems and different algorithms.

3.2.4. Conclusion

In section 3.2, the optimization problem of installing DG with DNR is proposed in two stages to expand distribution network. The proposed problem shows the efficiency when performing tests on two distribution network 33 nodes and distribution network 69 nodes using RRA, COA and GA algorithms with similar results. The test results also show that the proposed problem has results equivalent to the simultaneous optimization problem and better than the VT-CS and DNR problems. The proposed problem has solved two separate problems, making the optimization algorithm simple, shortening the calculation time and efficiency in each design and operation phase. The problem is proposed to be researched, implemented and published in works [1], [5] and [7].

3.3. Determine the operating configuration of distribution network when expanding the capacity of DG

A suggested method to solve the DNR problem is to use an improved CSNTB. This method is based on the load factor to determine the improved CSNTB through the addition of a certain amount of capacity in the branches with participating PV. Power compensation for branches for accurate CSNTB and accurate DNR.

3.3.1. Mathetical model

Equation (3.7) shows the objective of DNR problem to reduce power loss [44].

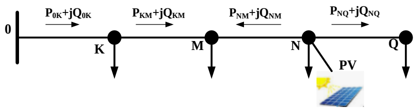

Figure 3. 4. Distribution network system connected to PV

$$\text{Min: } \Delta A(X) = \sum_{m=1}^{M} t_m \times \sum_{i=1}^{N_{br}} R_i \times \left(\frac{P_i^2 + Q_i^2}{V_i^2}\right) \quad (3.7)$$

Formula (3.8) is the deviation of branch power loss MN between closed and open grid [39].

$$\delta P_{MN} = \Delta P_{hở} - \Delta P_{kín} = I_{MNpeak}^2 R_{Loop} \quad (3.8)$$

$$\delta A_{MN} = \sum_{i=1}^{n} \Delta P_{iMN} T_i \quad (3.9)$$

$$= 24 \frac{R_{Loop}}{V^2}\left(\left(\frac{P_{MNavg}}{LF}\right)^2 + \left(\frac{Q_{MNavg}}{LF}\right)^2\right)(aLF + (1-a)LF^2) \quad (3.10)$$

From (3.10), δA is determined through CSNTB (P_{BRavg}) and load factor LF [45].

Case 1: CSNTB (P_{BRavg}) on the one-way branch from source to load is calculated by formula (3.11)

$$\sum_{i\epsilon 0C} P_{BRavg} = \frac{\sum_{i\epsilon 0A}(P_{Load}t_i - P_{PV}t_i)}{\sum_{i\epsilon 0A} t_i} + \frac{\sum_{i\epsilon AB}(P_{PV}t_i - P_{Load}t_i)}{\sum_{i\epsilon AB} t_i} + \frac{\sum_{i\epsilon BC}(P_{Load}t_i - P_{PV}t_i)}{\sum_{i\epsilon BC} t_i} \quad (3.11)$$

Case 2: Improved CSNTB (P^N_{BRavg}) on transmission branch when PV is present. Now the bidirectional transmission power, is calculated as (3.12)

$$\sum_{i\epsilon 0C} P^N_{BRavg} = \frac{\sum_{i\epsilon 0A}(P_{Load}t_i - P_{PV}t_i)}{\sum_{i\epsilon 0A} t_i} - \frac{\sum_{i\epsilon AB}(P_{PV}t_i - P_{Load}t_i)}{\sum_{i\epsilon AB} t_i} + \frac{\sum_{i\epsilon BC}(P_{Load}t_i - P_{PV}t_i)}{\sum_{i\epsilon BC} t_i} \quad (3.12)$$

We have P^N_{BRavg} từ (3.11) và (3.12) when connected to PV as (3.13).

$$\sum_{i\epsilon 0C} P^N_{BRavg} = \sum_{i\epsilon 0C} P_{BRavg} + 2\frac{\sum_{i\epsilon AB}(P_{Load}t_i - P_{PV}t_i)}{\sum_{i\epsilon AB} t_i}$$

$$= \sum_{i\epsilon 0C} P_{BRavg} + 2P_{BRavgAB} = \sum P_{BRavg} + P_{BRneg} \quad (3.13)$$

Consider an isosceles triangle with base AB and altitude P_s^{12h}. We have:

$$A_{neg} = 24P_{BRneg} = \frac{(P_s^{12h})^2 T_{PV}}{2P_{PV}^{12h}}$$

$$\Leftrightarrow P_{BRneg} = \frac{(P_s^{12h})^2 T_{PV}}{2P_{PV}^{12h} 24} \quad (3.14)$$

$$P^N_{BRavg} = P_{BRavg} + P_{BRneg} \quad (3.15)$$

$$\delta A = \frac{24R_{Loop}}{V_i^2}\left(\left(\frac{P^N_{BRavg}}{LF}\right)^2 + \left(\frac{Q_{BRavg}}{LF}\right)^2\right)(aLF + (1-a)LF^2) \quad (3.16)$$

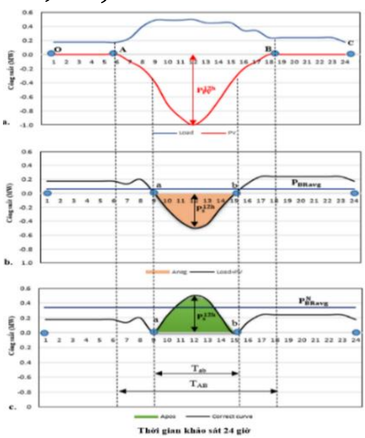

Figure 3.5. Load capacity and PV

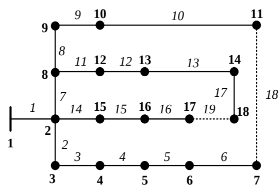

Figure 3. 6. Diagram of an 18-node distribution network

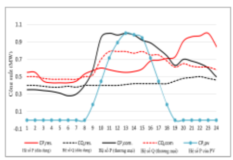

Figure 3.7. Graph of load and PV

Consider a 10 kV distribution network with 18 nodes: 19 branches, 17 closed switchs and 2 open switchs {17, 18}. Tested 2 DNR scenarios with 18 node distribution network when PV capacity is installed and capacity expansion.

Case 1: Distribution network expands with PV1 at node 18 with P_{PV1} = 560 kW. Because PV has a small capacity, it does not affect much to the CSNTB of branches of the distribution network e and the results of the improved CSNTB and improved CSNTB methods are the same. Figure 3.9 shows the direction of power transmission of the branches in the presence of PV. Table 3.5 shows the test results with the original case and P^{N}_{BRavg}.

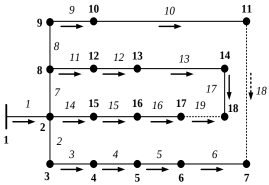

Figure 3.8. Power transmission direction without PV

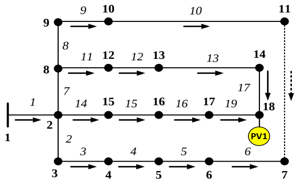

Figure 3.9. Power transmission direction with PV1

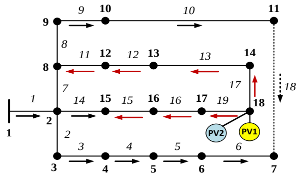

Figure 3.10. Power transmission direction when adding PV2

Table 3.5. Open switch in case of PV with capacity of 560 kW

Case	P_{PV1} (kW)	P_{PV2} (kW)	P_{PV} (kW)	Open switch	ΔA (kWh)
Initial – no PV	-	-	-	{18, 19}	1514,0
Initial – with PV	560	-	560	{18, 19}	1345,5
CSNTB	560	-	560	{17, 18}	1325,1
Improved CSNTB	560	-	560	{17, 18}	1325,1

Case 2: Distribution network has P_{PV1} and expanded P_{PV2} = 2440 kW at node 18. Table 3.6 and Table 3.7 show the results of CSNTB, improved CSNTB and δA of the branches of the 2 closed loops. Due to the impact of PV on the branches of distribution network, δA will be incorrect. The improved CSNTB method is simple, easy to implement and gives accurate results.

Table 3.6. Parameters when additional PV is installed at node 18 with P_{PV2} = 2440 kW

Branch	Switch	Direction	P_{BRneg}(kW)	P_{BRavg} (kW)	P^{N}_{BRavg} (kW)	δA (Wh)
2 - 15	14	Không	0	1046.5	1046.5	642.8
15 - 16	15	Có	4.5	658.9	663.4	266.9
16 - 17	16	Có	40.65	272.4	313.1	66.1
17 - 18	*19*	*Có*	*114.8*	***120.2***	***235***	***32.7***
14 - 18	17	Có	410.3	307.8	718.1	279.4
13 - 14	13	Có	227.1	**51.4**	**278.5**	**41.6**
12 - 13	12	Có	74	269	343.0	72.6
8 - 12	11	Có	11.8	525.7	537.5	181.9
2 - 8	7	Không	0	1651	1651	1650

Table 3.7. Open lock in case when expanding PV2 with P_{PV2} = 2440 kW

Case	P_{PV1} (kW)	P_{PV2} (kW)	P_{PV} (kW)	Open switch	ΔA (kWh)
Initial – no PV	-	-	-	{18, 19}	1514.0
Initial – with PV	560	2440	3000	{18, 19}	1196.5
CSNTB	560	2440	3000	{18, 13}	1312.0
Improved CSNTB	560	2440	3000	{18, 19}	1196.5

3.3.2. Improved branch exchange algorithm for DNR problem when distribution network is connected PV

Trong (3.16), là độ lệch cho vòng lặp thứ i và j như (3.17) và (3.18).
In (3.16), δA_i and δA_j are the offsets for the ith and j_{th} loops like (3.17) and (3.18).

$$\delta A_i = \Delta A_{initial} - \Delta A_i \tag{3.17}$$
$$\delta A_j = \Delta A_{initial} - \Delta A_j \tag{3.18}$$

We have: formula (3.18) - formula (3.19) $\delta A_i - \delta A_j = \Delta A_j - \Delta A_i$ (3.19)

From formula (3.20), it can be seen that: If $\delta A_i > \delta A_j$ then $\Delta A_i < \Delta A_j$ (3.20)

3.3.3. Test results

The system has 12.66 kV, 33 nodes: 37 branches with 32 closed switchs and 5 open switchs {33, 34, 35, 36, 37} as shown in Figure 3.11. Figure 3.13 shows the improved branch exchange algorithm. The proposed method tested for 33 nodes system shows that the method is simple, the computation time is small and the accuracy is high.

Table 3.8. DNR results of the proposed method for 33 nodes system

Method	Khóa mở	ΔA (kWh)
Initial	{33, 34, 35, 36, 37}	3304.82
Graph method	{7, 9, 14, 32, 37}	2243.98
EP [46]	{7, 10, 14, 31, 37}	2334.28
GSA [46]	{7, 10, 14, 17, 28}	2075.51
Recommended method	{7, 10, 14, 17, 28}	2075.51

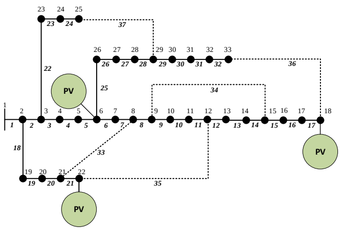

Figure 3. 11. DN 33 nodes

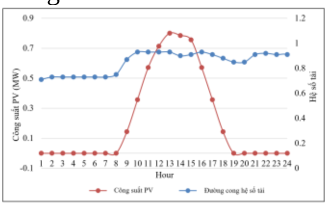

Figure 3.13. Graph of load and PV

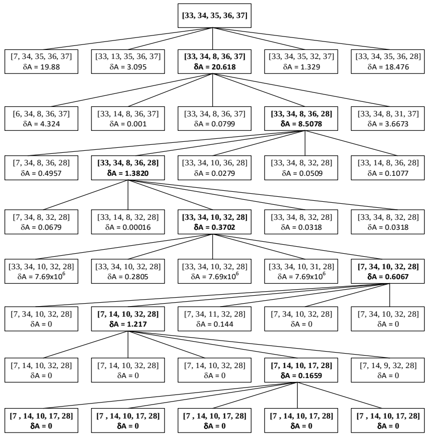

Figure 3.12. DNR process for a 33 node distributed network with PV

3.3.4. Conclusion

The proposed problem has improved CSNTB to have an accurate value for power loss deviation between closed and open loop in system and power loss deviation between different configurations. From there, it is possible to accurately determine the configuration with the smallest energy loss. The advantage of the problem is that it is simple, easy to implement and accurate in determining the configuration of the system. The proposed problem has been researched, implemented and published in [2].

3.4. Expanding distributed power source for distribution network Chu Pong

Chu Prong system has 257 nodes, 259 branches, load is 8,6357 MW and three open switchs {33 - 34, 154 - 238, 164 - 182}. Table 3.9 shows the possible installation DGs at some nodes in the system with the capacity of the DG allowing connection

[47]. Chu Prong system has 3 connected DGs with optimized quantity, capacity and location as shown in Figure 3.14.

Table 3.9. Area and capacity allowed for DG connection - Chu Prong system [47]

STT	DG is connected	P (MW)	Possible node that allows DG to connect
1	Ia Drang 2 (DG 1)	1.50	221, 222, 223
2	Ia Drang 3 (DG 2)	1.60	164, 165, 166, 167, 168, 169, 170, 171, 172, 173
3	Ia Puch 3 (DG 3)	3.40	34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51

Table 3.10. Stages of installing DG into Chu Prong system

Parameter	Initial	COA	RRA	GA
P_{DG} (MW)	-	0.661 (221); 1.489 (164); 2.256 (48)	0.731 (221); 1.502 (164); 2.156 (48)	0.682 (221); 1.385 (164); 2.188 (48)
Total P_{DG}	-	4.406	4.389	4.255
ΔP (kW)	81.566	43.116	45.426	46.421
Vmin (pu) - node	0.9717- 99	0.9717 - 99	0.9717 - 99	0.9717 - 99
Vmax (pu)	1.0 (nút 1)	1.0 (nút 1)	1.0 (nút 1)	1.0 (nút 1)
LBI	0.00441	0.00141	0.00144	0.00144
(I/Iđm)max	0.28341	0.17231	0.17245	0.17265

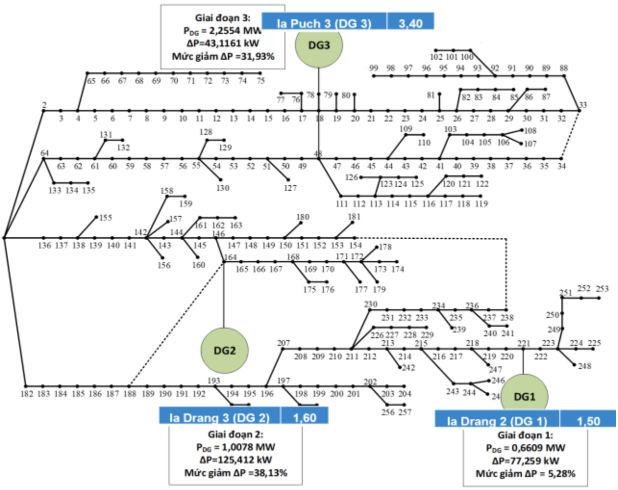

Figure 3.14. Chu Prong system with 3 stages of expansion installation DG

3.5. Kết luận chương 3

In this section, Chu Pong distribution network is applied to expand through DG installation in order to maximize the penetration capacity and minimize the power loss of the system. The problem proposes three installation stages of DG corresponding to three locations and feasible capacity that can be installed in Chu Pong distribution network. COA, RRA and GA algorithms are used effectively for problem 1 and continue to be applied to test the problem of installing three DGs for Chu Pong distribution network. From the results of three optimized DGs, the thesis proposes a plan to install DG expansion for Chu Prong system through three phases to suit the investment and installation of DG in the coming time. The proposed problem has been researched, implemented and published in [3], [8] and [9].

CHAPTER 4: EXPANDING THE PERFORMANCE OF ENERGY STORAGE SYSTEMS ON THE DISTRIBUTION NETWORK

4.1. Introduce

Energy storage systems (ESS) have many different technologies. In particular, battery energy storage system (BESS) is widely used for power system because of response time, storage capacity and independence [48]. Lithium-ion batteries are the most notable for their fast response time, low weight, small size, ease of installation, and savings [49], [50].

$$P_S(t) = P_G(t) - P_L(t) \tag{4.1}$$

$$W_S(t) = \int_0^t P_S(\tau)\, d \tag{4.2}$$

During the charging phase: $E_{t+1} = E_t + P_t\eta$ (4.3)

During the discharge phase: $E_{t+1} = E_t - P_t$ (4.4)

BESS plays a prominent role in the complete chain of the power system: generation - transmission - distribution - load. It creates a new rapid response mechanism in the power industry's new supply chain.

- Energy price difference: $P_i = P_i^+ - P_i^-$ với i = 1…24 (4.5)

During BESS's charging time$P_i = -P_i^-$ and during discharge time $P_i = P_i^+$. Therefore, the benefit through the price difference over time is as formula (4.6).

$$T_1 = \sum_i (P_i^+ - P_i^-)\, C_i \tag{4.6}$$

- Reduced line access costs: T_2 is the benefit of cost reduction:

$$T_2 = \sum_{i \epsilon \{\text{thời gian phí thấp}\}} (P_i^+ - P_i^-) C_a + \sum_{i \epsilon \{\text{thời gian phí cao}\}} (P_i^+ - P_i^-) C_b + \sum_{i \epsilon \{\text{thời gian phí trung bình}\}} (P_i^+ - P_i^-) C_c \tag{4.7}$$

Table 4. 1. Transmission cost

Line access cost	Cost ($ / kW - month)
Time period with low cost	C_a
Time period with high cost	C_b
Time period with average cost	C_c

BESS is a powerful tool to reduce energy purchase costs and correct technical constraints, BESS is a component to improve RES performance by shifting energy usage time [52], [53].

4.2. Description of the problem

The objective function in optimal location and operating power of BESS in 24 hours is determined as formula (4.8):

$$OF(S) = \sum_{i=1}^{24} \left(P_{s,i} + P_{loss,i} \right) C_i \tag{4.8}$$

Where P_(s,i) is the power purchased from the system at time interval i, $P_{loss,i}$ is the power loss at time interval i and C_i is the price of electricity at interval i.

K is the solution for the operating capacity and position of the BESS, formula (4.9):

$$K = [x_1, x_2, \dots, x_{25}] \quad (4.10)$$

Here, the first variable will be the position and the remaining variables will be the operating capacity of the BESS. With these variables being Pđm of BESS (% value) and BESS capacity in each interval, the storage capacity corresponds to S as in formula (4.11).

$$BESS_{capacity}(S) = \max(|\,cumulative\_sum(x_2, \dots, x_{25})\,|) \quad (4.11)$$

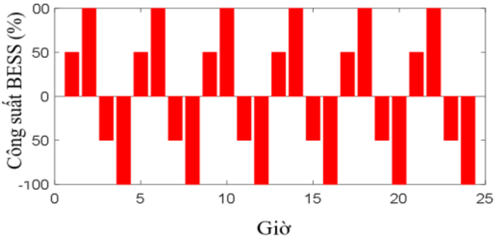

Figure 4. 1. Values in a typical solution of BESS

Assume that the $P_{đm}$ of BESS is 1 MW. Thus, to operate in this case, the capacity must be 150% Pdm ie 1.5 MWh. To be efficient, the accumulated energy over a 24-hour period is zero. Therefore, the problem of optimal position and operating power of BESS needs to satisfy the constraint conditions in formula (4.12).

$$\sum_{i=1}^{24} P_{BESS,i} = 0 \quad (4.12)$$

The constraints in formula (4.14) need to be considered.

$$\begin{cases} I_j < I_{j,rate} & ; j = 1,2, \dots, n_{branch} \\ V_i > V_{low} \text{ và } V_i < V_{high} & ; i = 1,2, \dots, n_{bus} \end{cases} \quad (4.13)$$

Adaptive function: objective function with constrained conditions, formula (4.14).

$$f = OF + p.\left[\max(V_{low} - V_{min}, 0) + \max(V_{max} - V_{high}, 0) + \max(KI_{max} - KI_{rate}) + \left|\sum_{i=1}^{24} P_{BESS,i}\right|\right] \quad (4.14)$$

4.3. Optimizing the capacity and location of BESS

4.4. Test results

Assume that there are three types of industrial, residential and commercial loads. Then, the load at each node is calculated as formula (4.15) [44], [51].

$$\begin{cases} P_{j,i} = \sum_{k=1}^{3} P_{j,peak}.R_{j,k}RP_{k,i} \\ Q_{j,i} = \sum_{k=1}^{3} Q_{j,peak}.R_{j,k}RQ_{k,i} \end{cases} \quad (4.15)$$

Assume the discharge and charge times are equal and Pdm is 1 MW. The penalty coefficient p is chosen with the value of 10000. The timetable and electricity price are as shown in Table 4.2 [52], [53].

Table 4. 2. Time frame and electricity price

Hour	Peak time	Standard time	Off-peak time
Time	9:00 am - 11:00 am 17:00 - 20:00	4:00 am - 9:00 am; 11:00 - 17:00; 20:00 - 22:00	22:00 - 4:00
Price ($/kWh)	0.1289	0.07	0.0454

4.4.1. The system has 18 nodes

DN 18 nodes have a voltage of 10 kV as shown in Figure 4.2. The total load is as shown in Figure 4.3 with PV connected to node 7 with the power output shown in Figure 4.4.

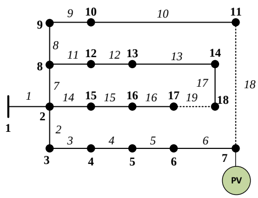

Figure 4. 2. 18-node system with PV

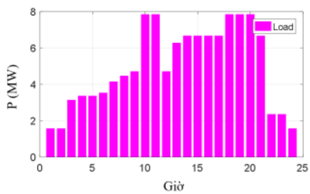

Figure 4. 3. Load of the 18-node system

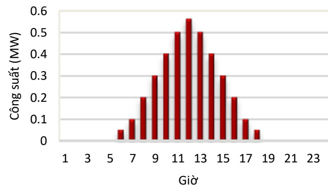

Figure 4. 4. Power generation of PV

After performing optimization for operating capacity and location by CSA, the position is node 15 and the 24-hour operating capacity (%Pdm) is {-24; 49; 24; 100; -25; -8 ; -37; 81; 3; -38; -100; 42; -35; 1; -66; 11; 28; -82; -97; -4; 9; 48; 100; 20}.

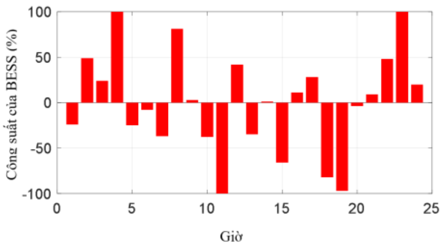

Figure 4.5. Operating capacity of BESS - system of 18 nodes

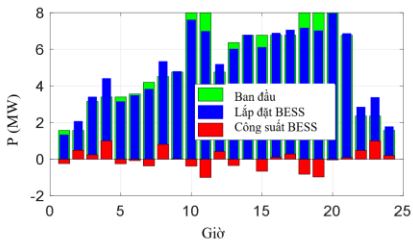

Figure 4.6. Purchase capacity of 18-node system

The maximum value is 177, corresponding to a capacity of 1.77 MWh. The results from CSA for distribution network 18 nodes are as shown in Table 4.3. When having BESS, the cost savings is $ 258.2807 (equivalent to 2.45%). Figure 4.7 and Figure 4.8 show that BESS has no adverse effect on the current and voltage profile. CSA had better results than GA, SFO and PFA in 30 independent runs.

Table 4. 3. Results after installing BESS for 18-node system

Status	Objective function	Purchase cost ($)	Cost savings ($)	ΔA (kWh)	Cost ΔA ($)
Initial	10682.3856	10523.5441	-	1679.4449	158.8308
BESS	10420.9595	10265.2634	258.2807	1674.7208	155.6961

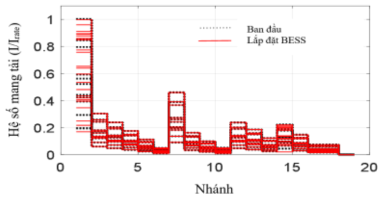

Figure 4.7. Branch current with BESS - 18-node system

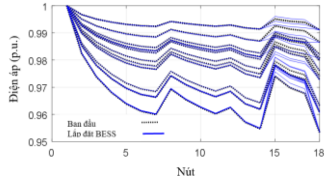

Figure 4.8. Node voltage with BESS - 18-node system

Table 4. 4. Calculation results of CSA, GA, SFO and PFA – 18 nodes system

Method	Location (nút)	S (MWh)	OF	Purchase cost ($)	Cost savings ($)	ΔA (kWh)	Cost ΔA ($)
Initial	-	-	10693.0598	10523.5441	-	1679.4449	158.8308
CSA	15	1.77	10420.9595	10265.2634	258.2807	1674.7208	155.6961
GA	9	2.22	10570.5415	10407.4480	116.0961	1705.2337	157.5186
SFO	3	1.58	10532.4499	10364.9542	158.5899	1689.2404	157.4761
PFA	18	1.8	10461.2865	10304.1091	219.435	1783.7335	157.1775

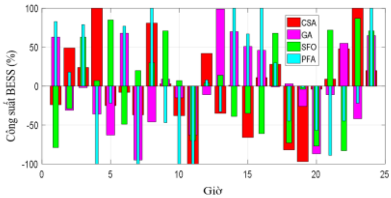

Figure 4.9. BESS operating capacity with CSA, GA, SFO and PFA

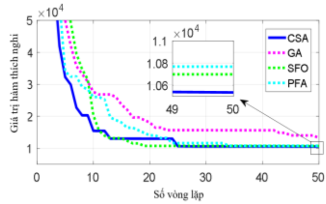

Figure 4.10. Convergence curves of PFA, SFO, GA and CSA

Table 4.5. Efficiency of CSA, GA, SFO and PFA with BESS for 18-node distributed network

Method	CSA	GA	SFO	PFA
Minimal adaptation	10420.9595	10570.5415	10532.4499	10461.2865
Moderately adaptive	10534.7008	13186.7217	10698.2309	10767.8222
Extremely adaptive	10624.4975	34809.9839	11028.3392	11175.5319
Standard deviation	58.6329	7307.463	111.2877	152.4096
Average number of convergences	123.3688	28.5333	27.6667	40.1667
Time (s)	106.6542	54.951	56.0792	57.5677

The proposed solution saves $258.2807 while the solution from GA, SFO and PFA is only $116,961; $158,5899 and $219.435. CSA is more reliable and efficient than GA, SFO and PFA for optimal installation of BESS as shown in Figure 4.9 and Figure 4.10.

4.4.2. Distributed network system 33 nodes

The DGs connected to the system are 3 PVs. The connection locations are node 18, node 22 and node 26. The maximum value of 373 corresponds to a storage capacity of 3.73 MWh and this is the required capacity of BESS. Figure 4.13 and Figure 4.14 show BESS operating capacity and purchasing capacity. Figure 4.15 and

Figure 4.16 show the voltages of the nodes and the currents on the branches of a 33-node system.

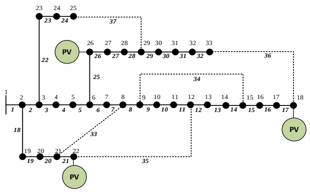

Figure 4.11. The 33 node distribution networkwith 3 PV

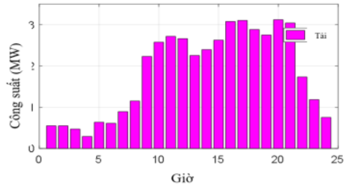

Figure 4.12. Load of the 33 node distribution network

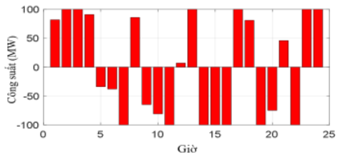

Figure 4.13. Operating capacity of BESS – 33 node distribution network

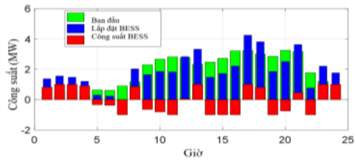

Figure 4.14. Purchase capacity of the 33 node distribution network

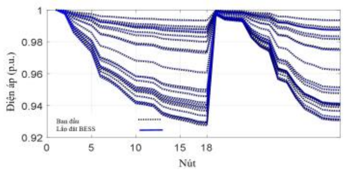

Figure 4.15. Node voltage with BESS – 33 node distribution network

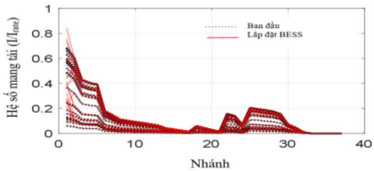

Figure 4.16. Branch current with BESS - 33 node distribution network

Table 4.6. Results after installing BESS for the system of 33 nodes

Status	The value of OF	Purchase cost ($)	Cost savings ($)	ΔA (kWh)	Cost ΔA ($)
Initial	4117.2242	3971.4943	-	1506.884	137.777
BESS	3813.0712	3667.8305	303.6638	1506.4889	137.1419

Table 4.7. Calculation results of CSA, GA, SFO and PFA - 33 node system

Method	Location (nút)	S (MWh)	OF	Purchase cost ($)	Cost savings ($)	ΔA (kWh)	Cost ΔA ($)
Initial	-	-	4117.2242	3971.4943	-	1506.8840	137.7770
CSA	2	3.73	3813.0712	3667.8305	303.6638	1506.4889	137.1419
GA	3	2.94	3943.8311	3787.6752	183.8191	1505.0175	135.1959
SFO	10	2.23	3945.0977	3815.5320	155.9623	1452.1091	125.8681
PFA	3	2.81	3845.8422	3711.6225	259.8718	1506.5038	133.5666

Table 4.8. Efficiency of CSA, GA, SFO and PFA with BESS - 33 node system

Method	CSA	GA	SFO	PFA
Minimal adaptation	3813.0712	3943.8311	3945.0977	3845.8422
Moderately adaptive	3998.0242	4235.0721	5005.2403	4297.219
Extremely adaptive	4189.6828	4793.4513	29803.6606	5885.5111
Standard deviation	70.4216	228.6883	4685.2723	485.7155
Average number of convergences	55.1	63.7667	65.5333	86.6333
Time (s)	237.4453	122.6167	122.6141	127.1943

Table 4.6 shows the cost savings results before and after the installation of BESS. Tables 4.7 and Table 4.8 show the calculation results and the effectiveness of other methods when installing BESS in the system.

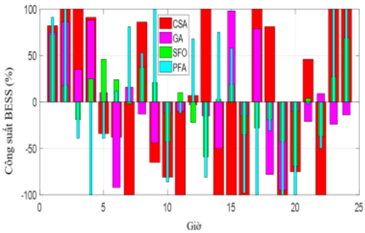

Figure 4.17. BESS operating capacity with CSA, GA, SFO and PFA

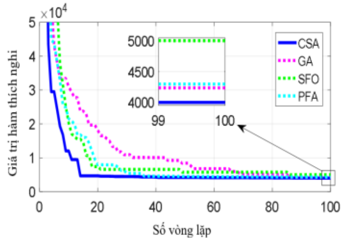

Figure 4.18. Convergence curves of PFA, SFO, GA and CSA

The results show that, BESS has helped reduce the cost of buying electricity by 3971.4943$ to 3667.8305$, a saving of 303.6638$ (corresponding to 7.65%). While GA, SFO and PFA saved 183.8191$; 155.9623$ and 259.8718$ are 119.8447$ lower, respectively; 147.7015 $ and 43.792 $ against CSA. The resulting cost savings of CSA outperformed GA, SFO and PFA as shown in Figure 4.17 and Figure 4.18.

4.5. Conclusion Chapter 4

Chapter 4 presents the problem of expanding the system through the installation of BESS. To optimize capacity and location BESS needs to consider optimal operating capacity in 24 hours and installation location with the goal of reducing electricity costs and energy loss costs. BESS capacity expansion joins the system to operate the system in order to reduce energy costs, smooth the capacity of the RES and improve technical factors. The two tested systems, the 18-node system and the 33-node system, showed that after optimizing the installation of BESS, the cost of purchasing electricity decreased by 2.45% and 7.65% for the 18-node system and the 18-node system. 33 buttons. BESS not only reduces power costs, but also reduces peak loads, reducing energy loss. In addition, the results of the proposed method show that the CSA method is more effective than the GA, SFO and PFA methods for the BESS optimization problem on the system. The problem of optimizing the installation of BESS on the system has been studied, implemented and published in [4] and [6].

CHAPTER 5: CONCLUSION

5.1. Conclusion

The thesis "Expanding the distribution generation and energy storage system on the distribution network" proposes three new problems and one applied problem as follows:

Problem 1: Expand the distribution network by determining the optimal location and capacity of the DG with consideration of the distribution network reconfiguration (DNR). The thesis presents a new problem to solve the problem of optimal position and capacity of DG through two stages. Phase I - Optimizing installation of DG in closed distribution networks and Phase II- Optimizing open switch for open grid operation. The problem proposes the optimal implementation of DG installation considering DNR with the objective function of minimizing power loss. The proposed problem is a new problem in DG installation optimization that considers DNR in addition to the optimization problems of position, power and DNR (simultaneously) and the problem of position optimization and then optimization. power priority and DNR (VT-CS and DNR). The proposed problem has the advantage of providing a globally optimal solution. The proposed problem shows that the number of variables decreases for each stage of the optimization algorithm by dividing it into two stages. In addition, the proposed two-phase problem also shows that it is appropriate for the long-term DG installation to be given priority first and the short-term DNR to be implemented later. The distribution network of 33 nodes and 69 nodes is tested and shows the effectiveness of the proposed problem. The proposed problem using RRA algorithm and comparing with COA and GA gave similar results. In addition, the two-stage problem is also compared with the concurrency problem and the position optimization problem first and then the power and DNR optimization to show its efficiency. When optimizing for a 33-node distributed network with a two-stage problem using RRA; concurrent (RRA), concurrent (CSA); VT-CS and DNR (FWA) and VT-CS and DNR (HSA) with a % reduction in power loss of 73%, respectively; 74.92%; 73.75%; 70%; 66.89% and 63.95%. Similarly, the 69-node distribution network is 82.52%; 84.35%; 83.54%; 82.55% and 82.08%. The simulation results of the proposed problem show that the power loss of the whole system is similar to the concurrency problem and better than that of the VT-CS and DNR problems. The results also show that RRA, COA and GA algorithms are effective to optimize DG installation for distribution network with DNR. The proposed problem has been implemented and published in [1], [5] and [7].

Problem 2: Determine the distribution network configuration when expanding the capacity of photovoltaic (PV) cells. The thesis proposes an improved branch exchange algorithm with average branch capacity (CSNTB) to determine the operating configuration of the distribution network when PV is expanded with the goal of minimizing energy loss. The advantage of the proposed problem is simplicity, ease of implementation and accuracy in determining the configuration of the distribution network. The 18-node distribution network was tested for the problem of using the improved CSNTB and proved to be effective when the distribution network has PV. The 33-node DN is applied experimentally to the improved branch exchange and CSNTB method. The energy loss of the proposed method is 2075.51 kWh, the load plot method is 2243.98 kWh and the EP method is 2334.28 kWh. The results show that the proposed method is simple, quickly determines the grid configuration and has high accuracy when compared with other problems. The proposed problem is researched, implemented and published in [2].

Problem 3: Apply and expand Chu Prong - Gia Lai distribution network. The problem proposes three stages of DG installation corresponding to three locations and feasible capacity to allow installation in Chu Prong distribution network. COA, RRA and GA algorithms are used effectively for problem 1 and continue to be applied to test the problem of installing three DGs for Chu Prong distribution network. From the results of three optimized DGs, a plan to install DG expansion for Chu Prong distribution network is proposed in three phases. Chu Prong distribution network installed DG in phase 1 with a capacity of 0.6609 MW (node 221) with power loss from 81,566 kW to 77.26 kW (down 5.28%). Phase 2, installing more DG with a capacity of 1,4898 MW (node 164), power loss reduced to 63,3393 kW (down 18.02%). Phase 3 installs more DG with a capacity of 2,2554 MW (node 48), the loss of power is 43,1161 kW (decreased 31.93%). The voltages of the nodes and the currents of the branches are within the allowable range. The problem of expanding Chu Prong distribution network with the goal of maximum power and minimized power loss is studied and published in [3] and [8].

Problem 4: Expand the distribution network through the installation of battery energy storage system (BESS) to reduce the cost of purchasing electricity. The thesis proposes the problem of determining the location and capacity of BESS on the distribution network in order to reduce the cost of purchasing electricity as well as reducing the cost of energy loss. The proposed problem has a new point of proposing an objective function to minimize energy costs and applying the CSA algorithm for the first time to the problem of optimizing the location and operating capacity of BESS. Optimizing BESS into the distribution network not only reduces the cost of purchasing electricity, but also reduces energy loss and other benefits. The proposed method tested on an 18-node distributed network showed a cost reduction of $258.2807 (decrease of 2.45%). 33-node distribution network, electricity purchase cost reduced by $303.6638 (decreased of 7.65%). In addition, energy loss is also reduced. The CSA algorithm shows more efficiency than GA, SFO and PFA. The proposed problem has been studied, implemented and published in [4] and [6].

5.2. Further research directions

The thesis has analyzed and proposed the problem of expanding the distribution network. However, the thesis still has some limitations as it has not considered all other extended problems. NCS continues to study other problems:

- The problem of expanding the distribution network through the installation of ESS with multi-objective function (economic goals combined with the goal of improving technical indicators);
- Distribution network expansion problem with penetration of wind turbines (WT) and photovoltaic (PV) combined with ESS;
- The ESS optimization problem considers costs such as investment, installation and operation of BESS on the distribution network.

REFERENCES

[1] C. L. T. Borges and V. F. Martins, "Multistage expansion planning for active distribution networks under demand and Distributed Generation uncertainties," *Int. J. Electr. Power Energy Syst.*, vol. 36, no. 1, pp. 107–116, 2012, doi: 10.1016/j.ijepes.2011.10.031.

[2] R. Payasi, A. Singh, and D. Singh, "Review of distributed generation planning: objectives, constraints, and algorithms," *Int. J. Eng. Sci. Technol.*, vol. 3, no. 3, pp. 133–153, 2011, doi: 10.4314/ijest.v3i3.68430.

[3] L. Gédéon and F. Guillemot, "Huy động tối đa nguồn tài chính để phát triển ngành năng lượng," *L'Asie du Sud-Est 2014 bilan, enjeux Perspect.*, pp. 369–399, 2018, doi: 10.4000/books.irasec.2494.

[4] J. Rockhold, *Kế hoạch Năng lượng sản xuất tại Việt Nam - Bài toán về việc sử dụng tập trung các nguồn lực trong nước của Việt Nam để kích thích đầu tư vào sản xuất năng lượng sạch, an toàn và chi phí hợp lý*. 2019.

[5] Asian Development Bank, *Handbook on Battery Energy Storage System*, no. December. 2018.

[6] C. K. Das, O. Bass, G. Kothapalli, T. S. Mahmoud, and D. Habibi, "Overview of energy storage systems in distribution networks: Placement, sizing, operation, and power quality," *Renew. Sustain. Energy Rev.*, vol. 91, no. November 2016, pp. 1205–1230, 2018, doi: 10.1016/j.rser.2018.03.068.

[7] G. J. May, A. Davidson, and B. Monahov, "Lead batteries for utility energy storage: A review," *J. Energy Storage*, vol. 15, pp. 145–157, 2018, doi: 10.1016/j.est.2017.11.008.

[8] M. Pesaran H.A, P. D. Huy, and V. K. Ramachandaramurthy, "A review of the optimal allocation of distributed generation: Objectives, constraints, methods, and algorithms," *Renew. Sustain. Energy Rev.*, vol. 75, no. September 2015, pp. 293–312, 2017, doi: 10.1016/j.rser.2016.10.071.

[9] E. S. Ali, S. M. Abd Elazim, and A. Y. Abdelaziz, "Optimal allocation and sizing of renewable distributed generation using ant lion optimization algorithm," *Electr. Eng.*, 2016, doi: 10.1007/s00202-016-0477-z.

[10] R. C. Dugan, T. E. McDermott, and G. J. Ball, "Distribution planning for distributed generation," *Pap. Electr. Power Conf.*, p. C4, 2000, doi: 10.1109/REPCON.2000.848048.

[11] R. H. A. Zubo, G. Mokryani, H. S. Rajamani, J. Aghaei, T. Niknam, and P. Pillai, "Operation and planning of distribution networks with integration of renewable distributed generators considering uncertainties: A review," *Renew. Sustain. Energy Rev.*, vol. 72, no. September, pp. 1177–1198, 2017, doi: 10.1016/j.rser.2016.10.036.

[12] W. Lip, J. Shiun, W. Shin, H. Hashim, and C. Tin, "Review of distributed generation (DG) system planning and optimisation techniques: Comparison of numerical and mathematical modelling methods," *Renew. Sustain. Energy Rev.*, vol. 67, pp. 531–573, 2017, doi: 10.1016/j.rser.2016.09.063.

[13] W. El-Khattam, K. Bhattacharya, Y. Hegazy, and M. M. A. Salama, "Optimal investment planning for distributed generation in a competitive electricity market," *IEEE Trans. Power Syst.*, vol. 19, no. 3, pp. 1674–1684, 2004, doi: 10.1109/TPWRS.2004.831699.

[14] D. Bogdanov *et al.*, "Low-cost renewable electricity as the key driver of the global energy transition towards sustainability," *Energy*, vol. 227, p. 120467, 2021, doi: 10.1016/j.energy.2021.120467.

[15] A. A. Bayod-Rújula, "Future development of the electricity systems with distributed generation," *Energy*, vol. 34, no. 3, pp. 377–383, 2009, doi: 10.1016/j.energy.2008.12.008.

[16] H. Chen, T. Ngoc, W. Yang, C. Tan, and Y. Li, "Progress in electrical energy storage system : A critical review," *Prog. Nat. Sci.*, vol. 19, no. 3, pp. 291–312, 2009, doi: 10.1016/j.pnsc.2008.07.014.

[17] M. Winfield, S. Shokrzadeh, and A. Jones, "Energy policy regime change and advanced energy storage: A comparative analysis," *Energy Policy*, vol. 115, no. January, pp. 572–583, 2018, doi: 10.1016/j.enpol.2018.01.029.

[18] E. Hossain, H. M. R. Faruque, M. S. H. Sunny, N. Mohammad, and N. Nawar, "A comprehensive review on energy storage systems: Types, comparison, current scenario, applications, barriers, and potential solutions, policies, and future prospects," *Energies*, vol. 13, no. 14. 2020, doi: 10.3390/en13143651.

[19] H. A. Behabtu *et al.*, "A review of energy storage technologies' application potentials in renewable energy sources grid integration," *Sustain.*, vol. 12, no. 24, pp. 1–20, 2020, doi: 10.3390/su122410511.

[20] A. K. Rohit and S. Rangnekar, "An overview of energy storage and its importance in Indian renewable energy sector: Part II – energy storage applications, benefits and market potential," *J. Energy Storage*, vol. 13, no. October 2017, pp. 447–456, 2017, doi: 10.1016/j.est.2017.07.012.

[21] V. Vahidinasab *et al.*, "Overview of Electric Energy Distribution Networks Expansion Planning," *IEEE Access*, vol. 8, pp. 34750–34769, 2020, doi: 10.1109/ACCESS.2020.2973455.

[22] P. S. Georgilakis and N. D. Hatziargyriou, "A review of power distribution planning in the modern power systems era: Models, methods and future research," *Electr. Power Syst. Res.*, vol. 121, pp. 89–100, 2015, doi: 10.1016/j.epsr.2014.12.010.

[23] B. Singh and J. Sharma, "A review on distributed generation planning," *Renew. Sustain. Energy Rev.*, vol. 76, no. December 2015, pp. 529–544, 2017, doi: 10.1016/j.rser.2017.03.034.

[24] V. F. Martins and C. L. T. Borges, "Active distribution network integrated planning incorporating distributed generation and load response uncertainties," *IEEE Trans. Power Syst.*, vol. 26, no. 4, pp. 2164–2172, 2011, doi: 10.1109/TPWRS.2011.2122347.

[25] N. S. Rau and Y. H. Wan, "Optimum Location of Resources in Distributed Planning," *IEEE Trans. Power Syst.*, vol. 9, no. 4, pp. 2014–2020, 1994, doi: 10.1109/59.331463.

[26] S. H. Lee and J. W. Park, "Optimal placement and sizing of multiple dgs in a practical distribution system by considering power loss," *IEEE Trans. Ind. Appl.*, vol. 49, no. 5, pp. 2262–2270, 2013, doi: 10.1109/TIA.2013.2260117.

[27] M. P. P. and N. D. H. G.J. Peponis, "Distribution network reconfiguration to minimize resistive line losses," *IEEE Trans. Power Deliv.*, vol. 10, no. No. 3, 1995, doi: 10.1109/APT.1993.673869.

[28] K. Taleski and D. Rajicid, "Distribution Network Reconfiguration For Energy Loss Reduction," vol. 12, no. 1, pp. 398–406, 1997.

[29] M. R. Sheibani, G. R. Yousefi, M. A. Latify, and S. H. Dolatabadi, "Energy storage system expansion planning in power systems: A review," *IET Renew. Power Gener.*, vol. 12, no. 11, pp. 1203–1221, 2018, doi: 10.1049/iet-rpg.2018.0089.

[30] H. Ebrahimian, S. Barmayoon, and M. Mohammadi, "The price prediction for the energy market based on a new method," *Econ. Res. Istraživanja*, vol. 31, no. 1, pp. 1–25, 2018, doi: 10.1080/1331677X.2018.1429291.

[31] T. T. Nguyen, T. T. Nguyen, A. V. Truong, Q. T. Nguyen, and T. A. Phung, "Multi-objective electric distribution network reconfiguration solution using runner-root algorithm," *Appl. Soft Comput. J.*, vol. 52, pp. 93–108, 2017, doi: 10.1016/j.asoc.2016.12.018.

[32] R. S. Rao, K. Ravindra, K. Satish, and S. V. L. Narasimham, "Power Loss Minimization in Distribution System Using Network Reconfiguration in the Presence of Distributed Generation," *IEEE Trans. Power Syst.*, vol. 28, no. 1, pp. 1–9, 2012, doi: 10.1109/TPWRS.2012.2197227.

[33] T. T. Nguyen, A. V. Truong, and T. A. Phung, "A novel method based on adaptive cuckoo search for optimal network reconfiguration and distributed generation allocation in distribution network," *Int. J. Electr. Power Energy Syst.*, vol. 78, pp. 801–815, 2016, doi: 10.1016/j.ijepes.2015.12.030.

[34] T. N. Ton, T. T. Nguyen, A. V. Truong, and T. P. Vu, "Optimal Location and Size of Distributed Generators in an Electric Distribution System based on a Novel Metaheuristic Algorithm," *Eng. Technol. Appl. Sci. Res.*, vol. 10, no. 1, pp. 5325–5329, 2020, doi: 10.48084/etasr.3372.

[35] A. M. Imran, M. Kowsalya, and D. P. Kothari, "A novel integration technique for optimal network reconfiguration and distributed generation placement in power distribution networks," *Int. J. Electr. Power Energy Syst.*, vol. 63, pp. 461–472, 2014, doi: 10.1016/j.ijepes.2014.06.011.

[36] R. S. Rao, K. Ravindra, K. Satish, and S. V. L. Narasimham, "Power Loss Minimization in Distribution System Using Network Recon fi guration in the Presence of Distributed Generation," *IEEE Trans. Power Syst.*, vol. 28, no. 1, pp. 317–325, 2013, doi: 10.1109/TPWRS.2012.2197227.

[37] T. T. Nguyen, A. V. Truong, and T. A. Phung, "A novel method based on adaptive cuckoo search for optimal network reconfiguration and distributed generation allocation in distribution network," *Int. J. Electr. Power Energy Syst.*, vol. 78, pp. 801–815, 2016, doi: 10.1016/j.ijepes.2015.12.030.

[38] M. Subramaniyan, S. Subramaniyan, M. Veeraswamy, and V. R. Jawalkar, "Optimal reconfiguration/distributed generation integration in distribution system using adaptive weighted improved discrete particle swarm optimization," *COMPEL - Int. J. Comput. Math. Electr. Electron. Eng.*, vol. 38, no. 1, pp. 247–262, 2019, doi: 10.1108/COMPEL-08-2017-0344.

[39] A. V. Truong, T. N. Ton, T. T. Nguyen, and T. L. Duong, "Two states for optimal position and capacity of distributed generators considering network reconfiguration for power loss minimization based on runner root algorithm," *Energies*, vol. 12, no. 1, 2019, doi: 10.3390/en12010106.

[40] N. T. Linh, N. T. Thuận, and T. N. Triều, "Tối ưu vị trí và công suất nguồn điện phân tán có xét đến tái hình cấu hình lưới điện phân phối," *Tạp chí phát triển KH&CN*, vol. 20, no. K7, pp. 5–14, 2017.

[41] A. Mohamed Imran, M. Kowsalya, and D. P. Kothari, "A novel integration technique for optimal network reconfiguration and distributed generation placement in power distribution networks," *Int. J. Electr. Power Energy Syst.*, vol. 63, pp. 461–472, 2014, doi: 10.1016/j.ijepes.2014.06.011.

[42] R. S. Rao, K. Ravindra, K. Satish, and S. V. L. Narasimham, "Power Loss Minimization in Distribution System Using Network Reconfiguration in the Presence of Distributed Generation," *IEEE Trans. Power Syst.*, vol. 28, no. 1, pp. 1–9, 2013, doi: 10.1109/TPWRS.2012.2197227.

[43] H.-D. Chiang and R. Jean-Jumeau, "Optimal network reconfigurations in distribution systems: part 2: Solution algorithms and numerical results," *IEEE Trans. Power Deliv.*, vol. 5, no. 3, pp. 1568–1574, 1990, doi: 10.1109/61.58002.

[44] T. T. Nguyen, T. T. Nguyen, L. T. Duong, and V. A. Truong, "An effective method to solve the problem of electric distribution network reconfiguration considering distributed generations for energy loss reduction," *Neural Comput. Appl.*, vol. 2, 2020, doi: 10.1007/s00521-020-05092-2.

[45] K. Malmedal and P. K. Sen, "A better understanding of load and loss factors," *IEEE Ind. Appl. Soc.*, pp. 1–6, 2008, doi: 10.1109/08IAS.2008.376.

[46] K. G. Ing, H. Mokhlis, H. A. Illias, M. M. Aman, and J. J. Jamian, "Gravitational Search

Algorithm and Selection Approach for Optimal Distribution Network Configuration Based on Daily Photovoltaic and Loading Variation," *J. Appl. Math.*, vol. 2015, 2015, doi: 10.1155/2015/894758.

[47] Nguyễn Thanh Thuận, *Tái cấu hình lưới điện phân phối sử dụng các giải thuật tìm kiếm tối ưu*. Luận án Tiến sĩ - Trường Đại học Sư phạm Kỹ thuật Tp. HCM, 2019.

[48] Y. Yang, S. Bremner, C. Menictas, and M. Kay, "Battery energy storage system size determination in renewable energy systems: A review," *Renew. Sustain. Energy Rev.*, vol. 91, no. June 2017, pp. 109–125, 2018, doi: 10.1016/j.rser.2018.03.047.

[49] X. Luo, J. Wang, M. Dooner, and J. Clarke, "Overview of current development in electrical energy storage technologies and the application potential in power system operation," *Appl. Energy*, vol. 137, pp. 511–536, 2015, doi: 10.1016/j.apenergy.2014.09.081.

[50] Y. Li, M. Vilathgamuwa, S. S. Choi, T. W. Farrell, N. T. Tran, and J. Teague, "Development of a degradation-conscious physics-based lithium-ion battery model for use in power system planning studies," *Appl. Energy*, vol. 248, no. August, pp. 512–525, 2019, doi: 10.1016/j.apenergy.2019.04.143.

[51] Y. Huping, P. Yunyan, and X. Ning, "Gradual Approaching Method for Distribution Network Dynamic Reconfiguration," pp. 257–260, 2008, doi: 10.1109/PEITS.2008.104.

[52] T. N. Ton, T. T. Nguyen, V. A. Truong, and P.-T. Vu, "Optimal location and operation of battery energy storage system in the distribution system for reducing energy cost in 24-hour period," *Int Trans Electr Energ Syst*, vol. e12861, no. February, pp. 1–17, 2021.

[53] Tôn Ngọc Triều, Nguyễn Tùng Linh, Trương Việt Anh, and và Phạm Văn Lới, "Nâng cao công suất của hệ thống pin lưu trữ trên lưới điện phân phối có kết nối năng lượng mặt trời nhằm giảm chi phí," *TNU J. Sci. Technol.*, vol. 226, no. 16, pp. 11–19, 2021.