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APPLY ARTIFICIAL INTELLIGENCE ALGORITHMS TO CALCULATE OPTIMAL GRID EXPANSION PLANNING

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SUMMARY OF THESIS

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LIST OF PUBLISHED PAPERS

1. **Huu Tinh Tran**, Ngoc Dieu Vo, and Huy Anh Quyen, ‘A Pseudo-Gradient Particle Swarm Optimization Approach Applied to Transmission Expansion Planning’, *12th GMSARN Int. Conf. Ener. Connect. Environ. Develop. ECED 2017*, Energy – E76, 2017.
2. Dieu Ngoc Vo, Tri Phuoc Nguyen, **Tinh Huu Tran**, and Hai Minh Nguyen, ‘A Hybrid Particle Swarm Optimization and Differential Evolution for Security-Constrained Optimal Power Flow’, *12th GMSARN Int. Conf. Ener. Connect. Environ. Develop. ECED 2017, Energy – E75, 2017.*
3. Quy Truong Xuan, Dieu Vo Ngoc, and **Huu Tinh Tran**, ‘Pseudo-Gradient Integrated in Particle Swarm Optimization for Solving Security Constrained Optimal Power Flow Problem’, *12th GMSARN Int. Conf. Ener. Connect. Environ. Develop. ECED 2017*, Energy – E82, 2017.
4. **Tinh, T. H.**, Hieu, T. N., & Thien, V. M. (2019), ‘Reliability Evaluation of Power System Considering Force Outage Rate’, *TNU Journal of Science and Technology*, *195*(02), 89-94. (Thai Nguyen University)
5. **Tinh, T. H.**, Đieu, V. N., & Anh, Q. H. (2020), ‘Overview of Transmission Expansion Planning’, *TNU Journal of Science and Technology*, *225*(06), 223-228. (Thai Nguyen University)
6. **Tinh, T. H.**, Đieu, V. N., & Anh, Q. H. (2021), ‘Power System Expansion Planning In Consideration of Optimal Reserve’, *No. 75*, pp. 89-95. (Sai Gon University)
7. **Tran, H.**, Vo, N., Quyen, H., & Pham, T. Transmission System Expansion Planning in Consideration of Reliability Criteria and Optimal Reserve. *In International Conference on Advanced Mechanical Engineering, Automation and Sustainable Development*, pp. 918-923, 2021(Scopus – Q4). Cham: Springer International Publishing.
8. **Huutinh Tran**, Ngocdieu Vo, Huyanh Quyen, ‘Optimal Transmission Expansion Planning Using Crow Search Algorithm’, *The 4th Inter. Conf. on Engi. Technology. Innov. Research. ICETIR 2022,* pp.1-6, 2022.
9. **Huutinh Tran**, Ngocdieu Vo, Huyanh Quyen, ‘A Search Method for Power Transmission System Planning Problem in Ben Tre Province, Viet Nam’, *In International Conference on Advanced Engineering Theory and Applications.*, pp. 333-344, 2022. (Scopus – Q4). Singapore: Springer Nature Singapore.
10. **Huutinh Tran**, Ngocdieu Vo, Huyanh Quyen, ‘A Cuckoo Search Algorithm for Transmission Expansion Planning’, *Proceedings of 2023 International Conference on System Science and Engineering ISBN: 979-8 3503-2294-1*, 2023.

INTRODUCTION

1. Reasons for choosing the topic

Electricity is one of the indispensable forms of energy in human life and production. In modern society, people cannot live without electricity. Because, without electricity, most equipment and machinery in daily life and industry cannot operate. Therefore, the energy demand for life and production increases in quantity and quality at the most reasonable price.

The main function of the power system is to produce, transmit, and distribute electricity to meet load requirements continuously with the high quality, and the reasonable price. Besides, power plants are often located far from load centers, and we need to have transmission and distribution for electrical energy from power plants to consumers. Therefore, the issue of improving the power grid is a necessary work in the development of the power system. The transmission expansion planning problem is to answer the questions "Where do we need to plan and expand?", "What capacity needs to be expanded?", "What is the total cost for planning?" , “How is the reliability of the power system improved after planning?”, etc. In the past 3 decades, there have been many different algorithms and approaches that have proven effective in solving the problems of planning and transmission power grids such as ant colony optimization, genetic algorithm, swarm optimization, tabu search, hidden enumeration zero – one, harmonic search and distributed search, etc. In which, artificial intelligence method is widely applied with advantages such as shortening the search time and determining the global optimal solution accurately. However, there are still some limitations in computational process for solving real world problems. Especially, methods which are used to address problems with interaction between variables. At the same time, the number of variables is huge and the constraints are complex, so it will be difficult for optimization tools to solve these problems.

In this thesis, the content of the research is to solve the power grid expansion planning problems, select advantageous methods to solve the power grid expansion planning problems, consider short-term constraints, and find the best solutions. In addition, this study also develops a novel method based on the foraging behavior of animals in nature for addressing the power grid expansion planning problems to determine the most suitable solution.

2. Research objectives

a. General objective

Apply artificial intelligence methods to optimally calculate the transmission expansion planning problem.

b. Detail objectives

Research on the transmission expansion planning problem and the distribution grid planning problem.

Research on applying the bound and branch algorithms to solve the transmission expansion planning problem and demonstrate the effectiveness of the applied algorithm through real power grids in the Mekong Delta region and provinces in the Mekong Delta such as Ben Tre and Hau Giang.

Research and develop a novel optimization algorithm based on the behavior of searching food sources of crows and Cuckoos to find the possible solutions for the transmission expansion planning problem.

Research on applying the modified PSO algorithm to the distribution power grid planning problem and prove the effectiveness of this method by comparing the obtained results with many other methods on the same power networks.

3. Research tasks

Develop the plan for expanding the power grid to meet load demand.

Propose artificial intelligent optimization methods to solve the transmission expansion planning and distribution planning networks.

The methods are implemented for addressing the power grid planning problem to minimize the investment cost and operating cost.

4. Research limits and scopes

The considering problems for planning: investment cost, operating cost, and power system reliability after having the power grid expansion planning.

The power grid expansion planning is based on existing load forecast results. The problems are solved with established conditions.

The bound and branch method is applied to solve the TEP problem, which is verified through real power networks in Ben Tre province, Hau Giang province, and the Mekong Delta region; The simulation results demonstrated the effectiveness of artificial intelligence methods of CS and CSA. These methods are used in solving the transmission expansion planning problem and proving the same power network.

Artificial intelligence methods have been proven effective on Garver's 6-node power system, IEEE 25-node power system, 46-node Southern Brazilian power system, and 32 nodes beam power networks.

The TEP problem considers constraints on balance of currents at node, power distribution on the line, priority rights, node voltage, phase angle, and reliability index.

The distribution power network planning problem considers constraints on node voltage limits, transmission capacity distribution, generation capacity, beam-shaped power network structure, node power balance, capacity lines, station capacity, distributed generation capacity, and budget limitations.

5. Research approaches and methodologies

Apply research methods that involve the relevant literatures, and theory combined with simulation.

Statistical processing with the support of Microsoft Excel.

Simulation is implemented by Matlab, Powerworld, and Fortran platforms.

6. Scientifics and practical significances

Develop artificial intelligence methods to solve the optimal grid expansion planning problem.

Apply Matlab software to calculate the optimal grid expansion planning problem through using the artificial intelligence methods.

The optimal solution will meet the requirements of the proposed objective function for minimizing investment cost as well as operating cost, and this will satisfy the constraints which involve the assessment of reliability indexes after planned grid.

The simple and effective algorithm can solve many the power grid planning problems.

Research and development of the novel artificial intelligence algorithms for solving the problem of the optimal grid expansion planning will quickly and accurately address the optimal grid expansion planning problem.

7. The structure of the thesis

The thesis is arranged in 5 chapters

Introductions

Chapter 1: Overview

Chapter 2: Transmission Expansion Planning Considering Reliability

Chapter 3: DC Transmission Expansion Planning

Chapter 4: Distribution Grid Planning

Chapter 5: Conclusion and Development

Chapter 1. OVERVIEW

1.1. Overview of the optimal transmission planning problem

This study examines power grid expansion plans from many different aspects [1].

1.2. Transmission expansion planning considering reliability

In the past, many scientists have paid attention to power system planning to meet load demand development in the future. The problem for power system managers and operators is to plan how to minimize investment cost while still ensuring safe operation. Therefore, it is extremely important for power system planning to consider the conditions of reliability criteria. Currently, there are many methods to solve the transmission system planning problem that consider reliability, with many effective results as follows:

- Bound and Branch algorithms [2-7].
- Swarm optimization algorithm (PSO) [8].
- Genetic algorithm (GA) [9].
- Frog leap algorithm (SFLA) [10].
- Ant colony optimization algorithm (ACO) [11].
- Differential evolution algorithm (DE) [12].

The transmission expansion planning using reliability criteria is built as follows: the proposal process is the first step in preparing the transmission expansion planning through applying probability evaluation methods of reliability indices to ensure the reliability of the power system. The power system modeling problem is defined as a set of integers and the uncertainty problem is considered by the probability model.

1.3. DC Transmission grid planning

The main goal of the transmission expansion planning problem (TEP) is to achieve the minimun investment cost but still meets the load demand development and reliable operation for the grid. Currently, the TEP is built for a multi-objective problem, so it cannot be solved by using classical methods. A number of algorithms have been proposed to solve the problems related to TEP using the strongly developed the meta-heuristic method, including the following algorithms:

- Ant colony optimization algorithm (ACO) [13].
- Artificial neural network connection algorithm [14].
- Artificial bee colony algorithm (ABC) [15].
- Differential evolution algorithm (DE) [16].
- Frog leap algorithm (SFLA) [17].
- Genetic algorithm (GA) [18,19,20,24,25].
- Tabu search algorithm (TSA) [21].
- Hidden enumeration algorithm 0-1 (Zero - One) [22].
- Swarm optimization algorithm (PSO) [23].

The linear programming problem can be solved effectively by using a complex dual algorithm. The result of the complex Lagrange multiplier solution combined with each constraint is achieved effectively. The objective function is provided taking into account both financial and technical aspects.

1.4. Distribution grid planning

The distribution grid planning involves many different tasks as:

- Finding the location of the transformer station and power supply.
- Allocating transformer stations and supply capacity.
- Allocating electrical load capacity.

These tasks must be performed while optimizing different goals such as economic cost and system reliability[28-32].

Not only distribution grid planning provides low costs but also it meet three key technical requirements: voltage drop limits, substation capacity limits, and power supply and beam configuration.

In the past, there have been many methods applied to the distribution planning power network problem. Currently, the artificial intelligence methods applied to power distribution grid planning have been developed because they achieve a high level of accuracy and provide the optimal solutions. The artificial intelligence methods include the following:

- Swarm optimization algorithm (PSO) [28,29,34].
- Genetic algorithm (GA) [33].

Another outstanding advantage of distribution system expansion planning using the differential evolution algorithm is that it provides several non-dominated solutions, allowing system managers and operators to decide on which solution to use the best based on the importance of different goals and taking into account budget constraints.

1.5. Methods applied to the grid expansion planning problem

The disadvantages of the previous study can be briefly presented as follows [18-23].

- The researchers did not pay attention to the issue of reactive power planning in the transmission expansion planning, even though it is very important information.
- Uncertainty conditions when changing generation sources are not considered and are always assumed to be met.
- All methods of the transmission expansion planning are simulated in the one-way power system model.
- Reliability constraints and safety standards are not considered in many previous methods.
- Flexible control equipment for the AC power system in the planning to expand the transmission grid is not considered appropriate.

Indeed, recently published studies are evaluated from a variety of perspectives with the common aim of meeting the needs of future load growth.

1.6. Research contents and contributions

In this thesis, the following contents are considered as:

Research on the transmission expansion planning problem considering the reliability constraints, the DC power grid expansion planning problem with considering the constraints on current balance at node, limit of power distribution on the line, priority right, node voltage phase angle limit and distribution grid planning, node voltage limit, transmission power distribution, generation capacity, beam power network structure, balancing node capacity, line capacity, station capacity, distributed generation capacity, budget constraints.

The research will apply the bound and branch algorithms to solve the transmission expansion planning problem with reliability constraints into the real power grid in Ben Tre province, Hau Giang province, and the Mekong Delta region.

The research also determines the strengths of the CS and CSA algorithms to find the optimal solution to the DC transmission grid planning problem proven on a standard power system; This will help power system operators easily manage under developed load conditions.

Research on modified PSO algorithm for applying the distribution grid planning problem to standard power network system to improve the search ability and avoids local convergence traps.

Chapter 2. TRANSMISSION EXPANSION PLANNING CONSIDERING RELIABILITY

2.1. Introduction

The transmission expansion planning problem must meet the conditions of the power generation model and meet the future electricity load demand and the need to assemble new connection lines to the total minimun investment costs and subject to reliability constraints. Developing the transmission grid expansion plan can be formulated as an integer programming problem considering reliability as presented below.

2.2. Problem formulation

2.2.1. Objective function

Normally, the transmission expansion planning problem is a function of the total minimum cost of C^T investment along with new investment in the transmission lines [5] described as follows:

$$minimize\, C^T = \sum_{(x,y)\in\rho}\left[\sum_{i=1}^{m(x,y)} C^{(i)}_{(x,y)} U^{(i)}_{(x,y)}\right] \quad (2.1) \qquad U^{(i)}_{(x,y)} = \begin{cases} 1 & P_{(x,y)} = P^{(0)}_{(x,y)} + P^{(i)}_{(x,y)} \\ 0 & P_{(x,y)} \neq P^{(0)}_{(x,y)} + P^{(i)}_{(x,y)} \end{cases} \quad (2.2) \qquad P^{i}_{(x,y)} = \sum_{j=1}^{i} \Delta P^{j}_{(x,y)} \quad (2.3)$$

2.2.2. Constraint conditions on grid reliability index standards

$$LOLE_{SYS}(P^{(i)}_{(x,y)}, \Phi) \leq_R LOLE \quad (2.4) \qquad LOLE_{SYS} = \sum^{n} K_i P_i (C_i - L_i) \quad (2.5)$$

$$LOLE_{SYS} = \sum_{i=1}^{n} p_k t_k \quad (2.6) \qquad LOLE_{SYS} = \sum_{i=1}^{n} (t_k - t_{k-1}) P_k \quad (2.7)$$

2.3. Application of the bound and branch methods

2.3.1. Modeling grid

The power system consists of many discrete elements. To determine the optimal transmission system planning using mathematical methods, the modeling power system is extremely important in this work[6].

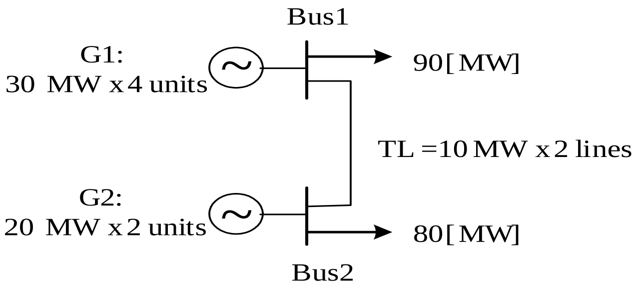


Figure 2.1 Single-line diagram of the power system

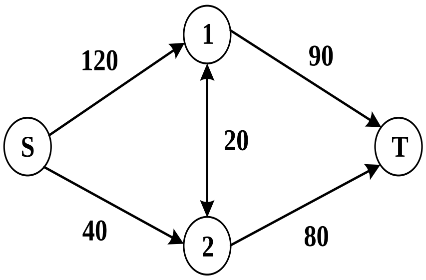


Figure 2.2 Equivalent network diagram

2.3.2. Maximum current theory and minimum cross-section

To determine where the minimum cross-section lies in the network, that place will need to be expanded. Therefore, the planning and operations need to identify bottle-necks as shown in Figure 2.3.

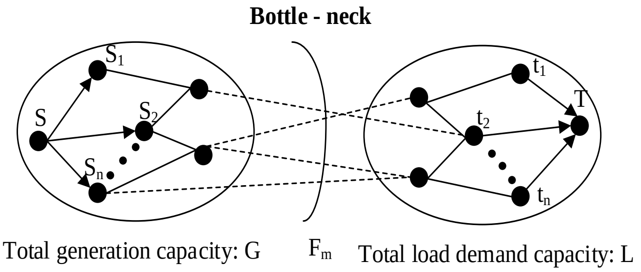


Figure 2.3 General power system simulation diagram

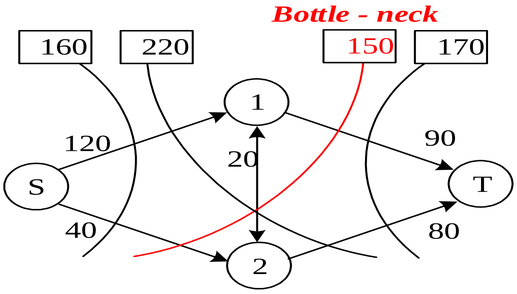


Figure 2.4 Minimum cross-section

2.3.3. Built an algorithm flowchart

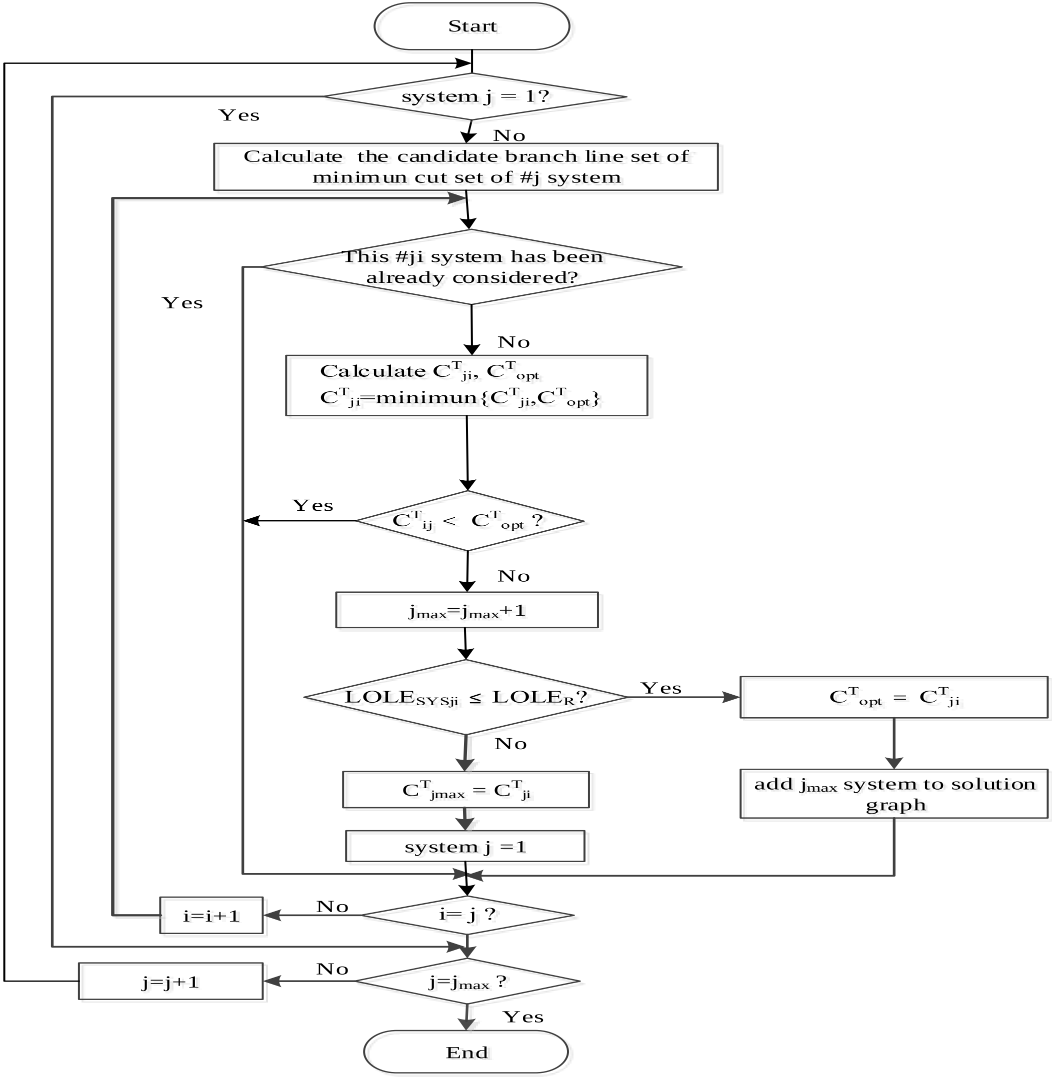


Figure 2.5 Algorithm flowcharts of bound and branch algorithms

2.4. Calculation Results and Discussions

2.4.1. Calculation results for the power grid Mekong Delta

Applying algorithms to solve the problem of planning power grids with voltage levels of 220kV or higher in the Mekong Delta region based on construction and operation plans for 500kV lines. The achieved results show all reliability indicators as presented in Table 2.1.

Table 2.1 Power system reliability criteria

Case	$LOLE_R$ hour/year	EENS MWh/year	ELC MW/Cur.year	$LOLE_{SYS}$ hour/year	EIR pu
N-1TL	22,0	10.710.400	5.013	21,4	0,867
	21,0	10.074.200	4.871	20,7	0,875
	20,0	9.454.600	4.724	20,0	0,883
N-2TL	50,0	24.498.900	4.954	49,5	0,696
	46,0	19.943.700	4.383	45,5	0,753
	45,0	19.119.200	4.268	44,8	0,763

Table 2.2 Optimal transmission system planning

Case	$LOLE_R$ hour/year	Request line extension	Cost M$
N-1TL	22,0	T^1_{32-14} , T^2_{32-14} , T^1_{9-10} , T^1_{11-12}	40
	21,0	T^1_{32-14} , T^2_{32-14} , T^1_{9-10} , T^1_{11-12} , T^1_{6-7}	47
	20,0	T^1_{32-14} , T^2_{32-14} , T^1_{9-10} , T^1_{1-5} T^1_{11-12} , T^1_{6-7} , T^1_{15-16}	64
N-2TL	50,0	T^1_{32-14} , T^1_{9-10}	20
	46,0	T^1_{32-14} , T^1_{9-10} , T^1_{11-12}	30
	45,0	T^1_{32-14} , T^1_{9-10} , T^1_{11-12} , T^1_{6-7}	37

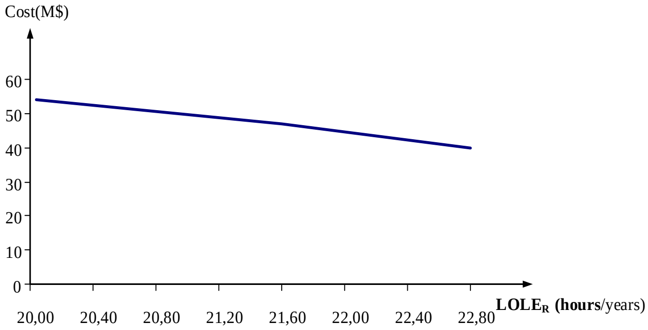


Figure 2.6 Relationship of Reliability criteria and total cost in Case 1

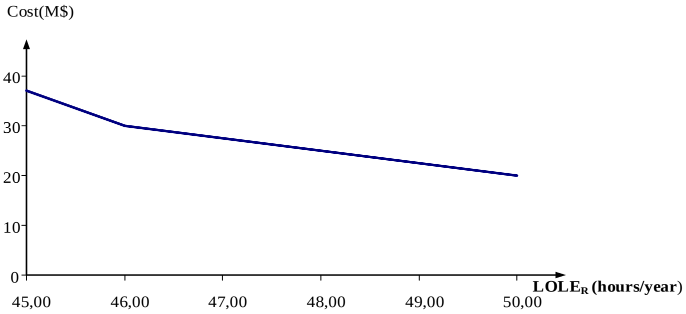


Figure 2.7 Relationship of Reliability criteria and total cost in Case 2

Used PowerWorld software to check the stability and load capacity of lines and transformers after renovation to see if they are overloaded like before renovation, and voltage parameters after renovation.

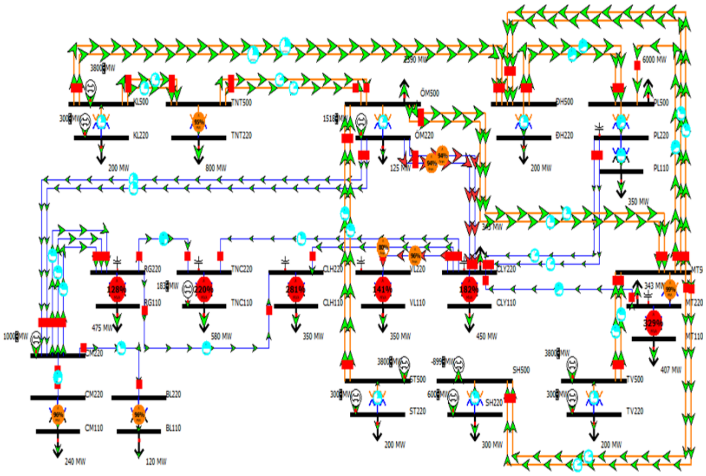


Figure 2.8 Power system before planning

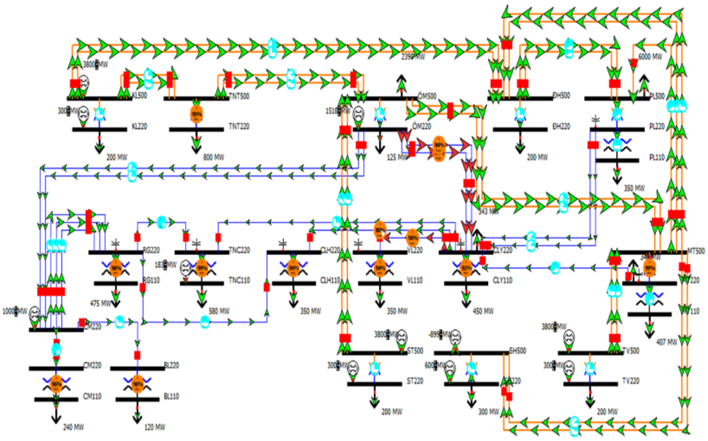


Figure 2.9 The following system expands to 7 additional routes with $LOLE_R$ = 20.00 (hours/years)

Figure 2.15 shows that when the load increases, the connection positions RG220 – RG110, TNC220 – TNC110, CLH220 – CLH110, VL220 – VL110, CLY220 – CLY110, MT220 – MT110 exceed the load by over 100% and Figure 2.16, the results show that After planning, the system was invested in 7 new routes T^1_{32-14}, T^2_{32-14}, T^1_{9-10}, T^1_{1-5}, T^1_{11-12}, T^1_{6-7}, T^1_{15-16} so there are no overloaded entrances. Prove that the results for new investment expansion are suitable to meet load demand

2.4.2. Calculation results for Ben Tre province's power grid

Implement optimal expansion planning of Ben Tre province's power grid at voltage levels of 220kV and 110kV. The achieved results show all reliability indicators of the power system after planning.

Table 2.3 System reliability criteria

Case	Year	$LOLE_R$ hours/yr	EENS MWh/yr	ELC MW/ Cur.year	$LOLE_{SYS}$ hours/yr	EIR pu
N-1TL	2024	20,0	0	0	0	1
	2030	20,0	60.284,8	100.000	602,848	0,988
	2045	20,0	54.693,2	100.000	564,932	0,990
N-2TL	2024	20,0	0	0	0	1
	2030	20,0	0	0	0	1
	2045	20,0	0	0	0	1

Table 2.4 Optimized transmission system planning

Case	Year	$LOLE_R$ hours/yr	Line new	Cost M$
N-1TL	2024	20,0	T^1_{1-9}	1
	2030	20,0	T^1_{1-9}	1
	2045	20,0	T^1_{1-9}	1
N-2TL	2024	20,0	T^1_{1-9}	1
	2030	20,0	T^1_{1-9}, T^1_{2-10}, T^1_{3-12} ,T^1_{4-11}, T^1_{5-14}, T^1_{6-13}, T^1_{7-15}, T^1_{8-16}, T^1_{6-2},	10
	2045	20,0	T^1_{1-9}, T^1_{2-10}, T^1_{3-12} T^1_{4-11}, T^1_{5-14}, T^1_{6-13}, T^1_{7-15}, T^1_{8-16}, T^1_{6-2},	10

The power grid diagram after planning for the N-1TL power system case is shown in Figure 2.10 to Figure 2.11; The solid lines represent existing lines and transformer stations, and the red dotted lines represent lines and transformer stations that need additional investment and expansion to meet load demand.

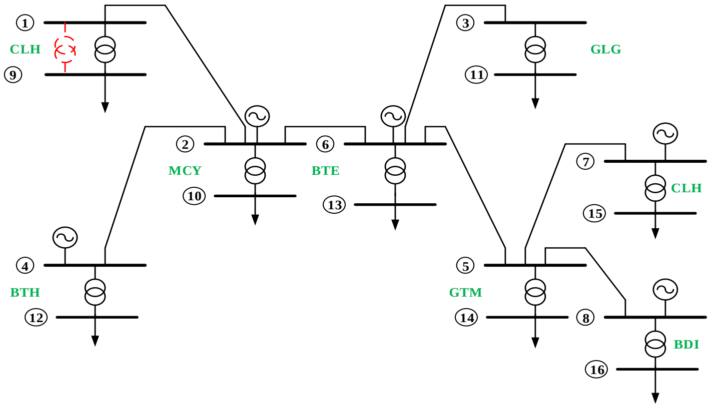


Figure 2.10 Power grid after long-term planning in 2045, case N-1TL

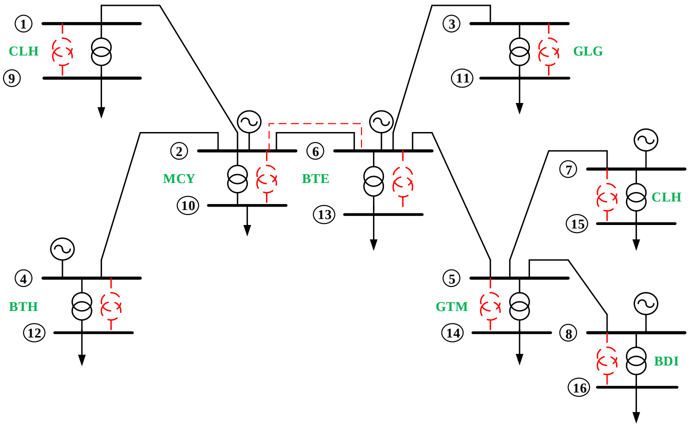


Figure 2.11 Power grid after long-term planning in 2045, case N-2TL

Check the stability of the power grid system blue circles on lines and transformer stations: load less than 100%. The red circle on lines and transformer stations: overload warning

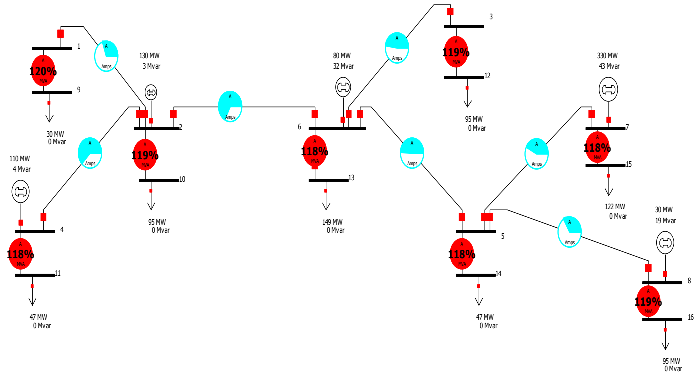


Figure 2.12 Power system before planning in 2045

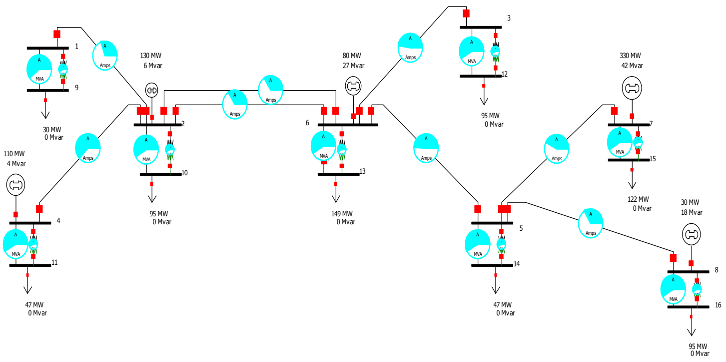


Figure 2.13 Power system after N-2TL case expansion in 2045

Figure 2.12 shows when the load increases according to the forecast results of connecting lines 1-9, 4-11, 2-10, 6-13, 3-12, 5-14, 7-15, and 8-16 exceeding overload of over 100% capacity and Figure 2.13, the results show that the system after planning has no overloaded entry points, proving that the results of a new expansion investment are suitable to meet the additional demand load. The algorithm has proven its feasibility in the long-term planning of 220kV and 110kV high-voltage power grids.

2.4.3. Calculation results for Hau Giang province's power grid

This study will apply to power grids with voltage levels from 110kV to 220kV based on the plan for construction and operation of the power system along with power system development. This study used the results of long-term load demand forecasting. The results are shown in Table 2.5. The more the busbar node reserve increases, the more reliable the electrical system is. This will increase the investment costs.

Table 2.5 Results of the TEP by reserve level

CASE	BRR (%)	NEW INVESTMENTS	Cost VND.10^9
1	0	T_{3-8}^{1}, T_{3-8}^{2}, T_{3-4}^{1}, T_{7-19}^{1}, T_{7-19}^{2}, T_{8-12}^{1}, T_{20-21}^{1}, T_{19-20}^{1}, T_{8-21}^{1}, T_{12-19}^{1}, T_{10-15}^{1}	2.089
2	5	T_{3-8}^{1}, T_{3-8}^{2}, T_{3-8}^{3}, T_{3-4}^{1}, T_{7-19}^{1}, T_{7-19}^{2}, T_{8-12}^{1}, T_{20-21}^{1}, T_{19-20}^{1}, T_{8-21}^{1}, T_{12-19}^{1}, T_{10-15}^{1}	2.099
3	10	T_{3-8}^{1}, T_{3-8}^{2}, T_{3-8}^{3}, T_{3-4}^{1}, T_{7-19}^{1}, T_{7-19}^{2}, T_{8-12}^{1}, T_{20-21}^{1}, T_{19-20}^{1}, T_{8-21}^{1}, T_{12-19}^{1}, T_{10-15}^{1}	2.099
4	15	T_{3-8}^{1}, T_{3-8}^{2}, T_{3-8}^{3}, T_{3-4}^{1}, T_{7-19}^{1}, T_{7-19}^{2}, T_{8-12}^{1}, T_{8-12}^{2}, T_{12-19}^{1}, T_{12-19}^{2}, T_{10-15}^{1}	2.225
5	20	T_{3-8}^{1}, T_{3-8}^{2}, T_{3-8}^{3}, T_{3-4}^{1}, T_{7-19}^{1}, T_{7-19}^{2}, T_{7-19}^{3}, T_{8-12}^{1}, T_{8-12}^{2}, T_{12-19}^{1}, T_{12-19}^{2}, T_{10-15}^{1}	2.381
6	25	T_{3-8}^{1}, T_{3-8}^{2}, T_{3-8}^{3}, T_{3-4}^{1}, T_{7-19}^{1}, T_{7-19}^{2}, T_{7-19}^{3}, T_{8-12}^{1}, T_{8-12}^{2}, T_{12-19}^{1}, T_{12-19}^{2}, T_{10-15}^{1}	2.381

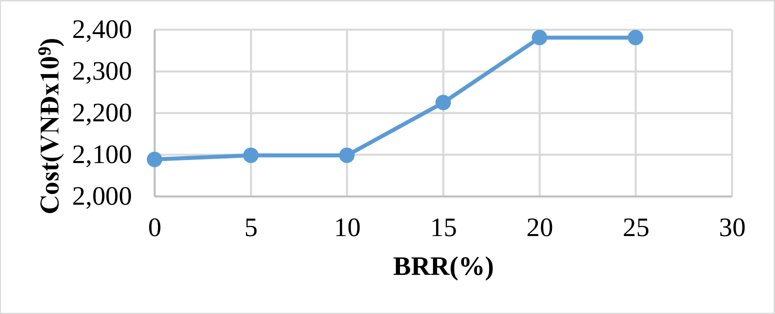


Figure 2.14 Total investment cost curve according to BRR reserve requirement (%)

The single-line diagram of the transmission system will be expanded to meet increased load requirements as shown in Figure 2.15.

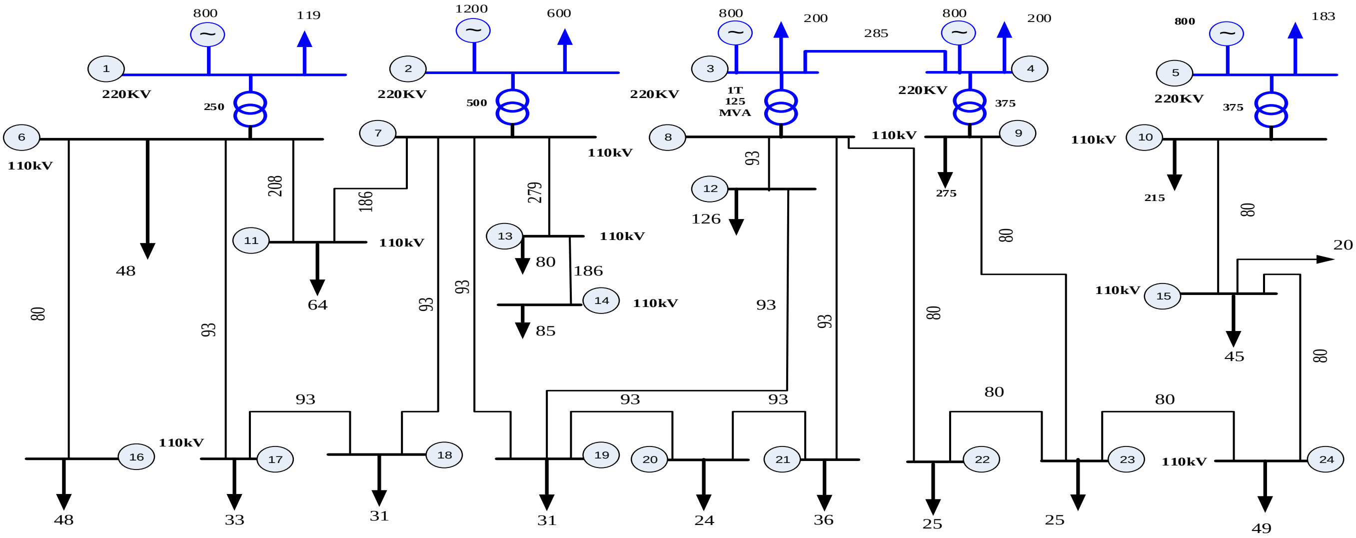


Figure 2.15 Single-line diagram of transmission system (BRR=5%)

Evaluation, outage cost curve, and optimal BRR, IEAR = 3,000 (VND/kWh)

Table 2.6 Reliability criteria and total cost

Case	BRR (%)	Construction costs VNĐ.10^9	EENS MWh/day	EENS MWh /year	Power outage costs VNĐ10^9	Total costs VNĐ.10^9
1	0	2.089	218,878	79.890,47	2.396,71	4.485,71
2	**5**	**2.099**	**210,855**	**76.962,08**	**2.308,86**	**4.407,86**
3	**10**	**2.099**	**210,855**	**76.962,08**	**2.308,86**	**4.407,86**
4	15	2.225	207,285	75.659,03	2.269,77	4.494,77
5	20	2.381	205,524	75.016,26	2.250,49	4.631,49
6	25	2.381	205,524	75.016,26	2.250,49	4.631,49

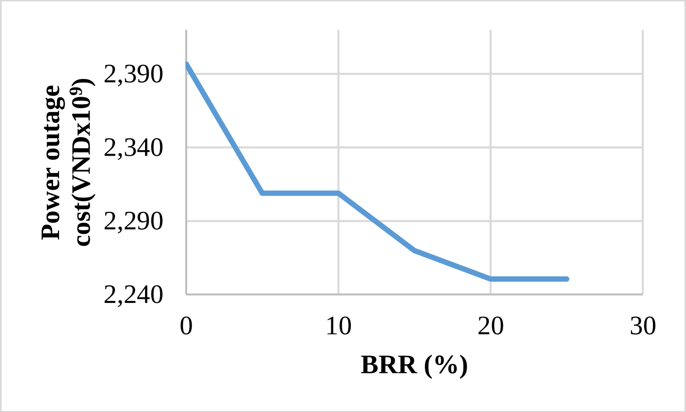


Figure 2.16 Customer outage cost curve

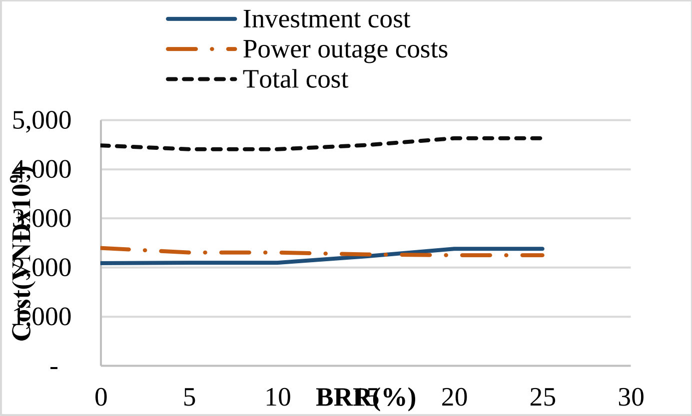


Figure 2.17 Total cost curve and reliability optimal point

Thus, by applying the above algorithm to check the optimal value in the transmission system planning of Hau Giang province, the optimal reserve value of the planned power system at BRR = 5% and 10%.

d. Test power capacity distribution by PowerWord software

Figure 2.18. Indicates lines and transformer stations are overloaded by over 90%. Figure 2.19. is a figure showing that the power grid has been invested and expanded according to the requirement of BRR reserve = 5%.

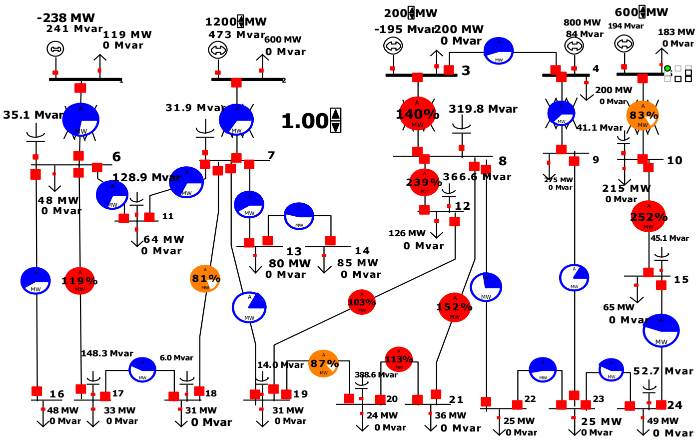


Figure 2.18 System before planning inspection

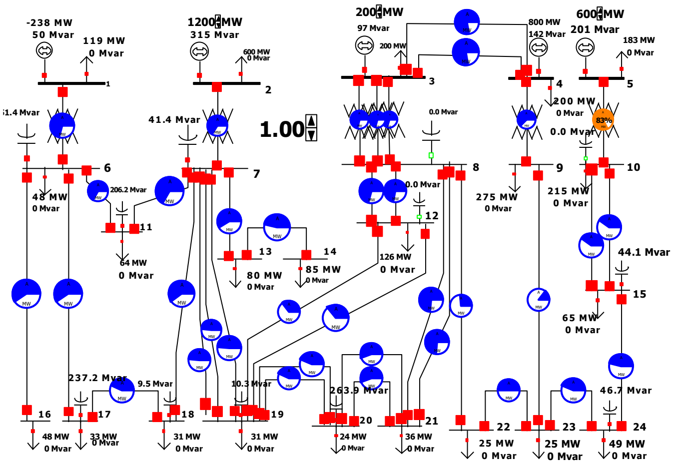


Figure 2.19 System after checking planning with BRR=5% reserve

Research results show that the method of considering optimal reserve conditions in transmission system planning has been successfully applied and similarly to the above using the PowerWorld software tool to check the system first. and after the new expansion investment planning, Figure 2.30 shows when the load increases according to the load forecast results of connecting routes 6-17, 3-8, 8-12, 12-19, 20-21, 8-21, 10-15 exceeded the load above 100% capacity and Figure 2.3 results also show that the system after planning has been improved without overloaded entrances, so the results are exported. The new investment expansion is appropriate to meet the load demand.

2.5. Conclusion for chapter 2

The above content focuses on solving the TEP problem considering reliability in transmission system planning using the bound and branch method. Use the PowerWorld software tool to verify the system after planning.

This study also considers the reserve level in transmission system planning, the results have been proven on the real power system in Hau Giang province in the Mekong Delta.

The bound and branch method applying the TEP problem have been researched, implemented, and published in works [4-7] and works [9]. In Chapter 3, the artificial intelligence CS and CSA methods are presented to solve the TEP problem in the DC model with the objective function of the total minimun investment cost to satisfy the economic and operational constraints.

Chapter 3: DC TRANSMISSION EXPANSION PLANNING

3.1. Introduction

The DC model is the most common model which is used to model the TEP problem because it is less complex and easier to solve, without requiring much time; At the same time, the DC model has relatively high accuracy.

3.2. Problem formulation

3.2.1. Objective functions

The objective function of the grid expansion planning is to minimize total investment costs which satisfying the economic and operating constraints. The classic DC model used for TEP is formatted as follows:

$$TC = \sum_{i,j\in\Omega} \beta \times cl_{ij} \times n_{ij} \qquad (3.1)$$

$$cl_{ij} = (clf_{ij} + clv_{ij}) \times l \qquad (3.2)$$

3.2.2. Constraints

$$P_i = \sum_{j=1}^{NB} P_{ij} + d_i \quad (i = 1, 2, \ldots., NB), \; (\forall i, j \in \Omega) \qquad (3.3)$$

$$\sum_{y=1}^{Nu_i+Nc_i} P_{yi} = d_i + \sum_{j=1}^{NB} \gamma_{ij} \times (n_{ij}^0 + n_{ij}) \times (\theta_i - \theta_j) \qquad (3.4)$$

$$(n_{ij}^0 + n_{ij}) \times |(\theta_i - \theta_j)| \times |\gamma_{ij}| \le (n_{ij}^0 + n_{ij}) \times P_{ij}^{max} \qquad (3.5)$$

$$|(\theta_i - \theta_j)| \times |\gamma_{ij}| \le P_{ij}^{max} \qquad (3.6)$$

$$0 \le n_{ij} \le n_{ij}^{max} \qquad (3.7)$$

$$|\theta_i| \le |\theta_i^{max}| \qquad (3.8)$$

3.3. Apply artificial intelligence methods

3.3.1. Descriptive algorithms

The Cuckoo Search (CS) algorithm is one of the most recent natural algorithms developed by Yang and Deb in December 2009 [23]. In addition, this algorithm is enhanced by so-called Lévy flights, further by simple random isotropic gradients. [26].

The Crow Search Algorithm (CSA) is one of the natural search algorithms built by Alireza Askarzadeh in March 2016 [27]. CSA is an algorithm for hiding food and can recall food hiding places from several months ago; The crow can deceive others into protecting food by leading to another place.

3.3.2. Problem model applying algorithms

3.3.2.1. Cuckoo Search Algorithm (CS)

Real systems are very complex which they cannot be accurately modeled by computer algorithms in their fundamental formation. An egg represents a solution and stores in the same nest.

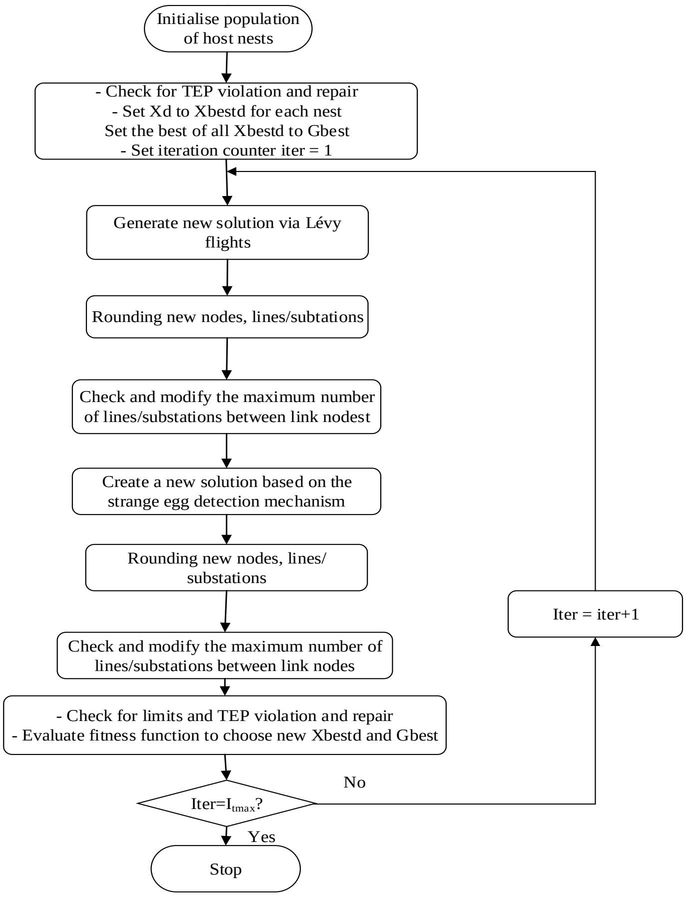
i. Cuckoos search for the most suitable nest to lay their eggs to maximize their survival rate. An elite selection strategy is applied to have the best eggs (the best solution near the optimal value) so that other bird eggs have a chance to develop and become adult howler bird (next generation).

ii. The number of other bird species' nests placed in. Other birds discover eggs that are not theirs (a bad solution from the optimal value) with a probability of these eggs being thrown out or the nest being left behind and a new nest being completed. built in a new location. The egg matures and lives on in the next generation.

3.3.2.2. Crow Search Algorithm (CSA)

The principles of CSA listed are: crows live in flock formations, crows remember their hiding places, crows chase other species to steal and crows protect. their hiding place from being stolen as far as possible.

3.3.3. The algorithms apply to the problems



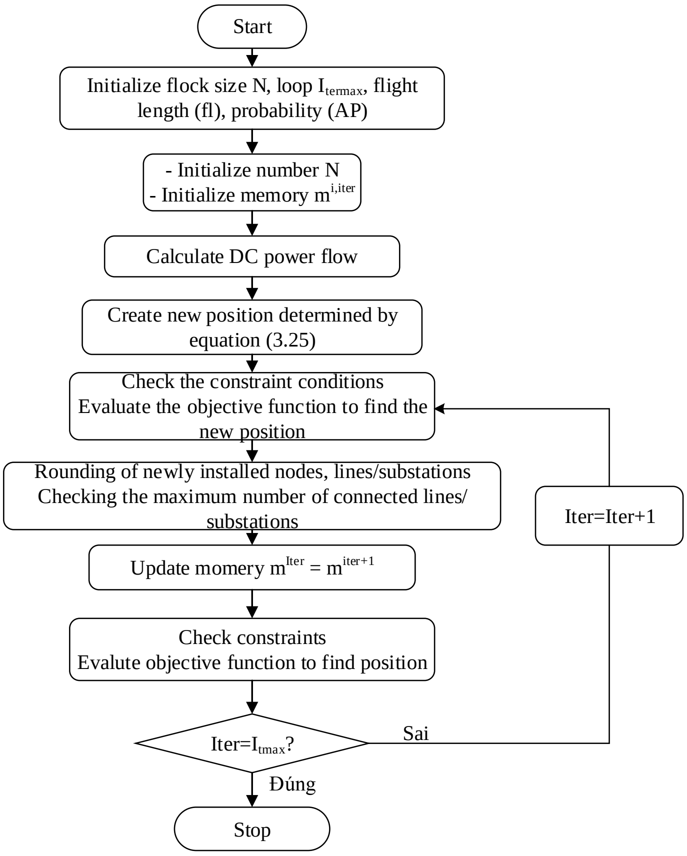


Figure 3.1 CS - TEP algorithm flow chart

Figure 3.2 Flow chart of CSA - TEP algorithm

3.4. Results and discussion

3.4.1. Apply the Crow Search algorithm

a. Garver's 6-node power system

Applying the CSA algorithm to solve the TEP problem is tested on a Garver's 6-node power system. This is the Garver standard electrical system with 6 nodes and 15 branches [13]. The total load demand is 760MW and the parameters are given in Table 3.1. Shows source parameters and load locations; Table 3.2 represents the number of branch links between nodes.

Table 3.1 Generation parameters and load demands of the Garver's 6-node power system.

Bus	**Generator power (MW)**		**Load power (MW)**
	Max	**Level**	
1	150	50	80
2	-	-	240
3	360	165	40
4	-	-	160
5	-	-	240
6	600	545	-

Table 3.2 Parameters of connecting branches of the Garver's 6-node power system.

Banch	n_{ij}^{0}	***r (p.u)***	***x (p.u)***	P_{ij}^{max} ***(MW)***	**Invesment costs ($10^3$$)**
1-2	1	0,10	0,40	100	40
1-3	0	0,09	0,38	100	38
1-4	1	0,15	0,60	80	60
1-5	1	0,17	0,20	100	20
1-6	0	0,05	0,68	70	68
2-3	1	0,10	0,20	100	20
2-4	1	0,08	0,40	100	40
2-5	0	0,01875	0,31	100	31
2-6	0	0,15	0,30	100	30
3-4	0	0,15	0,59	82	59
3-5	1	0,25	0,20	100	20
3-6	0	0,12	0,48	100	48
4-5	0	0,16	0,63	75	63
4-6	0	0,0375	0,30	100	30
5-6	0	0,15	0,61	78	61

b. Steps to apply Crow search algorithm to TEP and results

The steps of the CSA search algorithm can be described as follows: the variable x will be the food hiding location and a feasible location will be selected as a solution. The population is fixed at 15 for all systems, the redundancy probability is set to 0.1, and the flight length is 2. The maximum number of iterations for CSA is 500 for the system. Diagram Figure 3.3. Shows the red lines that need new investment and expansion. The obtained results are compared with artificial intelligence algorithms [13].

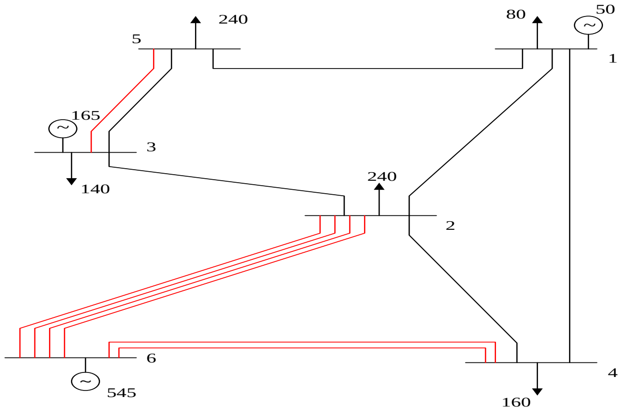


Figure 3.3 Garver's 6-node power system after planning

Table 3.3 Results of investment cost optimization

Methods	n_{ij}	**Investment costs (10^3\$)**			**Standard deviations**	**Calculation times (*s*)**
		Bad	**Average**	**Good**		
GA	7	368	227	200	41,27	46,686
TS	7	244	218	200	26,56	36,983
CSA	7	200	200	200	0	15,72

The results obtained have lower investment costs obtained by the CSA method and shorter calculation time. This proves that the CSA method can find more optimal solutions than other methods.

3.4.2. Applying the Cuckoo Search algorithm

a. Steps to apply the Cuckoo search algorithm to TEP and the results of the IEEE 25-node power system

The optimal solution of CS algorithm for the IEEE 25-node power system has four main parameters that must be determined in advance: the number of groups 36, the maximum number of repetitions of link branches 4, the distribution coefficient 1,5 and the probability of foreign eggs being detected in the nest its value varies from 0.1 to 0.9 with a step size of 0.1. The maximum number of loops for CS is 5000. The power system after network planning is shown in Figure 3.4, the solid red lines need the expansion investment.

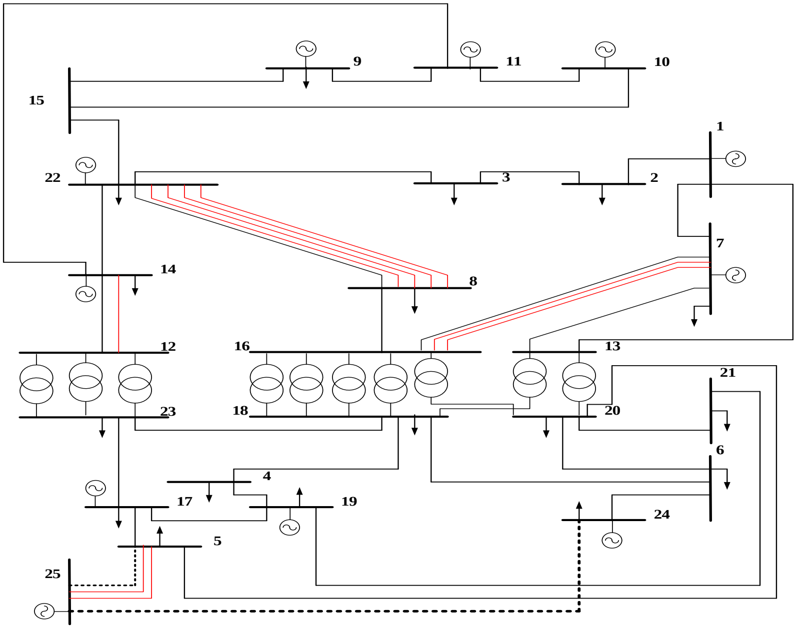


Figure 3.4 IEEE 25-node power system after planning

Statistical results comparing the CS method and the ABC method with the IEEE 25-node power system are concerned with investment costs and standard deviations shown in Table 3.5. Besides, the results of the method are also compared with ANN, GA&TS, DEA, and CGA methods in terms of investment costs as shown in Table 3.6.

Table 3.5 Results of optimizing investment costs for the IEEE 25-node power system

No	Planning results	Method ABC	Method CS
		Investment costs ($)	**Investment costs ($)**
1	Good ($)	112.046.000	111.371.000
2	Average ($)	113.847.250	111.371.000
3	Bad ($)	115.201.000	111.371.000
4	Standard deviation	1.095.358	0

Table 3.6 Comparison of results of methods tested on the IEEE 25-node power system

No	Methods	Investment costs ($)
1	ANN, GA&TS	114.560.000
2	DEA	114.383.000
3	CGA	114.526.000
4	ABC	112.046.000
5	**CS**	**111.371.000**

The results obtained are lower than the investment costs obtained by the CS method. This proves that the CS method has better solution quality

b. Steps to apply the Cuckoo search algorithm to TEP and results for the southern Brazilian 46-node power system

CS algorithm to obtain the optimal solution for the southern Brazilian 46-node power system has four main parameters that must be predetermined: the number of groups 79, the maximum number of iterations of connecting branches ranges from 5000 for the system, the distribution coefficient 1.5 and the probability of foreign eggs being detected in the nest its value varied from 0.7 to 0.9 with a step size of 0.1.

Table 3.7 Results of the 46-node Brazilian grid expansion planning system

From	To	Lines new	Costs $(10^3\$)$	Investment costs $(10^3\$)$
2	5	1	2.581	2.581
5	11	5	6.167	30.835
11	46	2	8.178	16.356
12	14	1	5.106	5.106
17	19	1	8.715	8.715
20	21	2	8.178	16.356
23	24	1	5.308	5.308
24	25	1	8.178	8.178
25	32	1	37.109	37.109
26	27	1	5.662	5.662
29	30	2	8.178	16.356
31	32	1	7.052	7.052
42	43	2	8.178	8.178
Total investment costs $(10^3\$)$				**175.970**

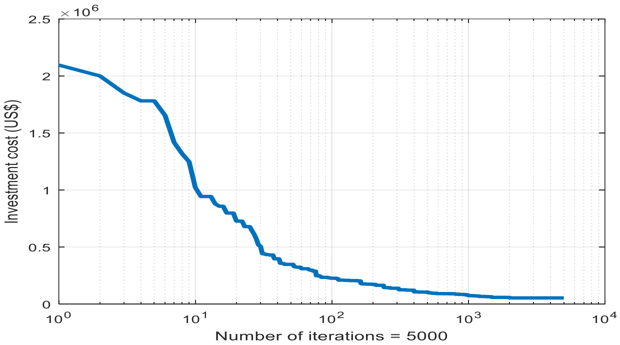


Figure 3.5 Total investment cost versus number of iterations

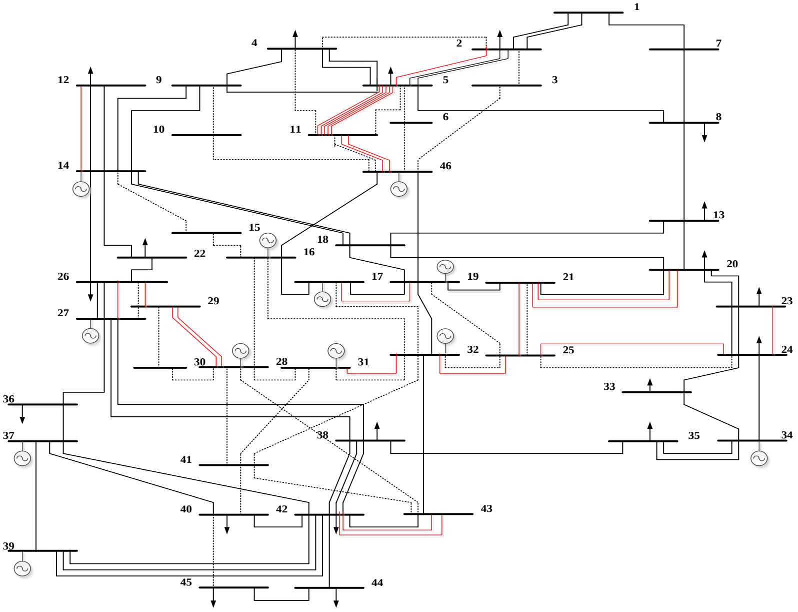


Figure 3.6 southern Brazilian 46-node power system after planning

Statistical results of the CS Search algorithm applied to solve the TEP problem in terms of investment costs and standard deviation are shown in Table 3.8. Besides, the results of the method are also compared with the BF-DEA and GA methods in terms of investment costs shown in Table 3.9 and compared with the HS algorithm [28].

Table 3. Results of optimizing investment costs for the southern Brazilian 46-node power system

No	**Planning results**	**Method CS** **Investment costs ($10^3\$$)**
1	Good ($)	175.970.000
2	Average ($)	175.970.000
3	Bad ($)	175.970.000
4	Standard deviation	0

Table 3.9 Comparison of the results of the methods tested on the southern Brazilian 46-node power system

No	**Methods**	**The evaluated number of the objective functions**	**Optimal investment costs ($10^3\$$)**
1	HS	$2,40.10^5$	337.809.000
2	BF-DEA	$2,98.10^5$	361.863.000
3	GA	$2,67.10^6$	432.350.000
4	**CS**	**$5,40.10^4$**	**175.970.000**

Table 3.10 Comparison of results of HS and CS methods, the number of individuals is 50

Method	**HS**				**CS**			
Pa	0,99	0,98	0,95	0,9	0,99	0,98	0,95	0,9
Expansion investment costs (x10^6 $)	337,809	337,809	337,809	340,679	323,443	324,687	322,755	323,847
Standard Deviation	21,39	18	15,55	48	19,2	18,7	13,4	36,67
The evaluated number of the objective functions	239.550	96.800	172.600	230.700	21.380	62.242	45.966	72.416

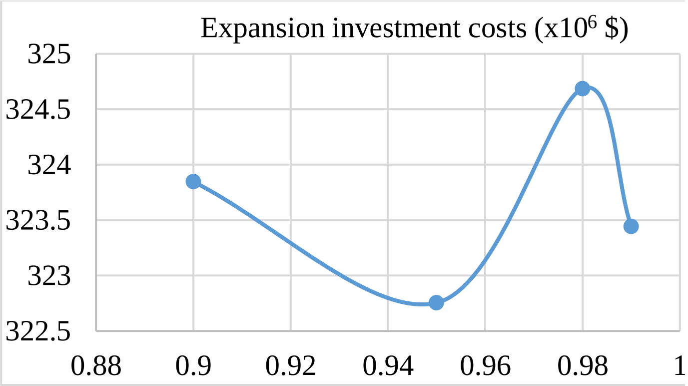


Figure 3.7 Graph showing the cost of expanding the power system of a CS with several individuals of 50

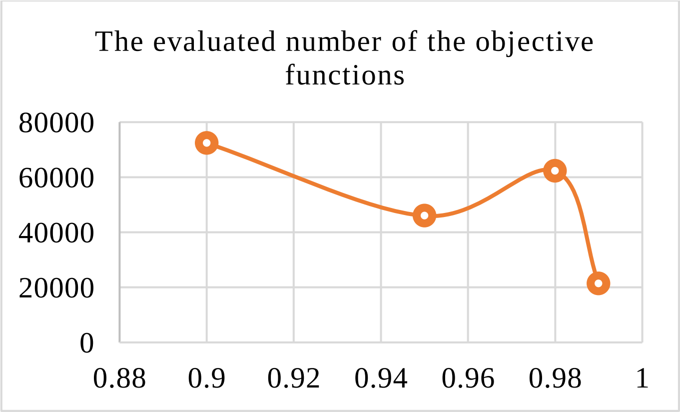


Figure 3.8 Graph showing the evaluation of the electrical system objective function of the CS number of individuals is 50

This study chooses the number to change from 25 to 100 individuals to 50, the optimal probability is 0.98 for the TEP problem. The calculation results of the CS search algorithm are compared with the HS algorithm [28]

Table 3.11 Comparison of results of HS and CS methods with p_a of 0.98

Methods	**HS**				**CS**			
Number of individuals	25	50	75	100	25	50	75	100
Expansion investment costs (x10^6 $)	340,679	337,809	337,809	337,809	322,588	324,791	323,597	325,280
Standard Deviation	42	18	29,5	17,809	39,5	17,6	25,6	16,2
The evaluated number of objective functions	79.900	96.800	117.975	155.300	262.996	13.787	16.900	10.620

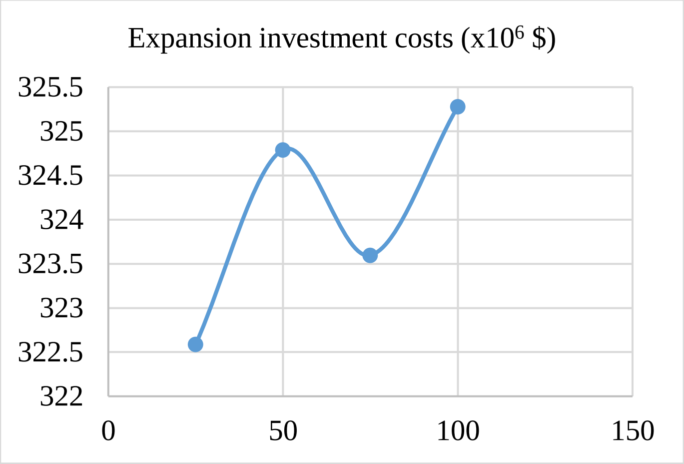


Figure 3.9 Graph showing the cost of expanding CS's power system with p_a of 0.98

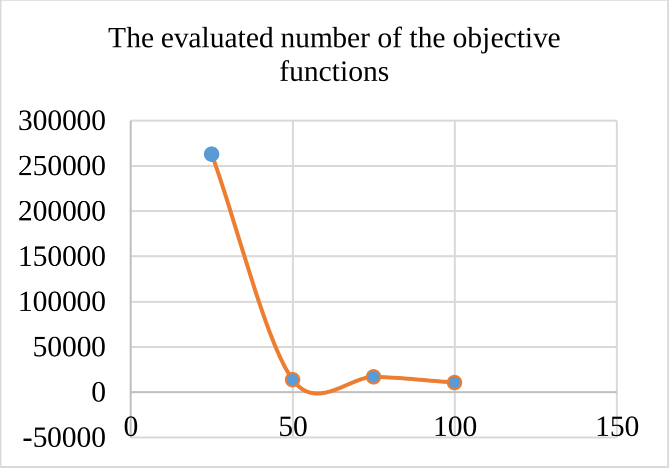


Figure 3.10 Graph showing assessment of CS's electrical system objective function with p_a of 0.98

According to Table 3.11, comparing the results of four cases with the number of individuals 25, 50, 75, and 100 shows that the investment cost, standard deviation, and enjoyment function value of the CS method are lower than the HS method. Figure 3.9 and Figure 3.10 respectively show that as the number of individuals increases, the cost increases, and the evaluation of the liking function decreases when considered with the same probability value of 0.98. Therefore, it is proven that the effectiveness of the CS method is considered along with the power system.

3.5. Conclusion for chapter 3

The results show that the proposed CSA and CS algorithms applied to the TEP problem provide better solutions in all cases with the evaluative numbers of the objective function.

The CSA method has been applied to solve the TEP problem and demonstrated through the Garver's 6-node power system. The results demonstrate the effectiveness of the CSA method is more optimal than other methods solving the same electrical network.

Besides, the CS Search method has also solved the TEP problem proven on the IEEE 25-node power system and the power system south Brazilian 46 nodes, resulting in the most minimal cost.

Furthermore, The obtained results by using the CS method have been compared with many other methods solving the same power system network, showing optimal efficiency, low investment costs, and shorter calculation time. This proves that the CSA and CS methods have better solution quality. The CSA and CS methods applying the TEP problem have been researched, implemented, and published in works [1], [8] and works [10]. In Chapter 4, the MPSO method is presented to solve the power grid planning problem with multi-objective functions of investment planning, reliability, and system losses with many constraints.

Chapter 4. DISTRIBUTION GRID PLANNING

4.1. Introduction

Distribution grid planning has two types of planning according to planning experience: short-term planning and long-term planning[29-34]. The purpose of short-term planning is to ensure that the system can continuously supply electricity to customers by adding distribution systems to be implemented shortly.

4.2. Problem formulation

4.2.1 Objective function

a. Minimize investment and operating costs

Investment and operating costs are built according to formulas (4.1) and (4.2) and are expressed as follows:

$$Cost_{Investment}(X) = \sum_{t=1}^{N_{Stage}} C_{NPV}^{t} \left(\sum_{k=1}^{N_B^t} IC_k + \sum_{S=1}^{N_S^t} IC_S + \sum_{dg=1}^{N_D^t} IC_{dg} \right) \tag{4.1}$$

b. Minimum undelivered energy

$$END_i = P_i \sum_{i,j \in V, j \neq i} (U_{j,i} + U'_{j,i}) \tag{4.4}$$

$$END(X) = \sum_{t=1}^{N_{Stage}} \sum_{j=1}^{N_{bus}^t} END_j^t \tag{4.5}$$

$$F_2(X) = END \tag{4.6}$$

d. Minimum voltage stability index based on short circuit capacity

$$S_{sc,j} = \frac{E_{th,j}}{Z_{th,j}} \tag{4.9}$$

$$I_{SCC,j} = \frac{S_{SC\,min,j}}{S_{SC}} \tag{4.10}$$

$$Cost_{Operation}(X) = \sum_{t=1}^{N_{Stage}} C_{NPV}^{t} \left(\sum_{k=1}^{N_B^t} OC_k + \sum_{S=1}^{N_S^t} OC_S + \sum_{dg=1}^{N_D^t} OC_{dg} \right) \tag{4.2}$$

$$F_1(X) = Cost_{investment} + Cost_{Operation} \tag{4.3}$$

c. Minimized power loss

$$P_{Loss}(X) = \sum_{t=1}^{N_{Stage}} \sum_{k=1}^{N_{branch}^t} \left(R_k^t \times \left| I_k^t \right|^2 \right) \tag{4.7}$$

$$F_3 = P_{Loss} \tag{4.8}$$

$$F_4 = \sum_{t=1}^{N_{Stage}} \frac{1}{N_{bus}^t} \sum_{i=1}^{N_{bus}^t} I_{SCC,i}^t \tag{4.11}$$

$$v_j^{min} \leq v_j \leq v_j^{max} \tag{4.12}$$

$$PF_k \leq PF_k^{max} \tag{4.13}$$

The structure of the distribution system should be radially arranged due to the simple protection scheme of the distribution network. For this purpose, the branch-bus ratio matrix is used to check the structure of the network.

4.2.2. Constraints

a. Limit the voltage at the nodes

$$v_j^{min} \leq v_j \leq v_j^{max} \tag{4.14}$$

b. Distribution of transmission capacity of branches

$$PF_k \leq PF_k^{max} \tag{4.15}$$

c. Output power of distributed generation source

$$P_{dg} \leq P_{dg}^{max} \tag{4.16}$$

d. Ray-shaped structure of the distribution grid

The structure of the distribution grid should be arranged in a ray shape due to the simple protection scheme of the distribution grid. For this purpose, the branch–node matrix is used to examine the structure of the network. The branch-node matrix of A is an N_{branch} x N_{bus} matrix in which the k_{th} row corresponds to the k_{th} branch in the network and the j_{th} column of the matrix corresponds to the j_{th} bus in the system. This has a branch leaving the node. The branch-node matrix is calculated as follows:

If branch k (corresponding to the k_{th} row) leaves the j_{th} node (corresponding to the j_{th} column), then the matrix element (a_{kj}) is equal to 1.

- If the k_{th} branch (corresponding to the k_{th} row) connects to the j_{th} node (corresponding to the j_{th} column), then the matrix element (a_{kj}) will be -1.

- All remaining cases will be 0.

- When the number of nodes is more than the number of branches in the ray-shaped distribution grid, the first column of the branch-node matrix should be deleted to have a square matrix A'.

- If the determinants of the branch-node matrix A' are 1 or -1, the graph of the grid will be ray-shaped.

4.3. Apply artificial intelligence methods

4.3.1. PSO algorithm

In the original PSO algorithm, each element is called an "instance position" and can move in multidimensional space. The algorithm is based on simulating the foraging activities of a flock of birds[30].

4.3.2. Modified PSO algorithm

a. Modified PSO algorithm

$$v_i^{iter+1} = k.[\omega.v_i^{iter} + c_1.rand(.).\left(x_i^{best} - x_i^{iter}\right) + c_2.rand(.).(x^{Gbest} - x_i^{iter}) \qquad (4.17)$$

$$x_i^{iter+1} = x_i^{iter} + v_i^{iter+1} \qquad (4.18)$$

b. Multi-target strategy

$$\forall m \in \{1, 2, \dots, N_{Obj}\}, F_m(X_1) \leq F_m(X_2), \qquad (4.19)$$

$$\exists n \in \{1, 2, \dots, N_{Obj}\}, F_n(X_1) < F_n(X_2), \qquad (4.20)$$

$$\mu_{Fm}(X) = \begin{cases} 1 & , F_m(X) \leq F_m^{min} \\ 0, \; F_m(X) \geq F_m^{max} & m = 1, 2, \dots, N_{Obj} \\ \frac{F_m^{max} - F_m(X)}{F_m^{max} - F_m^{min}} \;, & F_m^{min} \leq F_m(X) \leq F_m^{max} \end{cases} \qquad (4.21)$$

$$N_\mu(i) = \frac{\sum_{m=1}^{N_{Obj}} w_m \times \mu_{Fm}(X_i)}{\sum_{i=1}^{N_{rep}} \sum_{m=1}^{N_{Obj}} w_m \times \mu_{Fm}(X_i)} \qquad (4.22)$$

4.4. Results and discussion

Research on the multi-objective problem of the distribution grid expansion planning considering distributed generation sources applied to a distribution system including 2 power supplies, 32 buses, 5 branches, 5 switching wires, 32 devices switched[34]. This initial system has a transformer station with a capacity of 2,600 kW that it can upgrad to 4,355 kW. In addition, it contains 15 upgradeable branches and 12 routes for installing new branches as listed in Table 4.1.

Table 4.1 Parameters of new link branches

Number branch new	**To**	**from**	***R*** **(Ω)**	***X*** **(Ω)**	**U (hours/years)**	**U' (hours/years)**
1	19	34	0,1	0,2	0,5	0,08
2	20	34	0,15	0,2	0,7	0,07
3	21	34	0,1	0,3	0,9	0,05
4	22	34	0,2	0,25	1	0,05
5	23	35	0,1	0,2	0,6	0,02
6	24	35	0,1	0,3	0,8	0,04
7	25	35	0,15	0,2	0,7	0,01
8	26	35	0,2	0,25	0,1	0,05
9	21	36	0,2	0,25	1	0,07
10	22	36	0,1	0,2	1	0,07
11	23	36	0,1	0,3	1	0,04
12	24	36	0,15	0,2	0,8	0,03

Table 4.2 Demand information for new bus

Number branch new	**Active power demand (kW)**	**Reactive power demand (kVAr)**
34	300	250
35	100	30
36	200	80

Table 4.3 Objective function values in all cases

Case	**Number of subcases**	**Weights**				**F_1 ($)**	**F_2 (kWh/year)**	**F_3 (kW)**	**F_4 (pu)**
		w_1	***w_2***	***w_3***	***w_4***				
Case I		-	-	-	-	12254	48527	432,5161	0,009
Case II		-	-	-	-	149308	13290,3	151,3026	0,0088
Case III		-	-	-	-	155806	15846	95,49416	0,0088
Case IV		-	-	-	-	90576	30148	200,1479	0,008496
Case V	1	0,33	0,33	0,33	-	33879	46063,98	373,5442	-
	2	0,2	0,4	0,4	-	30633	46093,13	362,3144	-
	3	0,4	0,2	0,4	-	42360	41248,43	250,3062	-
	4	0,4	0,4	0,2	-	37998	42670,78	322,403	-
Case VI	1	0,33	-	0,33	0,33	105364	-	174,8745	0,009013
	2	0,2	-	0,4	0,4	105364	-	174,8745	0,009013
	3	0,4	-	0,2	0,4	105364	-	174,8745	0,009013
	4	0,4	-	0,4	0,2	105364	-	174,8745	0,009013
Case VII	1	-	0,33	0,33	0,33	-	31545,28	187,5481	0,00864
	2	-	0,2	0,4	0,4	-	30746,8	186,3287	0,008646
	3	-	0,4	0,2	0,4	-	27239,08	158,1417	0,008741
	4	-	0,4	0,4	0,2	-	31545,28	187,5481	0,00864
Case VIII	1	0,33	0,33	-	0,33	46578	43919,7	-	0,009134
	2	0,2	0,4	-	0,4	46578	43919,7	-	0,009134
	3	0,4	0,2	-	0,4	83201	30970	-	0,009091
	4	0,4	0,4	-	0,2	50325	48861,78	-	0,008934
Case IX	1	0,25	0,25	0,25	0,25	108885	47032,6	146,4991	0,008831
	2	0,1	0,3	0,3	0,3	111264	41338,4	141,6119	0,008835
	3	0,3	0,1	0,3	0,3	105984	30993,68	166,3473	0,008925
	4	0,3	0,3	0,1	0,3	105984	30993,68	166,3473	0,008925
	5	0,3	0,3	0,3	0,1	108885	47032,6	146,4991	0,008831

- Targets F_1 and F_3 have approximately the same value. Therefore, this study can be considered from the results of cases I, III, and VII of Table 4.3. In cases I and III where each F_2 or F_3 is minimized position by position; The remaining cases are also close to the minimum value. In case VII, different coefficients for F_2 and F_3 do not significantly change the solutions obtained. Therefore, these objective function values are equivalent.

- The objective function values F_1 and F_2 are opposing the objective functions. Indeed, while the grid output of DGs decreased, I&O costs were reduced but END was increased as demonstrated by cases I, II, V-2, V-3, VIII-2 and VIII- 3 according to Table 4.3

- The objective function values F_1 and F_3 are opposing the objective functions. Indeed, while the grid output of DGs was increased, I&O costs were increased but capacity losses decreased as evidenced in cases I, III, V-2, and V-4 according to Table 4.3.

- The value of the objective function F_2 is opposite to the value of the objective function F_4. To minimize END, DGs should generate more active power. Therefore, the voltage stability index (VSI) will be increased as demonstrated in cases II, IV, VIII-3 and VIII-4 according to Table 4.3.

- The voltage stability index has a small value in all cases. Therefore, case V-1 has a suitable exchange between all objective functions.

Table 4.4 the optimal power of distributed generation sources in the case $w_1 = w_2 = w_3 = 0.33$ and $w_4 = 0$

Power distribution capacity (kW)			
Stage	**Bus 18**	**Bus 32**	**Bus 33**
1	210	180	120
2	210	180	80
3	210	180	30

Table 4.3 Results of reliability analysis

Coefficient *U* and *U'*	Number of nodes added	Total capacity DG	END (kWh/year)	Capacity loss (kW)
0,6	10	0	28077	342
0,8	9	0	36875	362
0,9	14	0	41613	316
1	14	330	46064	374
1,1	8	660	46963	308
1,2	6	990	49411	374
1,4	11	330	597391	322

As a result of the evaluate influence of reliability parameters on MDEP results, the optimization problem was studied with different values of U and U'. Therefore, the values of U and U' have been multiplied by the factors 0.6, 0.8, 0.9, 1, 1.1, 1.2 and 1.4 for the case of the optimization problem. Multi-objective optimization with equal weight values for the objective functions ($w_1 = w_2 = w_3 = 0.33$). The END simulation results and the cost values are directly related to the factors U and U'. According to formula (4.15), the power loss values U and U' are not related to each other. However, since the objective functions have been optimized with the same weight value, the change in the objective functions of cost and power loss is appropriate. Table 4.5 shows the objective function values, DG installed capacity and number of reconnected lines for each value of U and U'.

Table 4.6 GD, SP and DM values for different optimization algorithms in 2 & 3 dimensions Pareto front

Algorithm	MPSO			PSO			GA		
Objective	**GD**	**SP**	**DM**	**GD**	**SP**	**DM**	**GD**	**SP**	**DM**
Cost-Loss	0,0022	0,0153	$3,36.10^{14}$	0,0037	0,0218	$3,33.10^{14}$	0,0082	0,0279	$5,49.10^{13}$
Cost-END	0,0168	0,0822	$1,20.10^{14}$	0,0109	0,0461	$4,25.10^{13}$	0,0129	0,053	$3,61.10^{13}$
Cost-VSI	0,0352	0,1152	$1,95.10^{13}$	0,0381	0,0992	$1,05.10^{13}$	0,2683	0,3678	$5,10.10^{12}$
Cost-END-Loss	$4,75.10^{-4}$	0,0064	$6,50.10^{14}$	0,0049	0,0241	$1,97.10^{13}$	0,0052	0,021	$1,84.10^{13}$
Cost-END-VSI	0,0039	0,0168	$1,06.10^{14}$	0,0068	0,0225	$4,05.10^{13}$	0,0121	0,0225	$3,17.10^{13}$
Cost-Loss-VSI	0,0027	0,0113	$8,81.10^{13}$	0,0036	0,0242	$1,03.10^{14}$	0,0039	0,0228	$8,59.10^{13}$
END-Loss-VSI	0,0382	0,0830	$7,44.10^{7}$	0,3057	0,5257	$7,30.10^{7}$	0,4005	0,5787	$4,13.10^{6}$

In Table 4.6. shows that the MPSO algorithm achieves better Pareto performance than the PSO and GA algorithms. This is because most of the SP and GD values of the MPSO algorithm are lower than the values obtained from the PSO, GA algorithms. Furthermore, the values of the DM metric of the MPSO algorithm are larger than the values obtained by the PSO and GA algorithms, proving that the Pareto efficiency obtained by the MPSO algorithm is more optimal.

4.5. Conclusion for chapter 4

The chapter 4 studies improving the reliability and voltage stability of the distribution power grid. The reliability index and voltage stability index based on SCC have been included in the MDEP problem. Accordingly, in the proposed MDEP, END active power loss and VSI were selected as the optimal objective functions. The Fuzzy method was used from the obtained Pareto solutions.

The proposed method can accommodate the opposing goals of the MDEP problem in a way that helps solve system planning problems of distribution grid reliability and safety.

Additionally, this study demonstrated the effectiveness of the proposed MPSO in generating Pareto optimal solutions efficiently. In the chapter 5, we present the results of the proposed methods when applied to solving the problem of planning power transmission and distribution grids, and propose directions for developing new methods in planning to expand the power grid to meet the needs of the grid economic and technical conditions.

Chapter 5: CONCLUSION AND DEVELOPMENT

5.1. Conclusion

In this thesis, we research and build new algorithms to solve the grid expansion planning problem for power transmission and distribution grids, which has been solved quickly and accurately.

- Research for applying the bound and branch algorithms to solve the transmission expansion planning problem with constraints on reliability and reserve standards into the real power grid in the Mekong Delta. Furthermore, the study applied bound and branch algorithms to solve the transmission expansion planning problem with reliability benchmark constraints into the real power grid in Ben Tre province in the Mekong Delta and solved the problem of planning to expand the power grid with constraints on reliability and reserve standards into the real power grid of Hau Giang in the Mekong Delta region.
- CSA search algorithm applied to planning problems in the Garver’s 6-node power system; The results compared the investment cost, standard deviation, and calculation time with GA and TS methods showed that the effectiveness of the method is to achieve more optimal values.
- The CS search algorithm applied to the transmission expansion planning problem is proven on the IEEE 25-node power system, 46-node Southern Brazilian power system; The result is that the investment cost and standard deviation have optimal values.
- Optimal planning of long-term distribution power grid with distributed generation sources applied to a 32-node beam distribution system. The distribution grid planning from the proposed heuristic approach is compared with full optimization models for the same distribution grid.

In short, the thesis focuses on researching and solving the problem of planning the expansion of the power transmission grid considering reliability, and building a new artificial intelligence method to apply the problem of power grid planning. DC transmission, and solving distribution grid planning problems. The strengths of the applied CS and CSA methods are that there are few input data sources, many constraints, finding locations that need expansion investment, and solving the transmission expansion planning problem. Especially the complex electrical system. The results are compared with other applied methods to demonstrate that the results of the solutions found are highly reliable.

5.2. Development

The obtained results for handling the problems of planning and transmission power grids are found by using the bound and branch methods. This research will use CS and CSA algorithms to solve the problems of planning and transmission power grids in the Mekong Delta region. The calculation results will be considered for the National Electricity Development Project for the period 2021 - 2030 with a vision to 2050.

- Apply CS and CSA algorithms to solve the problems of planning and transmission power grids on the same power systems to be able to compare the effectiveness of the two algorithms.
- Develop new CS and CSA algorithms to solve the problems of planning and transmission power grids, considering additional conditions for adding generation sources from renewable energy.
- Optimal planning of long-term distribution power grid with distributed generation will be applied to the beam distribution system using the proposed MPSO algorithm and the results will be compared with the model obtained by using the optimal model with the same distribution grid.

From the above research directions, research results are expected to be published in prestigious domestic and international scientific journals.

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