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RADIAL DISTRIBUTION NETWORK OPTIMIZATION THROUGH PROTECTIVE DEVICE PLACEMENT SCHEME USING GENETIC ALGORITHM

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ABSTRACT

Reliability refers to the likelihood of a system successfully completing its intended task. In this paper, the proponents assessed the reliability of the IEEE Bus 6 Roy Billington Test System (RBTS) distribution system by optimizing two reliability indices: the System Average Interruption Frequency Index (SAIFI) and Expected Energy Not Served (EENS). The proponents optimized the reliability indices by leveraging a Genetic Algorithm implemented in JavaScript within Visual Studio Code, aiming to determine the optimal placement of protective devices. Results revealed the optimized values for both SAIFI and EENS alongside the protective device placement. In section 1, the SAIFI optimized value is 1.4492 with its EENS at 24607.8729 kWh and cost at 244090.4 Philippine Peso (Php). Future researchers can use other algorithms to optimize as well as use the data gathered in this study to be compared with. Also, the code used in the study can be further developed into a software that is designed to calculate the reliability indices, SAIFI and EENS.

Keywords: Genetic Algorithm, JavaScript, IEEE Bus-6 RBTS System, Protective Devices, System Average Interruption Frequency Index.

I. INTRODUCTION

Over the past few decades, the reliability of distribution systems has become a major concern in the changing socio-economic conditions of consumers [1]. Once a fault occurs in a distribution system, consumers will experience either momentary or sustained interruptions. And these interruptions greatly affect the reliability of the distribution system. Thus, there are several ways to lessen this problem: improvement of power distribution reliability by minimization of the composite reliability indices [2].

The distribution system serves as a direct link to customers, exerting a profound influence on the reliability of power supply. Notably, statistics reveal that a significant majority of power outages stem from distribution system failures, underscoring the critical importance of evaluating distribution system reliability. Approximately 90% of the reliability issues faced by customers can be traced back to failures within electric power distribution systems [3,4,5].

Power outages are bound to happen due to various issues with the power supply, network, and the amount of electricity being used. Once a fault occurs in a distribution system, consumers will experience either momentary or sustained interruptions. These interruptions greatly affect the reliability of the distribution system. Thus, there are several ways to lessen this problem, including the improvement of power distribution reliability by minimizing the composite reliability indices [10].

Certain studies have employed the deterministic approach like Multi-Integer Programming (MIL), Binary Integer Programming, and ILP Method, to determine the optimal placement of the protective devices [16, 20, 22, 26], while others have employed heuristic methods, such as the ant-colony algorithm and the binary particle swarm algorithm, for optimization purposes [21, 23, 24, 25,]. Also, other studies made use of simulation like Monte Carlo method in optimizing and assessing distribution network reliability [33].

Recent studies opt to use genetic algorithms (GA), in 2020, GA is used to enhance the reliability of a distribution system [11]. Also, in 2021, GA shows an optimal placement of reclosers in a radial distribution system for reliability improvement [12]. In 2016, a method for optimal placement and sizing of the capacitors in a radial distribution feeder using the Genetic Algorithm (GA) with the objective of loss reduction and voltage profile improvement was presented [13].

In 2014, genetic algorithm was utilized for large-scale optimization of assignment, planning, and rescheduling [28]. Moreover, in 2022, genetic algorithm was used to optimize Nigerian radial feeders to mitigate power loss and voltage profile problems on the radial distribution network [29].

Meanwhile, in 2015, genetic algorithm (GA) was dealt into application in order to achieve an optimal location of FACTS devices in a distribution system. Using this optimization technique, only the best individuals in a population are selected to create new possible solutions, and, these solutions are meant to improve the energy efficiency of the system [40].

The main objective of this study is to optimize the crucial reliability indices – SAIFI and EENS of a radial distribution network through the optimal placement of protective devices such as reclosers, switches, and fuses using Genetic Algorithm. Specifically, the researchers intend to: 1.) Create a JavaScript code for genetic algorithm; 2.) Create a circuit diagram of the optimized system; and 3.) Compute for the cost of each optimized section.

This study will be limited to an IEEE RBTS BUS 6 test system installed with protective devices such as fuse, circuit breaker, disconnecting switch, and reclosers. It will cover only the optimal placement of protective devices to improve the system's reliability indices. The code will be limited to the optimization of SAIFI and EENS only.

II. METHODOLOGY

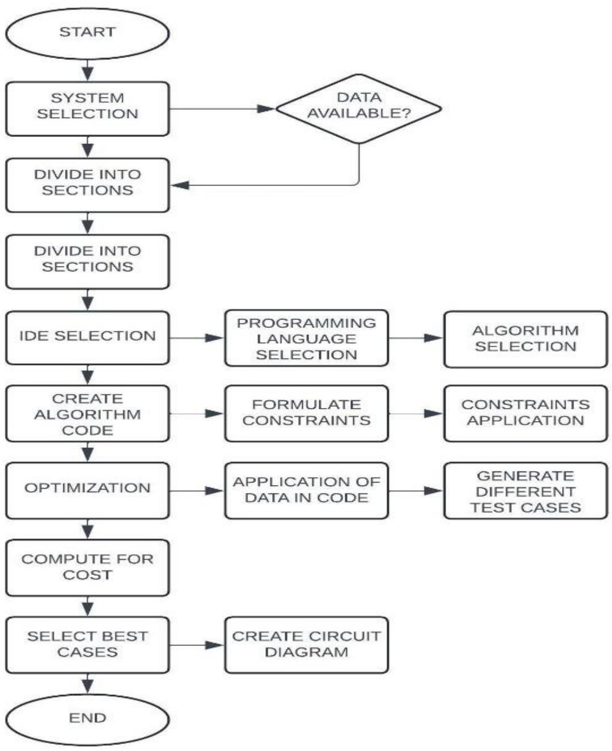

Figure 1: Research Flow Chart

The flowchart in Figure 1 illustrates a methodological approach to enhancing the reliability indices of a radial distribution system through the optimal placement of protective devices. The process begins with selecting a system that has the necessary data for optimization. The next step involves choosing the Genetic Algorithm (GA) as the optimization technique, along with the development environment (VS Code) and the programming language (JavaScript).

The algorithm is then implemented in JavaScript using VS Code, adhering to the GA flow, and incorporating the SAIFI and EENS formulas along with relevant constraints. Once the code is developed, researchers input the collected data to initiate the optimization process. This process generates ten potential results for each section of the system. Researchers then evaluate the cost associated with each result to determine the most effective solution. Ultimately, the best option is selected, and circuit diagrams are created to depict the optimal locations for the protective devices.

Test Case of the System

The researchers utilized the IEEE RBTS Bus 6 as the test case system of the study with the aim of optimizing the reliability indices through determining the optimal device placement. As seen in Figure 2, the distribution system has 23 load points, and 23 distribution transformers. The test case is divided into five sections, as the analysis of the test system will be simplified by dismantling portions of the system and analyzing the sections separately.

Section 1 will cover the portion feeders 1 to 9 and load points 1 to 7. Section 2 will cover the portion feeders 11 to 15 and load points 8 to 10. Section 3 will cover the portion feeders 19 to 24 and load points 14 to 18. Section 4 will cover the portion feeders 16 to 18, and load points 11 to 13. Lastly, Section 5 will cover the portion feeders 25 to 30, and load points 19 to 23.

The test system contains reliability data specific to each component with the reliability information for the transformers, feeder lines, and load points within the system given from the studies of [34, 38].

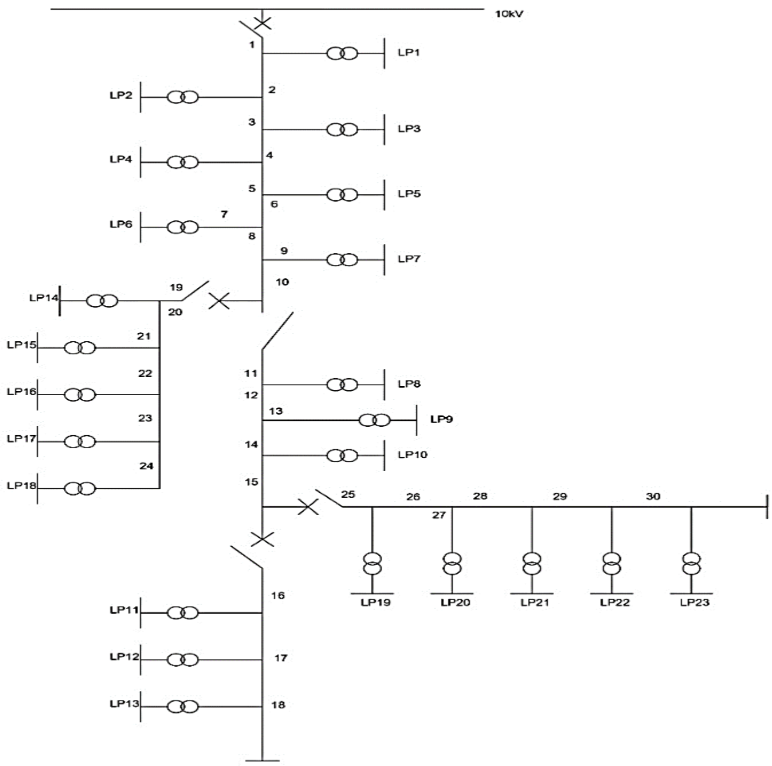

Figure 2: IEEE RBTS Bus 6

Visual Studio Code

Genetic Algorithm optimization will be conducted on VS Code version 16.11.36 by utilizing the programming language JavaScript. The optimization process will run under the minimum system requirements of Windows 10, with a processor speed of 1.6 GHz and at least 1.00 GB of RAM. Such specifications ensure that the optimization can be performed efficiently, leveraging the capabilities of both the chosen software and hardware environments. The use of VS Code version 16.11.36 provides a robust and feature-rich Integrated Development Environment (IDE) that supports JavaScript, facilitating the development and debugging of the Genetic Algorithm.

JavaScript

The inherent strengths of JavaScript make it an ideal platform for Genetic Algorithm development. Firstly, its platform independence ensures the GA's execution on any device equipped with a web browser, eliminating the

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need for specialized software installations [41]. This capability makes an excellent platform for the optimization of reliability indices.

Genetic Algorithm

Genetic algorithm (GA) offer a robust and versatile approach to solving optimization problems, particularly in scenarios with complex, non-linear, and multi-objective functions [40]. GA's ability to explore large solution spaces without getting trapped in local optima makes them well-suited for tackling challenges such as optimizing the placement of protective devices in power distribution systems. In this context, where the objective is to minimize the SAIFI and EENS while adhering to various constraints imposed by regulations and practical considerations, GAs excel at navigating the intricate decision space.

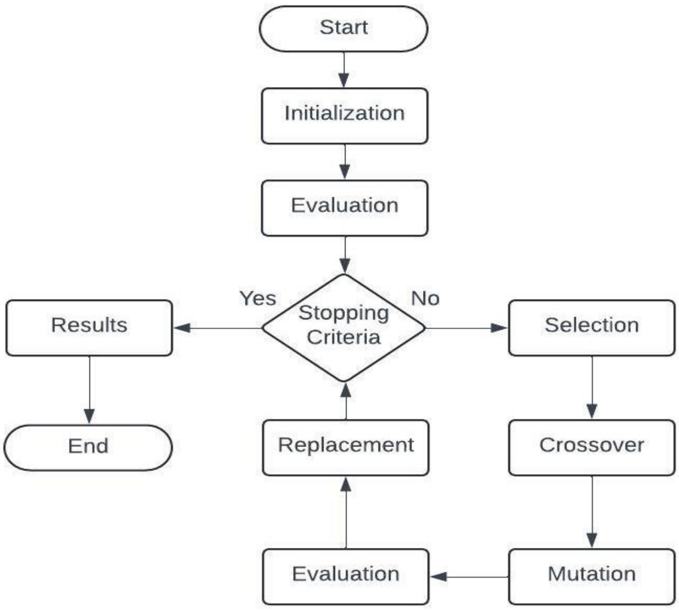

Figure 3: Genetic Algorithm Flowchart

Genetic algorithms solve problems in picking the best mutation possible. It starts with a pool of potential solutions (population), evaluates the population based on a scoring system (fitness), and picks the strongest ones to create the next generation. The "parents" mix and match solutions (crossover) with some random changes (mutation) to create new possibilities. Weaker solutions are replaced by these offspring, and the cycle repeats until the algorithm find the best solution.

SAIFI and EENS formula

SAIFI formula:

$$SAIFI = \frac{A_q}{N_t}$$

$$A_q = \sum_{ieL}(\lambda_i + \gamma_i)\, N'_i \sum_{ieL}(\gamma_i x_{i2})N'_i + \sum_{ieL}\lambda_i \sum_{jeF(i)}(N'_j - N'_{h(j,i)}) \prod_{keG(j,i)} x_{k1}x_{k2}x_{k3} + \sum_{ieL}\gamma_i \sum_{jeF(i)}(1 - x_{j2})\, N'_j \sum_{keG(j,i)} x_{k1}x_{k2}$$

EENS formula:

$$EENS = \sum_{i\in L}(\lambda_i + \gamma_i) r_{ri} L'_i - \sum_{ieL}\gamma_i x_{i2}\, L'_i + \sum_{ieL}\lambda_i\, r_{ri} \sum_{jeF(i)}(L'_j - L'_{h(j,i)}) \prod_{keG(j,i)} x_{k1}x_{k2}x_{k3}x_{k4}$$
$$+ \sum_{ieL}\lambda_i\, r_{si} \sum_{jeF(i)}(L'_j - L'_{h(j,i)}) \prod_{keG(j,i)} x_{k1}x_{k2}x_{k4}(1 - x_{k3})$$
$$+ \sum_{ieL}\gamma_i\, r_{ri} \sum_{jeF(i)}(1 - x_{j2})\, L'_j \sum_{keG(j,i)} x_{k1}x_{k2}$$

Utilizing the genetic algorithm flowchart, relevant formulas, and constraints, JavaScript code was written to yield optimized values for SAIFI and EENS, alongside with the placement of protective devices. This algorithm systematically explores various configurations, determining whether a protective device should be installed at each potential location. In the algorithm's results, a value of "1" indicates that a protective device should be installed at that specific location, while a value of "0" signifies that it should not be installed.

Constraints

The constraints utilized are as follows: Node 1 of every section is automatically installed with a circuit breaker, and fuses are not allowed at the main feeder. Additionally, all laterals, being heavy loaded segments with long lines, must be installed with a protective device, whereas not all nodes on the main feeder require one. Specifically, only one recloser is permitted for five or fewer load points, while two line reclosers are allowed for more than five load points. Furthermore, the system must include both a switch and a recloser. It is important to note that the line reclosers operating as sectionalizers between sections are not included in the quantity count. Finally, there are no limitations on the quantity of fuses to be installed, whether fuse-save or fuse-blown.

Computation of Cost

After the researchers optimize the locations of the protective devices, the researchers will compute the cost of the project. The cost of the project depends on the reliability index which is the EENS. Moreover, the least amount of cost with the optimum location of the protective devices will be selected as the best case in the system.

This study utilized Pampanga Electric Cooperative II (PELCO II) rate of ₱9.9192/kW-hr [43] as basis for computing the cost.

Using equation: **EENS =** $\sum U_i W_i$

Cost = EENS*9.9192 Php/kW-hr

III. RESULTS AND DISCUSSION

Comparing Optimized Results to Initial Case

Table 3.1 Comparison between Optimized and Initial Case

Sections	SAIFI		EENS	
	Initial Case	Optimized Case	Initial Case	Optimized Case
1	11.7874	1.1927	202,599.5	33,062.9472
2	8.9654	0.5892	70,436	14,869.5907
3	4.8393	1.3227	178,960.3	56,428.4525
4	6.0697	1.4492	71,665.33	28,225.1
5	11.4363	0.9011	234,041.1	56,976.07
Total	43.0981	5.4549	757,702.2	185,944.94

The researchers utilized the initial case from the study of [44] where the same test system is used to optimize reliability indices using Binary Integer Linear Programming. In [44] initial case, it assumed that there are no protective devices installed in the system other than the circuit breakers at the opening of each section as well as the disconnecting switches in between the sections. It can be observed how the optimized values shrink in numbers compared to the initial cases. The total SAIFI value of 43.0981 in the initial case is turned into only 5.4549. Moreover, the EENS value was cut from 757702.21 to 185944.94 kWh.

Section 1-5 Best Case Results

Table 3: 2 Best Case of Each Section

Section	Recloser	Fuse-Blow	Switch	Fuse-Save	SAIFI	EENS	COST
1	3	10,11,12,13,15	6	9,14	1.1927	33,062.95	327,958
2	3,	5,6	4	7	0.5892	14,869.59	147,494.4
3	4	7,8,9	2	6,a	1.3227	56,428.45	559,725.1

4	2	4	3	5,6	1.1648	28,225.1	279970.4
5	5	6,8,10	2	7,9	0.9011	56,976.07	565,157.1

In Table 3.2, the optimal configurations for each section of the system are presented. These configurations represent the cases with the smallest Expected Energy Not Supplied (EENS) and cost values, having undergone filtering to meet predefined constraints. The configurations determine the precise placement of protective devices throughout the system. Section 1 stood out as the most impactful among the five sections, given its position at the system's onset. Equipped with a recloser at position 3, a switch at 6, and multiple Fuse-blow instances at positions 10, 11, 12, 13, and 15, alongside Fuse-saves at 9 and 14, Section 1 experienced an 89.88% reduction in SAIFI, dropping from 11.7874 to 1.1927. Additionally, Section 1 EENS value decreased significantly by 83.68%, falling from 202,599.5 to 33,062.95.

In contrast, Section 4, located farthest from the substation, had the least impact. Despite a 76.12% decrease in SAIFI, from 6.0697 to 1.1648, it ranked second-lowest in terms of reduction percentage. Similarly, its EENS and cost reductions were the most modest among the five sections, with a 60.62% decline in EENS from 71,665.33 to 28,225.1.

Optimized Circuit

In Figure 4 is the optimized placement of the protective devices in respect to the optimize scheme. Also, there are automatically installed circuit breakers at the opening of each section as well as disconnecting switches between the sections.

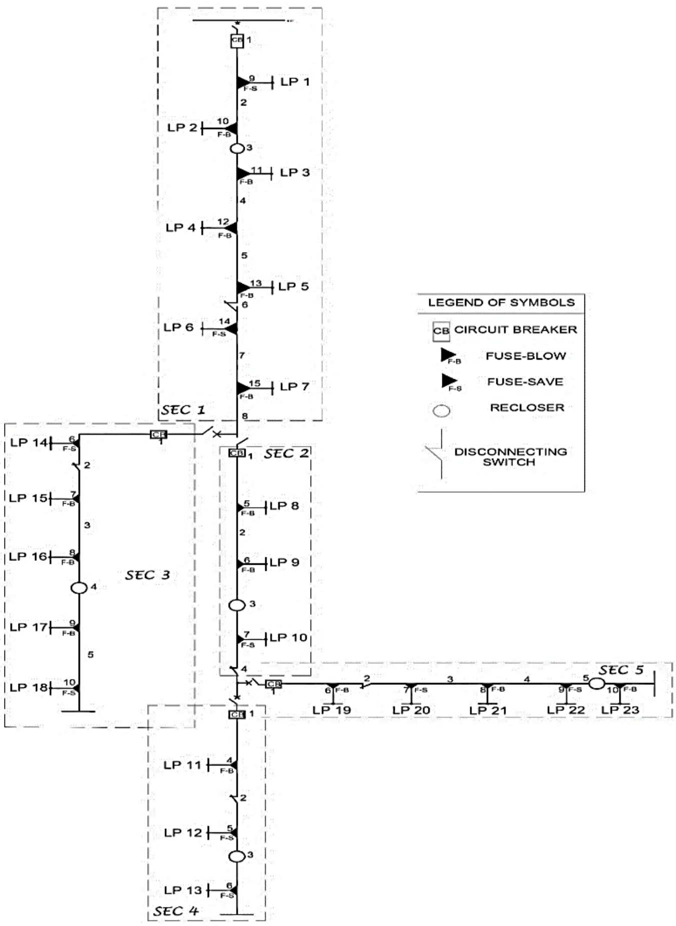

Figure 4: Optimized RBTS Bus 6 system

IV. RECOMMENDATION

The researchers suggest that future studies consider additional reliability indices such as the Momentary Average Interruption Frequency Index (MAIFI) and System Average Interruption Duration Index (SAIDI). It is also advisable to, (2) use another approach of well-known heuristic algorithms such as Particle Swarm Optimization, Bee Algorithm, etc. and (3) incorporate automated switching in the model. The future researchers can (4) compare the obtained results in this study for comparison and validation to other optimization techniques. (5) Expanding the analysis to real world constraints like budget limits, regulations, and implementation challenges of a utility into the optimization model to provide more practical recommendations for system planners.

Also, (6) the code used in the study can be further developed into a software that is designed to calculate the reliability indices, SAIFI and EENS

V. CONCLUSION

This study introduces a novel approach to optimize the reliability of power distribution systems by utilizing Genetic Algorithm (GA) to optimize two composite reliability measures: System Average Interruption Frequency Index (SAIFI) and Expected Energy Not Supplied (EENS). The focus of the research lies in determining the optimal placement of essential components such as reclosers, switches, and fuses within the distribution network. To evaluate the effectiveness of the proposed method, the researchers picked 10 distinct test cases from each of the five sections that are released by the genetic algorithm in VS Code.

Through the iterative application of Genetic Algorithm, the researchers successfully minimized the composite reliability indices, namely SAIFI and EENS. This optimization process involved determining the optimal placement of protective devices and identifying the most suitable values for each composite reliability index. Furthermore, the study considered the cost implications of Expected Energy Not Served, providing a comprehensive assessment of both reliability and economic factors. Ultimately, the best-case configurations were selected from each section based on the system's ability to minimize SAIFI and EENS values, thereby highlighting the effectiveness of the proposed optimization approach in enhancing the reliability of power distribution systems.

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