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Optimal multiple distributed generators placement and Recloser – Fuse co-ordination by using Water Cycle Algorithm in a radial distributed network

by

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A THESIS

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ABSTRACT

This paper proposes an adaptive protection coordination scheme for Recloser and Fuses in radial distribution systems with the integration of multiple Distributed Generators (DGs). The increasing adoption of DGs in distribution networks introduces new challenges in protection coordination due to varying fault currents and voltage profiles caused by the different placements and capacities of DGs. The suggested approach employs the Water Cycle Algorithm (WCA) to solve the optimization problem of Recloser and Fuse coordination, ensuring that the protection devices coordinate effectively under fault conditions on the IEEE 33 benchmark test system for radial distribution networks.

The analysis reveals that the optimal placement of DGs can significantly reduce distribution losses and improve voltage profiles across all buses in the network. For the single DG case, the optimal location is determined to be at bus 6 with size of 2.229 MW. In three DGs case, the optimal locations are found at buses 6, 14, and 31 with corresponding DG sizes of 1.229 MW, 0.604 MW, and 0.686 MW and significant reduction in feeder losses by 47.879% and 62.104%, respectively as compared to the base case. The penetration of DGs at the optimal location ensure that the Recloser-Fuse coordination remains effective under fault conditions and the upstream Fuses acts as back up for downstream Fuses along the faulted path. Hence the Fuses act as a primary protection for any kind of permanent fault that might occurs at anywhere in the system. The characteristics curve of all Fuses lies within the characteristics curve of the Recloser’s slow and fast mode operation with indicated the optimal coordination between Recloser and Fuses. Also, the value of objective function goes on decreasing from the base case with the placement of number of DGs in the network. It is because of the contribution of fault current by the DGs towards the faulted path.

In summary, this research demonstrates that the proposed adaptive protection coordination scheme, based on the Water Cycle Algorithm, is an effective method for achieving optimal Recloser-Fuse coordination in distribution systems with DG integration. The results not only ensure proper protection coordination but also provide recommendation for implementing protection strategies in real-world distribution systems with multiple DGs.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviation	**Full Form**
ABC	Artificial Bee Colony
ACO	Ant Colony Optimization
CB	Circuit Breaker
DBEA	Decomposition-Based Evolutionary Algorithm
DE	Differential Evolution
DG	Distributed Generators
EMTP	Electromagnetic Transients Program
ERACS	Electrical Arc Simulation and Coordination Software
ETAP	Electrical Transient & Analysis Program
FA	Firefly Algorithm
GA	Genetic Algorithm
IEEE	Institute of Electrical and Electronics Engineers
LSF	Loss Sensitivity Factor
MATLAB	Matrix Laboratory
MFCTI	Minimum Fuse coordination time interval
MFO	Moth-Flame Optimization
MINLP	Mixed-Integer Nonlinear Programming
MRCTI	Minimum Recloser Coordination Time Interval
NEA	Nepal Electricity Authority
NEPLAN	Network Planning
PCS	Pickup Current Setting
PSO	Particle Swarm Optimization
PV	Photo Voltaic
RD	Radial Distribution

RFM	Recloser Fast Mode
RSM	Recloser Slow Mode
SLD	Single Line Diagram
TDS	Time Dial Setting
TLBO	Teaching-Learning-Based Optimization
TMS	Time Multiplier Setting
WCA	Water Cycle Algorithm
WCMFO	Water Cycle–Moth-Flame Optimization

LIST OF SYMBOLS

Symbol	**Meaning**
I	Current
I_{FF}	Fault Current at Fuses
I_{FR}	Fault Current at Recloser
I_m	maximum current
kA	Kilo Ampere
kV	kilo Volt
kW	Kilo Watt
MVA	Mega Volt Ampere
MVAr	Mega Volt Ampere Reactive
MW	Mega Watt
pu	Per Unit
%	Percentage
R	Resistance
Sec	Second
V	Voltage
W	Watt
X	Reactance
Z	Impedance

LIST OF ANNEXES

CHAPTER ONE: INTRODUCTION

1.1 Background

A distributed generator (DGs) can be renewable as well as non-renewable according to the energy source that is used. It is the significant part of the energy mix to assist the electricity demand and the future of electricity generation. It is generally located to the distribution network closer to the point of use, so that they reduce energy losses, acts as backup power; enhance the reliability and security of distribution. The size of DGs can be micro (1W<5kW), small (5kW<5MW), medium (5MW<50MW) and large (50W<300MW) [1]. However, integration of DG power into the distribution system not easy task as they make the distribution network more complex.

In radial distribution networks, currents flow in one direction however, in case of the network containing the DGs, the direction of flow of current is no longer remain unidirectional. Moreover, multiple DGs connected during the fault can significantly change the direction of flow of currents at various locations on the same feeder of DGs sections. Consequently, there is always a chance that Recloser and Fuses will operate in an uncoordinated manner [2].

Protection coordination involves choosing the correct configuration for protective devices to ensure that these devices in the power system work together effectively. The protection coordination seeks to distinguish between temporary and permanent faults, quickly restoring the system during interruptions from temporary faults and reducing power disruptions to the fewest consumers possible in the event of permanent faults [3]. For this purpose, the correct coordination among the protective devices is necessary. The Recloser is typically placed on the sending end of main feeder, while the Fuses are generally positioned along the laterals of the main feeder such that the Recloser acts as an overall back up for rest of the devices during faulty condition in the system. The Recloser is a safety device that interrupts the circuit similar to a circuit breaker but automatically resets after a short period [4].

When a DG is introduced, it can supply additional fault current, altering the total fault level at different points in the system. In some cases, a Recloser upstream may see a lower fault current than a downstream Fuse, causing the Fuse to operate before the Recloser (which is opposite to conventional Fuse-Recloser coordination). Also, when DGs are added, they may feed fault current in the opposite direction, causing unexpected operation of protective devices. In a typical distribution system, Recloser operate before Fuses to clear temporary faults. However, Fuses, directional overcurrent relays, and other protective devices may mis operate or fail to detect the fault correctly due to this reversal. This defeats the Fuse-saving strategy and leads to unnecessary outages [5].

The presence of DGs can lead to false tripping of relays due to increased fault current contribution. In these situations, it is rather challenging to establish a shared configuration of Recloser and Fuses that can coordinate effectively, regardless of the presence of DG in the radial distribution network. Additionally, the existence of several DGs within the system complicates the coordination of Recloser and Fuses significantly [6]. An optimization-based approach is suggested in this paper to address this issue and to achieve adequate Recloser and Fuses coordination in a distribution system that includes DGs during fault condition.

1.2 Problem statement

Distribution System in Nepal is mostly radial having a circuit breaker without automatic Recloser facilities and it is also unreliable because of unstable voltage, overloading of distribution lines, frequent tripping of protective devices. It is due to improper selection of Fuse rating, unadaptive protective relaying system and mis-coordination between the existing protective devices. Nepal is heading to the smart grid with the automation of the distribution networks in near future. Distributed generations (DGs) are the important part of the smart grid for energy mix technologies. Furthermore, when there are no distributed generations (DGs) within a distribution network, the direction of current flow is unidirectional from source grid to loads. With the presence of DGs, the current flow direction is no longer unidirectional and protection coordination is made more complex. This research paper basically concerned with optimization of Recloser-Fuse coordination under the existence of distributed generations by using Water Cycle Algorithm (WCA) optimization tool in MATLAB programming language after short circuit analysis in ETAP Simulink.

1.3 Objective

1.3.1 Main objective

Optimal multiple DGs placement and Recloser- Fuse coordination by using Water Cycle Algorithm in a radial distributed network.

1.3.2 Specific objectives

- To find the optimal placement of DGs in a radial distribution Network.
- To analyze the voltage profile and power loss of network due to the presence of single and multiple DGs.
- To coordinate the operation of Recloser and Fuses in the presence of DGs during fault conditions in the system.

1.4 Scopes and Limitations

The primary scope of the study is to improve Fuse-saving operations by dynamically adjusting Fuse settings in response to changes in DG contribution. The proposed adaptive protection scheme ensures that temporary faults are cleared by the Recloser before the Fuse operates, preventing unnecessary Fuse blowouts and improving overall system reliability. Results show that the adaptive scheme successfully prevents unnecessary Fuse operations by ensuring effective fault clearance.

However, the study has several limitations. The effectiveness of the proposed scheme depends on accurate real-time network monitoring and fault current estimations. Any inaccuracies in DG parameters or fault levels [7] could impact its performance. Moreover, although the scheme improves Fuse-saving in moderate DG penetration scenarios, extremely high DG levels could still disrupt protection coordination, that might need the more advanced strategies. Another limitation is that the study focuses only active power DGs penetration while harmonics and dynamic load variation can affect the current leading to mis operation and improper coordination between Recloser and Fuses.

1.5 Outline of Thesis

This dissertation is structured into five chapters:

Chapter 1 serves as an introductory section that presents the general background, the problem statement of the study, research objectives, scopes and limitations, as well as the thesis outline.

Chapter 2 gives the overview of literature review for the various types of DGs and their impact in the distribution network. Similarly, this chapter gives the overview of literature review for Water Cycle Algorithm for optimization. Also, the Recloser Fuse operating characteristics are discussed. The motivations for this thesis research are also described in this chapter.

Chapter 3 outlines the approach taken to identify the best locations and sizes for DGs and the coordination of Recloser-Fuse using WCA. This chapter also outlines the tools and software employed for this research and also describe the general flowchart and algorithm to achieve the objective.

Chapter 4 describes the output of MATLAB coding using Water Cycle Algorithm for optimal placement of single and multiple DGs. This chapter also describes the short circuit analysis for finding fault current using ETAP, which is used as input parameter for Recloser Fuse coordination. And finally, the optimal settings and characteristics curve for base, single DG, and multiple DGs cases are presented in this chapter.

Chapter 5 recaps the dissertation, emphasizes its contributions, and suggests pathways for future research.

Finally, the thesis wraps up with a compilation of papers cited for this research.

CHAPTER TWO: LITERATURE REVIEW

An analytical approach for determining the optimal placement and sizing of distributed generators (DGs) in primary distribution networks by Acharya, N., Mahat, P., & Mithulananthan, N. focus on minimizing power losses and improving the voltage profile of the network. The proposed method uses a loss sensitivity factor (LSF) to identify the most suitable locations for DG installation. By calculating the sensitivity of power losses to changes in DG size and location, the approach efficiently narrows down candidate buses for DG placement. The authors validate their method through simulations on a radial distribution network, demonstrating significant reductions in power losses and improvements in voltage stability. This analytical approach is computationally efficient and provides a practical solution for utilities and planners aiming to integrate DGs into existing distribution systems [8].

El-Khattam, W., Hegazy, Y. G., & Salama, M. M. A. introduced An integrated optimization model for planning the placement and sizing of distributed generation (DG) units in distribution systems which propose a mixed-integer nonlinear programming (MINLP) approach to solve the optimization problem, that allows for both discrete and continuous variables. The proposed model is tested on a realistic distribution system, and the results demonstrate its effectiveness in improving system performance and reducing costs along with comprehensive framework that considers technical, economic, and environmental factors to optimize DG integration. The model aims to minimize total system costs, including investment, operation, and maintenance costs, while ensuring reliable and efficient operation of the distribution network. The optimization process incorporates constraints such as voltage limits, thermal limits, and power balance [9].

Meskin, Domijan, and Grinberg (2020) extensively reviewed the influence of DG on protection systems and proposed various remedial measures to mitigate associated challenges. Their study highlights the key issues arising from DG penetration, such as changes in fault current levels, miscoordination of protective relays, and bidirectional power flow, which complicates conventional protection schemes. This paper emphasizes that traditional overcurrent protection schemes are designed based on unidirectional power flow assumptions. However, with the integration of DGs, especially renewable energy sources, the power flow becomes bidirectional, leading to false tripping and failure to detect faults correctly. One major challenge identified is the miscoordination of overcurrent relays due to varying fault current contributions from DGs. Their study underscores the necessity of upgrading conventional protection schemes to accommodate the increasing penetration of DG in modern power distribution networks [10].

Hadi Eskandar et al. proposed the Water Cycle Algorithm (WCA) in 2012, inspired by the natural water cycle process which includes the flow of water from streams to rivers and from rivers to the sea, as well as evaporation and rainfall, provides a robust framework for global optimization. There are various metaheuristic optimization algorithms like Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Ant Colony Optimization (ACO). However, these algorithms have limitations, such as premature convergence, sensitivity to parameter settings, and difficulty in balancing exploration and exploitation so to address this issue WCA is introduced by the authors highlighting the benefits of WCA with high accuracy, adaptability, and computational efficiency so that WCA has been successfully applied in various engineering fields, including power system optimization, structural design, and control system tuning [11].

The optimal placement of distributed generation (DG) in electrical distribution systems, emphasizing three main goals: increasing reliability, minimizing power losses, and improving voltage profiles, by Borges, C. L. T., & Falcão, D. M offers an in-depth examination of different methods and techniques for establishing the ideal positioning and sizing of DGs. They talk about the effects of DG on system performance, highlighting its capability to lower losses, enhance voltage stability, and boost reliability by offering localized power supply. The document also emphasizes the difficulties related to DG integration, including protection coordination, voltage control, and power quality concerns. The authors examine various analytical approaches like sensitivity analysis and optimization methods like genetic algorithms, particle swarm optimization found in the literature for addressing the DG allocation issue. The study ends by highlighting the necessity for a comprehensive method that takes into account various goals and limitations to attain ideal DG integration [2].

A comprehensive definition and classification of Distributed Generation (DG) by Ackermann, T., Andersson, G., & Söder, L. discusses the various technologies, benefits, and challenges associated with integrating DGs into distribution networks analyzing its role in modern power systems [1].

WCA-based approach for the optimal placement and sizing of DGs and capacitor banks in distribution systems by Poudel, Y. K. focus to minimize power losses, reduce voltage deviation, lower total electrical energy costs, and improve voltage stability. Simulations conducted on the IEEE 69-bus test system and the Sankhu feeder network in Nepal demonstrated the WCA's effectiveness in enhancing system performance [12].

WCA technique to determine the optimal placement and sizing of various types of DGs in radial distribution networks by El-Ela, A. A., & El-Sehiemy, R. A. focus to minimizing power losses, improving voltage profiles, and reducing operational costs. The proposed WCA is tested on distribution system, and the results are compared with other optimization techniques such as PSO, DE, and GAs. The findings demonstrate that WCA outperforms other algorithms in terms of power loss reduction, voltage profile improvement, and cost minimization. For instance, in the IEEE 33-bus system, WCA achieves a power loss reduction of 64.9% when optimally placing DGs, compared to 58.9% with PSO. Similarly, in the IEEE 69-bus system, WCA reduces power losses to 71.5 kW, compared to 77.85 kW with FA. The WCA effectively handled both single and multi-objective optimization problems, providing a set of optimal solutions for decision-makers [13].

The application of the Water Cycle Algorithm (WCA) for optimizing the design of three-phase induction motors by Ghosh, P. K., Sadhu, P. K., Basak, R., & Sanyal, A. focus on improving energy efficiency by reducing power losses without increasing material costs. It compares WCA with Genetic Algorithms (GA) and demonstrates the superior performance of WCA in achieving optimal motor designs with minimum energy losses and better cost-effectiveness [14].

The increasing integration of distributed generators in distribution networks has a significant impact on the existing protection schemes, necessitating the need for coordinated protection strategies. Traditional protection systems are designed for unidirectional power flow, but the presence of distributed generators introduces multidirectional power flows, which can disrupt the coordination of protective devices [15].

The protection of distribution systems with distributed generation has become a critical concern due to the changing nature of power flow and fault characteristics. The impact of distributed generation on the protection system performance depends on various factors, including the design and coordination of the protective devices. Recent studies have highlighted the need for improved protection strategies to mitigate the challenges posed by the integration of renewable distributed generation [15], [6].

The importance of accurate electromagnetic transient modeling to understand the dynamic interactions between DG units and protection devices. By utilizing tools like the Electromagnetic Transients Program (EMTP), they demonstrate how detailed simulations can aid in designing and evaluating protection schemes that maintain system reliability amidst the complexities introduced by Martinez-Velasco, J. A., Leon, F. D., & Dinavahi, V. [16].

Ali et al. introduced an Enhanced Decomposition-Based Evolutionary Algorithm (E-DBEA) to address the multi-objective DG allocation issue in radial distribution networks. Unlike conventional methods such as Particle Swarm Optimization (PSO), Genetic Algorithms (GA) which often face challenges with local optima entrapment and premature convergence, the purpose strategy effectively strikes a balance between exploration and exploitation. The authors demonstrate its efficiency in minimizing active power losses, boosting the voltage profile, and enhancing voltage stability using the IEEE 33-bus, 69-bus, and 119-bus test systems [17].

Khalilpourazari and Khalilpourazary (2017) introduced a new algorithm called the Water Cycle–Moth-Flame Optimization (WCMFO) algorithm. This algorithm aims to improve the efficiency of solving numerical and constrained engineering optimization problems. The combination of the hybrid Water Cycle Algorithm (WCA) and Moth-Flame Optimization (MFO) algorithm shows better accuracy and convergence speed than other metaheuristic approaches like Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and Artificial Bee Colony (ABC). Additionally, WCMFO was applied to real-world constrained engineering problems, such as pressure vessel design and tension/compression spring design, where it outperformed existing algorithms in finding optimal solutions while satisfying complex constraints. The study highlights the effectiveness of hybrid metaheuristic approaches in global optimization and suggests that further improvements could be made in multi-objective and real-time applications [4].

2.1 Distribution system

Generally, Distribution system is classified with voltage level, Nature of current, system configuration and constructional feature. In Nepal distribution system low voltage distribution with voltage level 400/230 volts and high voltage distribution with voltage level 11kV and 33kV. 11kV Radial distribution is mostly emanated from nearby substation through circuit breaker without Recloser facilities in most of the places of Nepal.

2.2 Types of Distributed generators

Distributed Generation mainly classified into two categories such as energy source based and power conversion characteristics. Energy based source DGs can be renewable and non-renewable for example Photo voltaic, Biomass, Wind turbine, micro hydro based DGs are renewable and Diesel and gas turbine-based generation are the non-renewable types of DGs. power conversion based DGs can be inverted based and rotating machine-based generators. Power electronic devices based inverted system generally employed for solar Pv, wind and battery storage system. Synchronous generator and induction generators-based generation are rotating machine based DGs.

2.3 Impact of Distributed Generators in Radial Distribution Network

In radial distribution networks, currents flow in one direction however, in case of the network containing the DGs, the direction of flow of current is no longer remain unidirectional. Synchronous DGs like micro-hydro, biomass, diesel contribute high fault currents, impacting relay coordination and protection settings [1]. Induction-based DGs like wind turbines, small hydro has moderate fault currents but require reactive power compensation. Inverter-based DGs like solar PV, battery storage, wind with power electronics provide limited fault current, leading to protection challenges [1]. Hence the presence of DGs in radial distribution network have various impact on voltage profile, flow of current and protection system so the protection coordination is very important and must be implemented in case of DGs like adaptive relaying, directional protection, fault current limiters, and anti-islanding [18].

2.3.1 Impact of DG on voltage profile

When numerous DG connections gather on a particular feeder, the difference in power flow between feeder lines increases due to the back-flow from the DG. This variation could lead to the voltage profile of feeder straying from the appropriate range. The voltage of feeder may vary if the output of the distributed generation changes rapidly, and such variation could lead to over voltage or under voltage at the receiving point of customer [2]. The placement of the DG significantly influences voltage stability. For the entire system, allocating an equal capacity of DG across multiple buses and various locations is preferable for voltage stability than aggregating the same capacity at a single bus [19].

It is preferable for the DG units to be placed in appropriate locations of adequate size to enhance voltage profile, minimize system losses, and improve stability. In radial distribution systems, strategically locating DGs can lead to considerable enhancements in voltage stability concerns and reductions in system losses. Regrettably, the electric utility lacks complete authority over the locations for installation or the dimensions of DG, as these typically belong to the consumer. Despite these obstacles, it is crucial for the utility to possess a strategy for determining the appropriate location and size of DGs to enhance overall voltage profile, system stability, and reduce losses [20].

2.3.2 Impact of DG on fault current

Multiple DGs connected during the fault can significantly change the direction of flow of currents in feeder at various locations on the same feeder of DGs section Thus, the existence of DGs disregards the assumptions required for coordinating the Recloser Fuse algorithm used for a fully radial system fed from just a single source. The integration of DGs into an established network results in a rise in the fault level since it creates an extra parallel route for fault current so that one’s cannot predict the direction of flow of current. Fault level during the fault is the total apparent power during the short circuit condition which is generally expressed in MVA. Fault MVA is used to calculate the maximum fault current that would flow towards the fault location. It is depending upon the equivalent impedance and system voltage at the fault location.

2.3.3 Challenges to Protection Systems

The challenges of integration of DGs in distribution networks can be discussed as follows [10].

Reverse Power Flow: In traditional distribution networks, power flows unidirectionally from the source to the loads in Radial Distribution (RD). However, DG units can cause reverse power flow, leading to potential mis operation of Recloser and Fuses.

Unwanted Islanding: When a portion of the distribution network becomes isolated from the main grid but remains energized by DG units, it creates an Islanding which causes risks and complicate fault detection and isolation.

False Tripping: The presence of DG units can cause false tripping of protective devices, especially in RD. This occurs when the fault current seen by a protective device exceeds its setting due to the contribution of DG units, leading to unnecessary disconnection of healthy feeders.

Blinding of Protection: DG units can reduce the fault current seen by upstream protective devices, rendering them unable to detect and clear faults. This phenomenon, known as blinding of protection that is particularly problematic in networks with high DG penetration.

Loss of Coordination: The integration of DG units disrupts the coordination between protective devices, such as Recloser and Fuses. This miscoordination can result in delayed fault clearance and increased outage times.

Difficulties in finding fault Location: The integration of DG units challenges of fault location in distribution networks such that with DG the fault level changes whenever fault at occurs anywhere in the system so traditional impedance-based fault location methods are less accurate in the presence of DG due to changes in fault current magnitude and direction.

2.4 Optimization Technique

The placement and sizing of Distributed Generators (DGs) in a radial distribution network significantly impact voltage profile, power losses, reliability, and protection coordination. Several classical optimization techniques such as Loss Sensitivity Factor (LSF) Method, Particle Swarm Optimization (PSO), Liner Programming and

Metaheuristic Optimization Techniques like Genetic Algorithm (GA), Water Cycle Algorithm (WCA), Firefly Algorithm (FA), Teaching-Learning-Based Optimization (TLBO), Differential Evolution (DE), Artificial Bee Colony (ABC) Algorithm have been developed to determine the optimal DG placement while considering constraints such as power loss minimization, voltage limits, and protection coordination.

2.4.1 Water Cycle Algorithm

The Water Cycle Algorithm (WCA) is a metaheuristic optimization algorithm derived from the natural water cycle process, including rainfall, river flow, and evaporation. It was introduced by Hadi Eskandar et al. in 2012 for solving complex optimization problems [11]. It is the technique that address how water flows from rivers to the sea, searching for the optimal solution that means over iterations, streams merge into rivers, and rivers reach the optimal DG placement.

2.4.2 Comparison of WCA with other Optimization Technique

The Water Cycle Algorithm (WCA) has demonstrated superior convergence speed and constraint handling compared to GA, PSO, DE, ABC, and TLBO in solving engineering optimization problems. The table 2.1 adapted, shows the performance comparison of WCA with other metaheuristic algorithms [11].

Table 2.1: Comparative Analysis of WCA vs Other Metaheuristic Algorithms

S.N.	Algorithm	Evolutionary Mechanism	Strengths	Weaknesses	WCA Superiority
1	WCA (Water Cycle Algorithm)	Models water cycle process: Streams flow towards Rivers and finally to the Sea for best global solution. Uses evaporation and raining to escape local optima.	Fast convergence, Balanced exploration and exploitation, Efficient constraint handling, avoids local optima using evaporation process, Low	Requires parameter tuning, can get trapped in local optima in high-dimensional problems	Better exploration than GA & PSO, Faster convergence than DE & ABC, More efficient constraint handling than GA & PSO

S.N.	Algorithm	Evolutionary Mechanism	Strengths	Weaknesses	WCA Superiority
			computational cost		
2	GA (Genetic Algorithm)	Based on natural selection & survival of the fittest. Uses crossover & mutation to evolve solutions.	Strong global search ability, Works well for discrete optimization, can handle multimodal problems	Slow convergence, High computational cost, Poor constraint handling, Premature convergence due to stagnation	WCA has faster convergence, Better constraint handling, More efficient for real-world engineering problems
3	PSO (Particle Swarm Optimization)	Inspired by bird flocking, particles move towards their personal & global best positions.	Fast convergence, Simple to implement, Good exploration in early stages	Poor exploitation (easily trapped in local minima), Sensitive to parameter settings, Weak constraint handling	WCA has better global & local search balance, Stronger constraint handling with evaporation-raining process
4	DE (Differential Evolution)	Uses mutation, crossover & selection based on vector differences for population evolution.	Strong exploration, Good convergence for unimodal functions, less parameter tuning than GA	Slow convergence in high-dimensional problems, Weak in handling constraints, Computationally expensive	WCA converges faster with fewer function evaluations, Handles constraints better due to evaporation mechanism
5	ABC (Artificial Bee Colony)	Inspired by bee foraging behavior: employs scout, worker,	Good exploration, Handles local minima	Slow convergence, Poor exploitation (focuses too	WCA converges faster than ABC, Better balance

S.N.	Algorithm	Evolutionary Mechanism	Strengths	Weaknesses	WCA Superiority
		and onlooker bees to find food sources (solutions).	well, Self-adaptive mechanism	much on exploration), Weak constraint handling	between exploration & exploitation
6	TLBO (Teaching-Learning-Based Optimization)	Inspired by the teaching-learning process: Learners update solutions based on the best-performing individual.	No parameter tuning needed, Good global search, Robust in high-dimensional problems	Convergence depends on population size, Weak exploitation, Sensitive to initial population	WCA provides better convergence efficiency, Stronger local search ability

Based on various research paper, this paper uses the effectiveness of WCA among the various Metaheuristic Optimization Techniques for the optimal distributed generators placement along with the Recloser Fuse coordination [13], [12], [11], [21].

2.4.2.1 Applications of WCA

The applicability of WCA to constrained engineering optimization problem can be discussed as follows [11], [4]:

Engineering Design: Structural optimization, mechanical design, and aerodynamic shape optimization.

Power Systems: Optimal placement of Distributed Generation (DG) units, capacitor banks, and network reconfiguration.

Machine Learning: Hyperparameter tuning for neural networks and support vector machines.

Image Processing: Feature selection, image segmentation, and pattern recognition.

2.4.2.2 Importance of WCA in Engineering Optimization

The importance of WCA in Engineering optimization can be discussed as follows [11], [4]:

Global Search Capability: WCA efficiently explores the solution space by dynamically adjusting the movement of solutions (streams) based on their quality. This prevents premature convergence and ensures a robust global search.

Managing Constraints: The algorithm incorporates mechanisms for handling constraints, rendering it appropriate for intricate engineering issues involving several limitations, like power system optimization and relay coordination.

Quick Convergence: In contrast to conventional optimization methods, WCA demonstrates swift convergence owing to its adaptive characteristics and capacity to effectively balance exploration and exploitation.

Relevance to Power Systems: Due to its capability to address nonlinear and multi-objective challenges, WCA is especially beneficial in power system optimization activities such as optimal DG positioning, loss reduction, and relay synchronization in distribution networks.

2.5 Recloser and Fuse

A Recloser is a device that can identify phase and phase-to-ground overcurrent situations, interrupt the circuit if the overcurrent continues beyond a set duration, and then automatically reclose to restore power to the line. If the fault that caused the operation is still present, the Recloser will remain open after a predetermined number of operations, thereby isolating the faulty section from the rest of the system. In an overhead distribution system, 80 to 95 percent of faults are temporary and typically last only a few cycles or seconds. Therefore, the Recloser, with its ability to open and close, ensures that a distribution circuit does not remain offline due to temporary faults. Generally, Recloser is intended to perform as many as three open-close cycles, final operation of open action is to secure the process [22].

Coordinating with other protective devices is crucial to ensure that, when a fault happens, the smallest part of the circuit is isolated to reduce supply disruptions to customers. Typically, the timing feature and the operation sequence of the Recloser is chosen to align with mechanisms located upstream toward the source. Once the size and operation sequence of the Recloser have been chosen, the downstream devices are modified to ensure proper coordination. The sequence of operation of Recloser is illustrated in figure 2.1 [22].

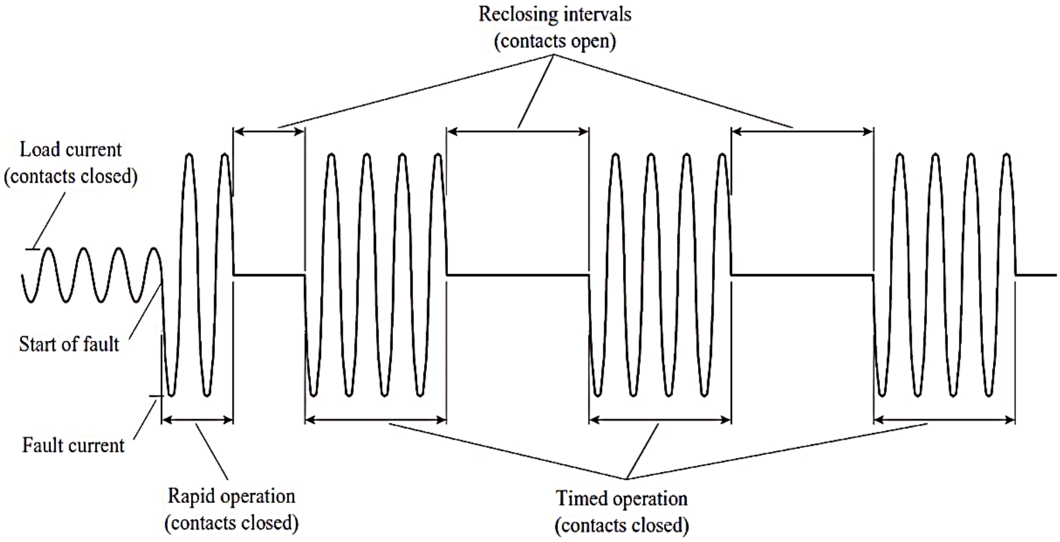

Figure 2.1: The sequence of Operation of Recloser

The initial shot is performed in immediate mode to resolve temporary faults before they inflict harm on the lines. The last three function in a scheduled way with pre-established time settings. If the fault is enduring, the time-delay function permits other protective devices closer to the fault to activate, reducing the extent of the network being isolated.

A Fuse is a protection device against overcurrent; it contains an element that gets heated directly by the flow of current and is ruined when the current surpasses a set limit. In distribution systems, the application of Fuse links labeled K and T for fast and slow types, respectively, based on the speed ratio, is quite common. The speed ratio refers to the minimum melt current required for Fuse operation at 0.1 seconds, compared to the minimum melt current necessary for a 300 seconds operation[22].

2.5.1 Recloser and Fuse Operating Characteristics

The primary protection must rectify a permanent or temporary fault before the backup protection activates, or remain functional until the circuit is isolated. Nonetheless, if the primary protection is a Fuse and the secondary protection is a Recloser, it is generally acceptable to adjust the quick operating curve or curves of the Recloser to actuate first, subsequently followed by the Fuse if the fault remains unresolved Loss of supply due to permanent faults should be limited to the smallest section of the system for the briefest duration feasible so that minimum number of consumers affected by the fault [22]. The position of the DG affects various fault locations, resulting in different instances of Recloser–Fuse miscoordination. The coordination is valid only when the fault current lies between the feeder's minimum and maximum fault currents, with a margin required between the operating times of both devices. This is due to the fact that the Recloser’s rapid characteristic curve sits beneath the minimum melting characteristic of the Fuse, while the slow characteristic curve of the Recloser must be positioned above the Fuse's total clearing characteristic, between the maximum and minimum fault current. Recloser Fuse Operating Characteristics is shown in figure 2.2 [23].

Nonetheless, the incorporation of distributed generation into the distribution network can impact the coordination of Recloser and Fuses accordingly based on the size, type, and placement of DG units [23]. Recloser-Fuse miscoordination may happen when the fault current exceeds the maximum fault current due to the extra fault current contribution from distributed generation (DG).

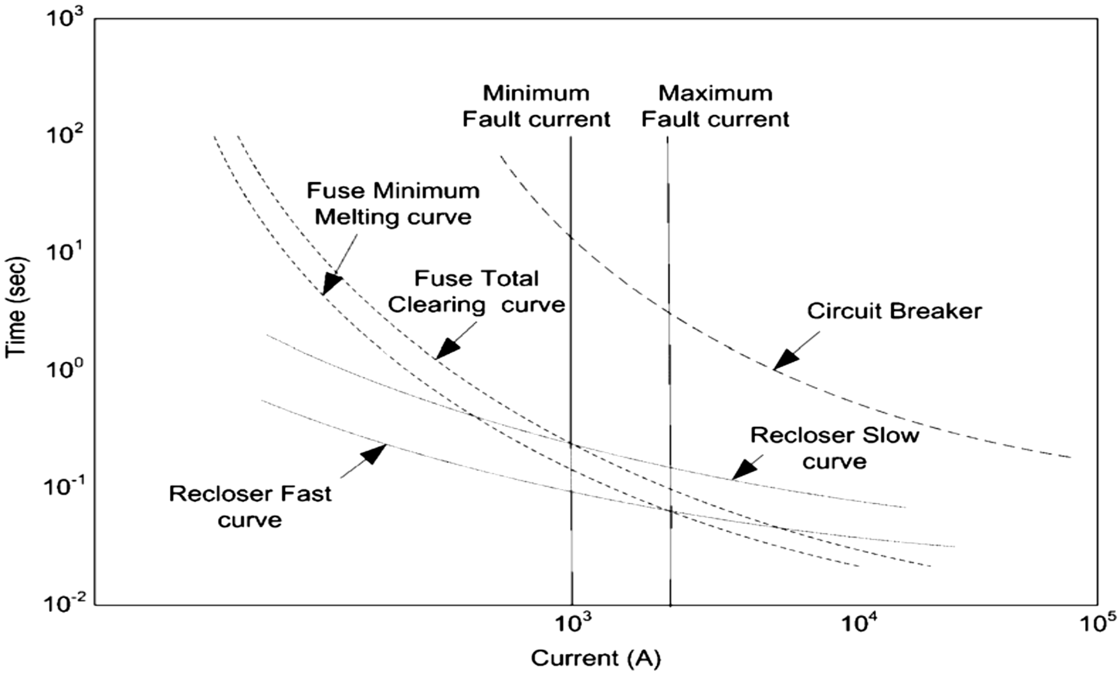

Figure 2.2: Recloser Fuse Operating Characteristics curve

This situation might occur when, because of the position of DG, the fault current detected by a Recloser is lower than the current flowing through a Fuse, even if the fault current lies between the minimum and maximum fault currents. Consequently, the Fuse might blow first, or both the Fuse and the Recloser could function simultaneously.

In the event of a permanent fault, after the Recloser finishes its fast mode operations, the Fuse blows to eliminate the fault while the Recloser is poised to act on its slow curve. The Recloser circuit breaker (CB) offers comprehensive backup protection to all the Fuses that lies lateral part of the feeder it is because time-current characteristic curve of Recloser is positioned above all other curves of Fuses.

2.5.2 Time Dial Setting

The time dial adjustment regulates the delay before the relay activates when the fault current equals or exceeds the relay's current setting. In electromechanical relays, the time delay is typically attained by modifying the gap between the movable and stationary contacts; a reduced time dial setting leads to quicker operating duration [22]. The TDS of Recloser is nothing but the time multiplier setting (TMS), which determines the how slow and fast the Recloser responds to the fault current. That means larger value of TDS gives delay operation and low value of TDS gives faster operation of Recloser.

2.6 IEEE-33 Bus Radial Distribution System

The IEEE 33-bus system is a widely used benchmark test system for radial distribution networks. It is commonly used for power flow analysis, loss reduction, DG placement, network reconfiguration, and voltage stability studies [24]. It has 33 number of bus and 32 branches with a slack bus at bus number 1 having initial total power loss 202.677 kW and weakest bus voltage 0.913 pu at bus number 18 without placement of DGs. The basic standard data of IEEE 33 bus system is well described in ANNEXES A, B and C.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 General

The research has been started with the identification and formulation of the problems with the integration of distributed Generators in the radial distribution network along with the protection coordination. To solve issues addressed above, an ideal strategy for protection coordination scheme of Recloser and Fuses is suggested in this work by using the effectiveness of Water Cycle Algorithm (WCA) to obtain an optimized Recloser and Fuses coordination curve which can work properly under faults conditions and locations of DGs in the IEEE 33-bus [12] (benchmark test system) radial distribution systems.

Initially the optimal location of DGs is figured out in standard system of IEEE33-Bus and the short circuit analysis perform in ETAP Simulink from where the relevant fault current data is fetched at different case scenarios like base case, single DG case and multiple DGs case. Here, the minimum short circuit analysis is performed from ETAP Simulink to get the fault current data in order to achieve the lowest possible fault current under the worse system condition so that Recloser and Fuse can operate at lowest actuating quantities [25]. Hence the sensitivity of the Recloser and Fuses improve to provide optimal Recloser Fuse coordination ensuring the protective devices are able to detect and clear the fault under weakest system condition. Thus, obtained fault current data is further analyzed in MATLAB with WCA to get the optimum values of Recloser setting (TDS) and Fuse constants for all Fuses. The overview of the research methodology as shown in the figure 3.1.

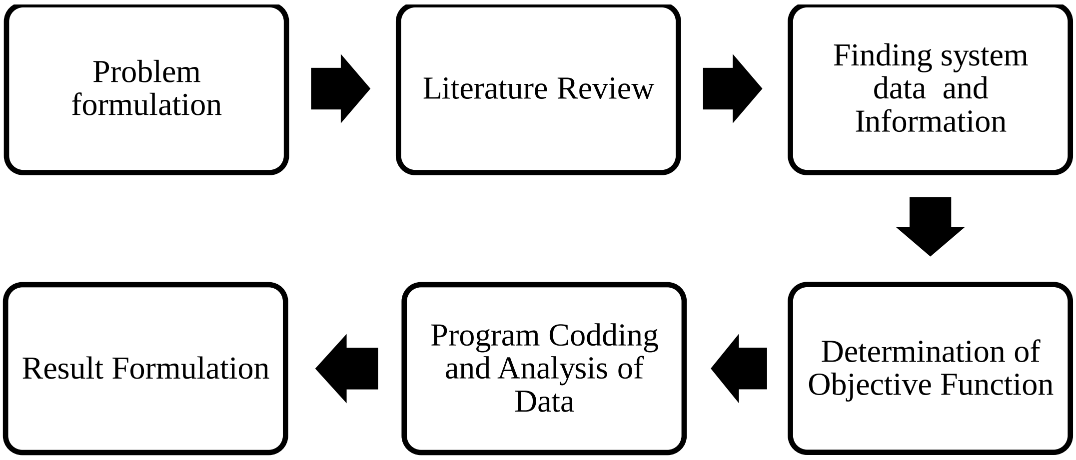

Figure 3.1: Overall Flowchart

3.2 Steps of the Water Cycle Algorithm (WCA)

Step 1. Initialize Population: Generate an initial population of candidate solutions (raindrops) randomly within the defined search space. Evaluate the fitness of each candidate solution based on the objective function.

Step 2. Rank the Population: Sort the solutions in ascending order of their objective function values (for minimization problems). Assign the best solution as the Sea and the next best solutions as Rivers. The remaining solutions become Streams.

Step 3. Distribute Streams Among Rivers and Sea: Assign streams to rivers based on their fitness values using a proportional allocation rule. Each stream flows toward its assigned river, and each river flows toward the sea.

Step 4. Move Streams and Rivers Towards Better Solutions: Update the positions of streams using a movement equation that directs them toward their respective rivers. Rivers move towards the sea using a similar equation.

Step 5. Evaporation and Convergence Check: If a stream reaches a better position than its assigned river, it replaces that river. If a river reaches a better position than the sea, it replaces the sea. If the movement of solutions stagnates, an evaporation condition is triggered, generating new random solutions to maintain diversity.

Step 6. Check Stopping Criteria: Repeat steps 3 to 5 until the maximum number of iterations is reached or convergence criteria (such as minimal improvement in objective value) are met.

Step 7. Return Optimal Solution: The best solution obtained (the sea) represents the optimal solution to the problem.

These steps ensure efficient exploration of the solution space while preventing premature convergence, making WCA a powerful tool for solving complex engineering optimization problems [11]. Logical Flow chart of Water Cycle Algorithm is shown in figure 3.2 [14].

3.3 Logical Flow Chart of WCA

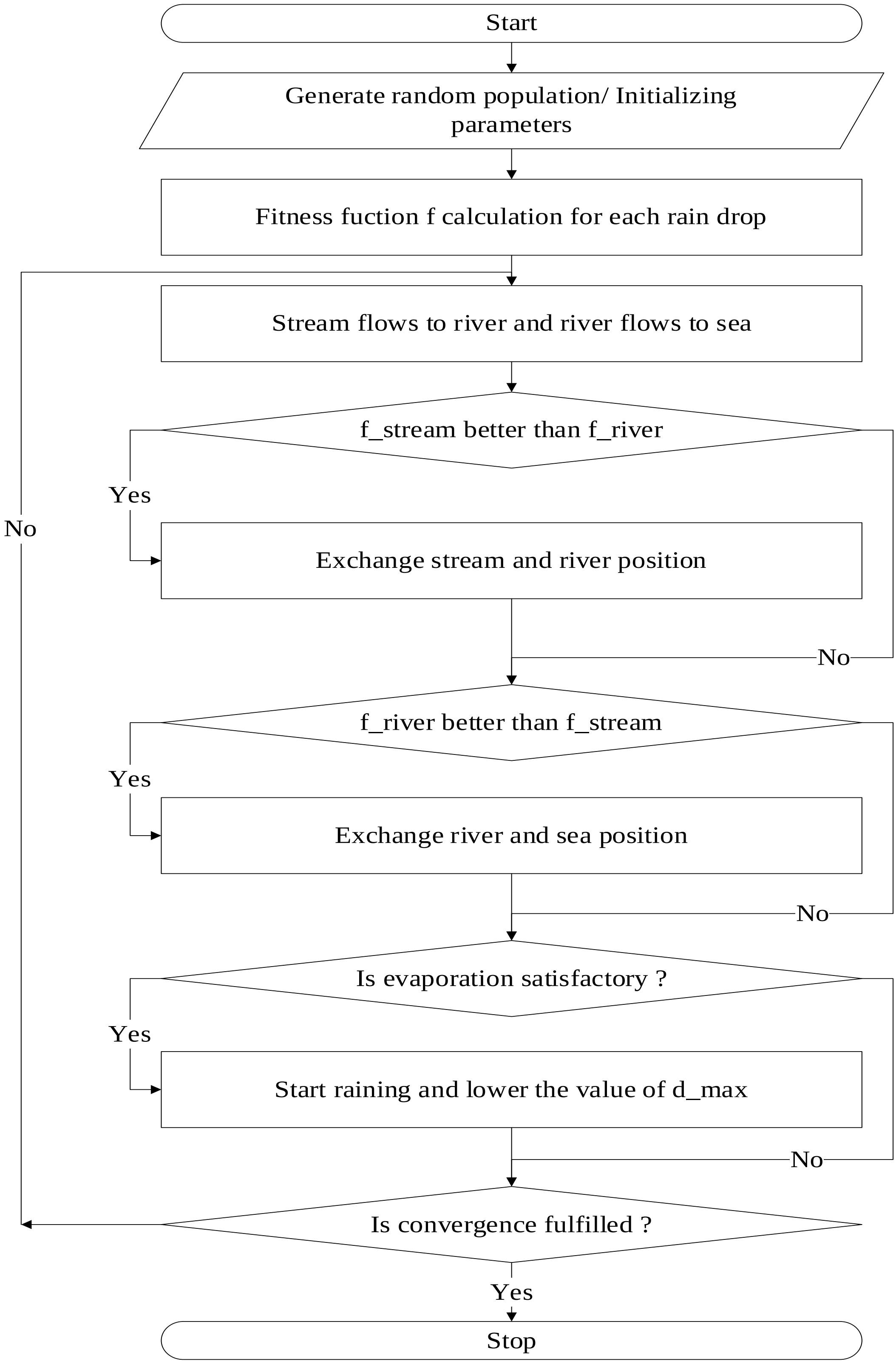

Figure 3.2: Logical Flowchart of the Water Cycle Algorithm

3.4 Methodological steps and flow chart

The overall Methodological steps of this research paper goes through the following steps.

Step 1: Read system data.

Step 2: Determine Base case, Single DG case or Multiple DGs case.

Step 3: Optimal Placement of DGs with WCA in MATLAB.

Step 4: Get the fault current in ETAP by Short Circuit Analysis.

Step 5: Get the short circuit current for optimal Recloser Fuse co-ordination with WCA in MATLAB.

Step 6: Find the Recloser Fuse constant and obtain optimum characteristics of Recloser Fuse co-ordination.

Step 7: Stop and Print Result.

The methodological steps can be shown in the figure 3.3.

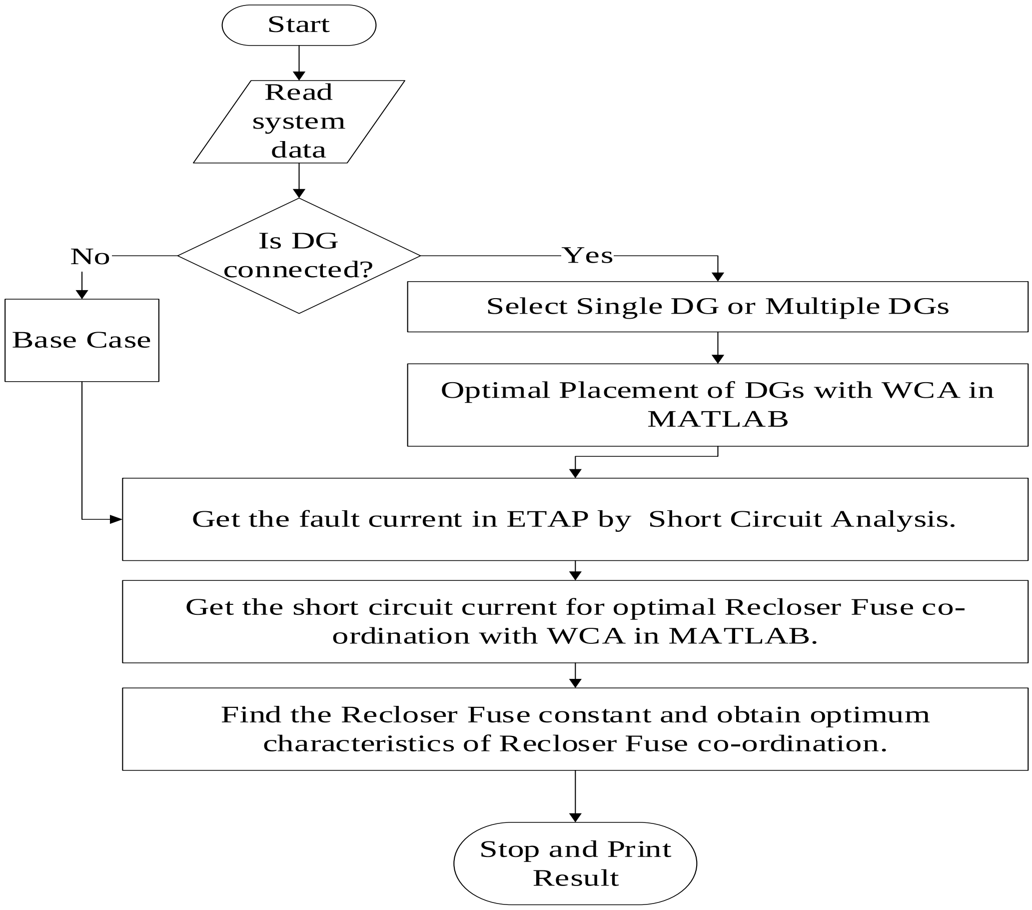

Figure 3.3: Flow chart of Methodological steps

Initially, the steps begin with the random DGs placement in different buses in IEEE 33 bus system such that it should give minimum power loss and voltage fluctuations along with the calculation of total power loss during load flow analysis, is followed by WCA in MATLAB among them the minimum total power loss and the respective bus selected as the optimal location and the corresponding size is the optimal size of the DG in single or multiple DGs case scenario. Here, the objective function for the placement of the DGs can be described as follows.

3.5 Objective function for Optimal DGs placement

System Power Loss

$$Minimize\ P_{loss} = \sum_{i}^{n} i_i^2 * R_i \tag{1}$$

Where,

i_i, R_i, and n are current in ith node, resistance of ith branch and total number of busses respectively.

Subjected to,

$$0.90\ \text{pu} \leq Vi \leq 1.1\ \text{pu} \tag{2}$$

Where, V_i is the voltage of ith bus.

If there is no any other source of power in the system, the voltage limit should at base case should not more that 10% and less than 10% in the tested IEEE 33 bus radial distributed network [26] so the voltage limit in the system should be maintained within the specified range to maintain the voltage profile.

3.5.1 Flow Chart for Optimal DGs placement

The algorithms of the optimal DGs placement goes through the following.

Step 1: Input line data and bus Data (IEEE 33 Bus System).

Step 2: Run the load flow for base case.

Step 3: Create the initial Random Population (DG size, DG type, Location and DG Number).

Step 4: Find the objective functions.

Step 5: Is Constraints Satisfy? if not go to the step 3.

Step 6: Calculate new objective function and compare with the previous values.

Step 7: Is Fitness function improved? if not go to the step 3.

Step 8: Stop and get the optimal size and placement.

The steps of the optimal DGs placement can be illustrated with flow chart in figure 3.4.

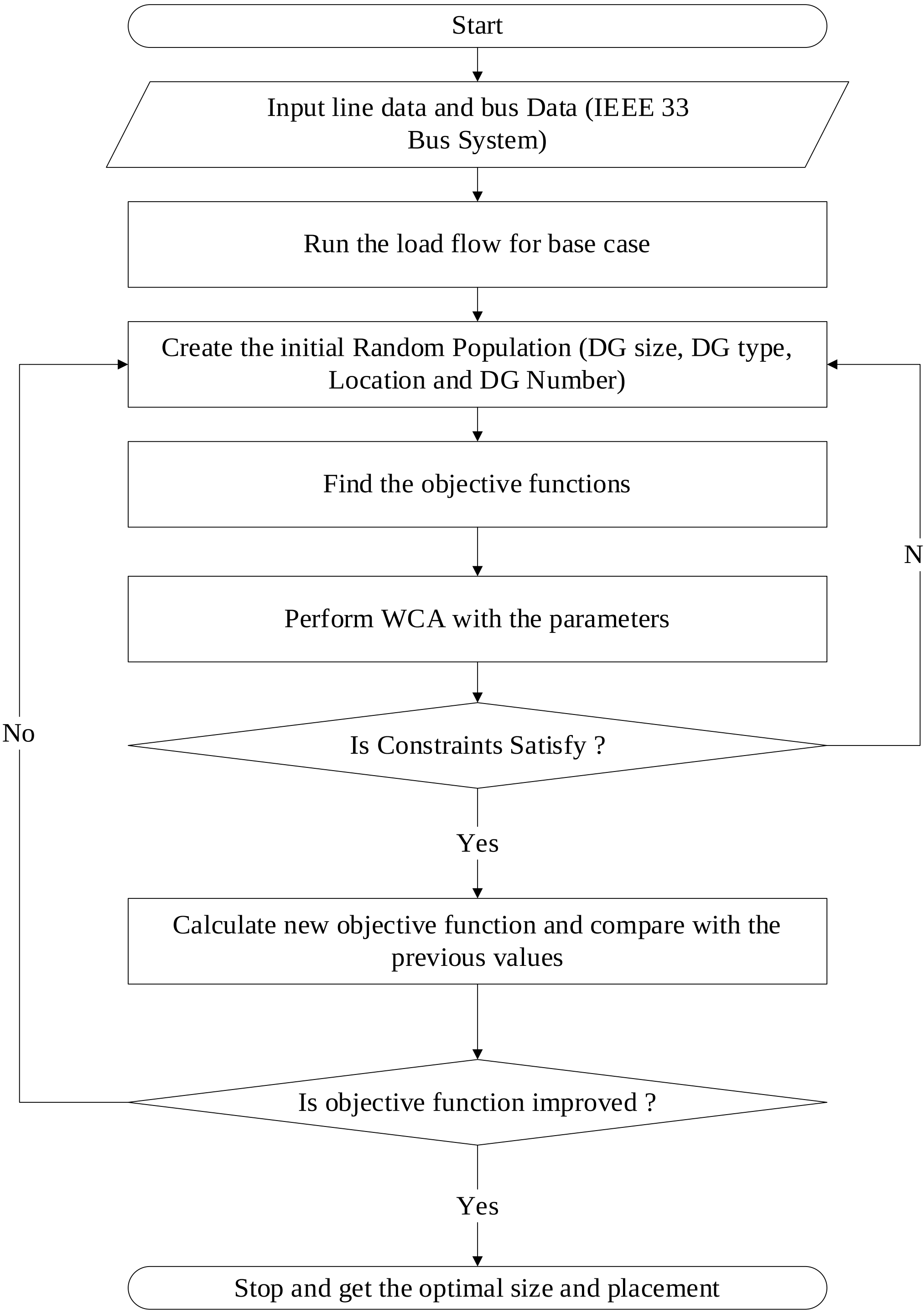

Figure 3.4: Flow chart of optimal placement of DGs.

After finding the optimal location and size of DGs, the corresponding model of IEEE 33 bus system in created in ETAP Simulink software with the different case scenario like in base case, single DG case and multiple DGs case for short circuit analysis and the fault current through the Recloser and Fuses along the faulted path is achieved by short circuiting each and every bus at a time which is further used in MATLAB to find the optimal Recloser Fuse coordination characteristics curve by using WCA.

3.6 Recloser and Fuse Modeling

The position of the DG affects various fault locations, resulting in different instances of Recloser–Fuse miscoordination. The coordination is valid only when the fault current lies between the feeder's minimum and maximum fault currents, with a margin required between the operating times of both devices. This is due to the fact that the Recloser’s rapid characteristic curve sits beneath the minimum melting characteristic of the Fuse, while the slow characteristic curve of the Recloser must be positioned above the Fuse's total clearing characteristic, between the maximum and minimum fault current. Typically, the timing feature and the operation sequence of the Recloser are chosen to align with mechanisms located upstream toward the source. Once the size and operation sequence of the Recloser have been chosen, the downstream devices are modified to ensure proper coordination.

3.6.1 Recloser and Fuse Characteristics

The extremely inverse characteristic curves of Recloser is used to have a proper coordination with the Fuses during the fault condition as fault current is extremally higher than normal current [27], [28]. The following mathematical equation is used as extremely inverse characteristic curves of Recloser.

$$t_{opR} = TDS * \left(\frac{A}{\left(\frac{I_{FR}}{PCS}\right)^{p} - 1} + B\right) \tag{3}$$

Where,

t_{opR} = Recloser operating time,

I_{FR} = Fault current at Recloser

PCS =Recloser pickup current setting

The PCS is the margin above the normal maximum current (I_m) which is fixed and the overloading factor for the PCS is taken as 1.25 [22], [29].

In this study, Recloser characteristic is extremely inverse so the values of Recloser constant A, B, and p are taken as 28.2, 0.1217, and 2, respectively [27].

$$\mathrm{PSC} = 1.25 * \mathrm{I_m} \tag{4}$$

Similarly, the characteristic of Fuse can be expressed as inverse current-time characteristic is described by log-log curve function as follows [28], [29].

$$\log\left(\mathrm{t_{opF}}\right) = \mathrm{a} * \log(\mathrm{I_{FF}}) + \mathrm{b} \tag{5}$$

Here, t_{opF} is the Fuse operating time, I_{FF} the fault current at Fuse along the faulty location. The *a* and *b* are the Fuse characteristics constants.

3.6.2 Recloser Fuse coordination objective function

In a radial distribution system, coordination between Recloser and Fuses is important. During fast operating mode of the Recloser, Fuse should not blow to prevent customers from losing power due to temporary faults. The Recloser must acts as an overall backup for the rest of the Fuses in the lateral part of the system. However, for permanent faults, the nearest Fuse should blow before the Recloser's last slow mode of operation to prevent unnecessary Recloser operation and minimize customer outages although the presence of DGs in the system. If the fault persists for longer duration, Fuse near to the fault location must blowout again if it fails to operate the next Fuse along the faulty section must blowout after the coordinated time. The operating sequence of the protective devices should be valid for the faults that might occurs at anywhere in the system.

The coordinated time is nothing but the Time Discrimination Margin or Minimum Coordination Time Interval of two successive time of operation of protective devices [22].

Here, the goal is to minimize the total operating times of all Fuses and the Recloser during the fault condition along the faulty section with the presence of DGs such that the operating time characteristics of all Fuses should lies within the operating time characteristics curve of the Recloser's fast and slow modes. This issue can be represented mathematically using the subsequent objective function (OF).

$$\mathrm{OF} = \mathrm{Min} \sum_{j=1}^{m} \left(\mathrm{t_{opR,fm,j}} + \mathrm{t_{opR,sm,j}} + \sum_{K=1}^{N_j} \mathrm{t_{opF,jk}}\right) \tag{6}$$

Subjected to:

$$t_{opF,jk} - t_{opR,fm,j} > MRCTI * 0.5 \tag{7}$$

$$t_{opF,j(k+1)} - t_{opF,jk} > MFCTI \tag{8}$$

$$t_{opR,sm,j} - t_{opF,jk} > MRCTI * 0.5 \tag{9}$$

$$t_{opR,sm,j} - t_{opR,fm,j} > MRCTI \tag{10}$$

$$\mathrm{TDS}_{min} \leq \mathrm{TDS}_{\mathrm{fm}} \leq \mathrm{TDS}_{max} \tag{11}$$

$$\mathrm{TDS}_{min} \leq \mathrm{TDS}_{\mathrm{sm}} \leq \mathrm{TDS}_{max} \tag{12}$$

Where,

$t_{opR,fm,j}$ = Recloser operating time at fast mode during fault at j node

$t_{opR,sm,j}$ = Recloser operating time at slow mode during fault at j node

$t_{opF,jk}$ = Operating time of kth Fuse during fault at j node

m = Total number of nodes

Nj = Total number of Fuses along the faulty section towards the Recloser from node j

MRCTI = Minimum Recloser coordination time interval

MFCTI = Minimum Fuse coordination time interval

TDS_{min} = Recloser TDS minimum limits

TDS_{max} = Recloser TDS Maximum limits

The Value of MRCTI and MFCTI are taken as 0.5 sec and 0.2 sec because it is generally in the range of 0.2 to 0.5 sec which provides sufficient margin to account in fault current devices tolerances and operating times [30], [22], [29].

Similarly, the time dial setting can be taken as 15 to 1 or greater range of time adjustment according to requirement [27]. In this study, the value of TDS_{min} and TDS_{max} are taken as 0.5 and 10 respectively [29].

The operating times of Recloser from the equation 3 can be used for fast and slow mode of operation as follows:

$$t_{opR,fm,j} = TDS_{fm} * (\frac{A}{\left(\frac{I_{FR,j}}{PCS}\right)^{p} - 1} + B) \quad (13)$$

$$t_{opR,sm,j} = TDS_{sm} * (\frac{A}{\left(\frac{I_{FR,j}}{PCS}\right)^{p} - 1} + B) \quad (14)$$

Similarly, the operating times of Fuses from the equation 5 can be used as follows:

$$t_{opf,jk} = \exp\,\hat{}((a_k * \log(I_{FF,jk}) + b_k) \quad (15)$$

Where,

I_{FR}, j =Recloser fault current for fault during fault at j node

I_{FF}, jk = Fault current of k^{th} Fuse during fault at j node

a_k, b_k = Characteristics coefficient of k^{th} Fuse

Here, the optimum values of Fuse Characteristics coefficients a_k and b_k of k^{th} Fuse towards the faulty section and Time Dial Setting of Recloser TDS_{fm} and TDS_{sm} is to be found out for optimal Recloser Fuse coordination by using WCA after finding the optimal location of DGs.

3.6.3 Flow chart of optimal Recloser Fuse Coordination

The algorithms of the optimal DGs placement goes through the following.

Step 1: Input fault current data from ETAP Simulation and data of PCS, MRCTI, MFCTI, A, B & p.

Step 2: Create the initial Random Population (Lower and Upper bound of TDS and a &b).

Step 3: Find the objective functions.

Step 4: Is Constraints Satisfy? if not go to the step 2.

Step 5: Calculate new objective function and compare with the previous values.

Step 6: Is Fitness function improved? if not go to the step 2.

Step 7: Get the optimal value of a, b and TDS.

Step 8: Stop and Display optimal coordination.

The steps of the Recloser and Fuses coordination can be shown with flow chart in figure 3.5.

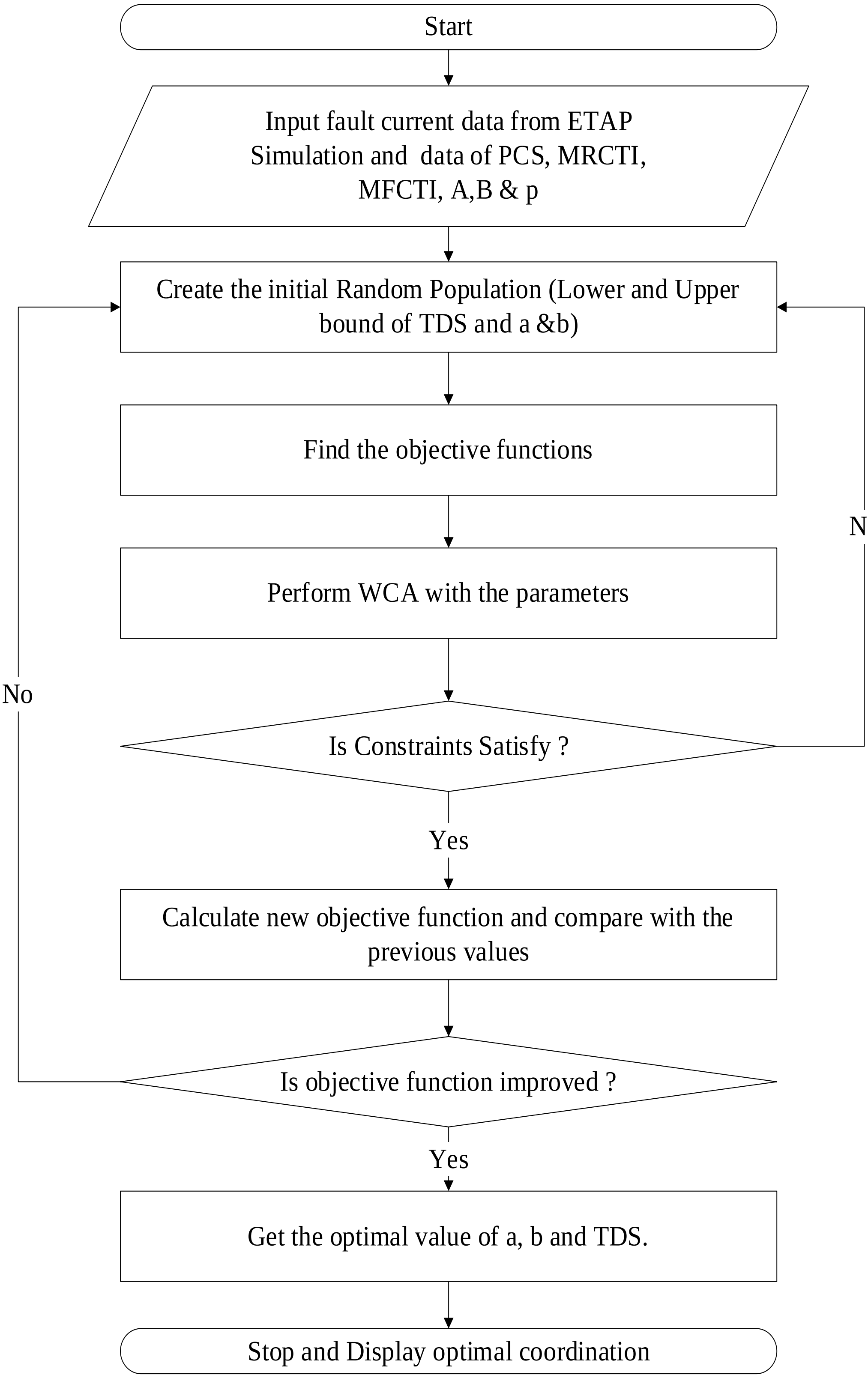

Figure 3.5: Flow chart of optimal Recloser Fuse Coordination

3.7 Tools and Software

In power system, Load flow analysis is essential for power system planning, load flow studies, network configuration, voltage profile and forecasting. Load flow study of power systems can be performed by using various software applications, including PowerWorld, ETAP, MATLAB, ERACS, NEPLAN, and PowerFactory. These instruments assist in calculating bus voltages, power losses, and stability of the system. In this research employs MATLAB and ETAP for data collection and issue resolution, utilizing MATLAB’s computational versatility and ETAP’s user-friendly interface for precise analysis and verification.

3.7.1 ETAP 19.0.1

In this study, Electrical Transient and Analysis Program (ETAP) 19.0.1, is used as major simulation tool. It is the most effective and reliable tool which is mostly used in power system automation, simulation, design process, operation and control and fault analysis etc., operation and control, optimization, and automation of power system. Here, it is used to create the model IEEE 33 bus system with the base case and multiple DGs case scenario and short circuit analysis is done to find the fault currents data at anywhere in the systems.

3.7.2 MATLAB R2018a

MATLAB is known as matrix laboratory. It is a programming language and platforms that uses the data in the form of matrices individual numbers. It is used for data analysis, modeling and simulation, research and development etc. that allows users to perform user interface and interface program. It also provides various inbuilt functions, Simulink block and toolbox that makes easy computation for any complex real-world problems.

In this research paper, MATLABR2018a is used to do load flow analysis (backward/forward sweep algorithm) and WCA algorithm for optimal placement of multiple DGs and Recloser Fuse coordination.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Overview

This chapter deals with the output results of MATLAB and ETAP simulation. Programming has done in MATLAB to obtain the optimal location and sizing of DGs in IEEE 33 bus system. Then the ETAP simulation model is generated at different case scenarios like base case, single DG case and multiple DGs case to get the fault current by short circuit analysis through the Recloser and Fuses along the faulty section. These fault currents data obtained after simulation in ETAP is used as input for the MATLAB code to get the best coordination of Recloser Fuse for base case, single DG case and three DGs case. The single line diagram for the IEEE 33 bus system is shown in figure 4.1.

However, this paper mainly presents WCA optimization technique, it also shows the effectiveness of WCA over PSO optimizations technique by comparing them for optimal placement and sizing of multiple DGs with respect to the objective function so that only effective result is further used for optimal Recloser Fuse coordination.

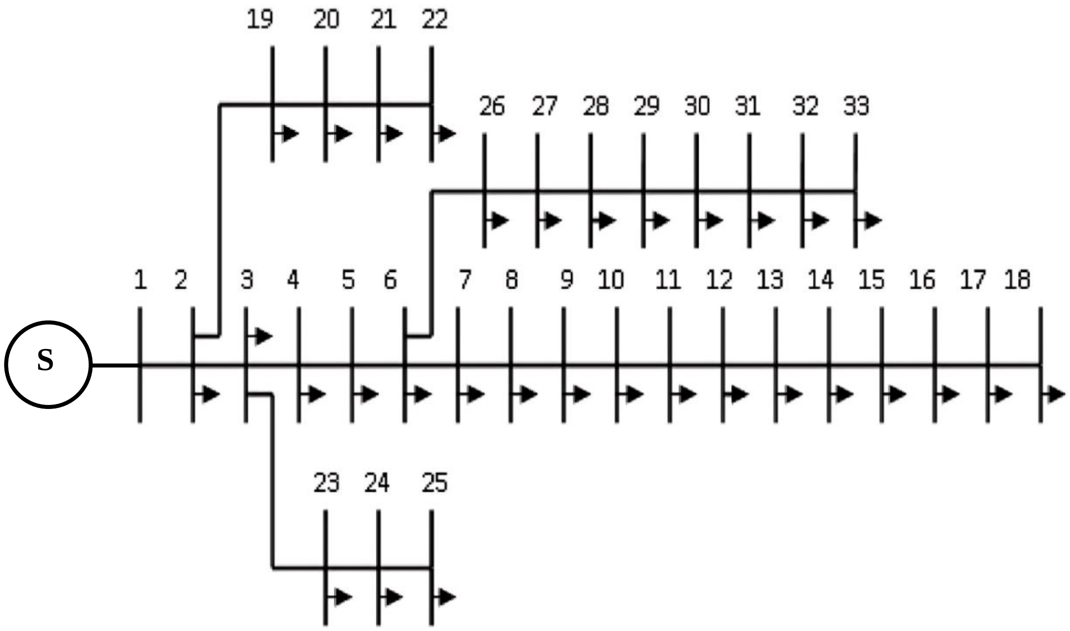

Figure 4.1: IEEE 33 bus system

4.2 Result obtained from MATLAB for optimal location and sizing of DGs

MATLAB coding of WCA and PSO optimization technique has done for optimal placement and sizing of both the single and multiple DGs cases. For convenient, we consider three DGs case only for multiple DG case because if more DGs then it will take more time to complete the iterations. Finally, the output results from the both optimization techniques are compared to achieve the best values.

4.2.1 Optimal location and sizing of DGs with WCA and PSO

At first, power loss is computed without DG for base case and then the optimal size and location of single and three DGs case are obtained along with the corresponding minimum losses by using WCA and PSO MATLAB code. The outputs are tabulated in table 4.1.

Table 4.1: Optimal location and sizing for single and three DGs case

<table>
<tr><th colspan="3">Location and Sizing of 1 DG case</th></tr>
<tr><th>Optimization Technique</th><th>Bus Location</th><th>Size of DGs (MW)</th></tr>
<tr><td>WCA</td><td>6</td><td>2.229</td></tr>
<tr><td>PSO</td><td>6</td><td>2.229</td></tr>
<tr><th colspan="3">Location and Sizing of 3 DGs case</th></tr>
<tr><th>Optimization Technique</th><th>Bus Location</th><th>Size of DGs (MW)</th></tr>
<tr><td rowspan="3">WCA</td><td>6</td><td>1.229</td></tr>
<tr><td>14</td><td>0.604</td></tr>
<tr><td>31</td><td>0.686</td></tr>
<tr><td rowspan="3">PSO</td><td>6</td><td>1.311</td></tr>
<tr><td>14</td><td>0.604</td></tr>
<tr><td>33</td><td>0.606</td></tr>
</table>

For the single DG case, the optimal location for the placement has been found at bus 6, with size 2.229 MW form both optimization technique. However, for three DGs case, from WCA the optimal location for the DGs has been found at bus 6, 14, and 31 with sizes 1.229 MW, 0.604 MW and 0.686 MW respectively and from PSO the optimal location for the DGs has been found at bus 6, 14 and 33 with sizes 1.311 MW, 0.604 MW, and 0.606 MW respectively.

4.2.2 Loss comparison WCA Vs PSO

Furthermore, the loss in both single and three DGs placement cases are compared with the base case scenario and the comparison has been tabulated in table 4.2 and graph figure 4.2.

Table 4.2: Comparison of loss in case of single and three DGs cases with base case

Power Loss Comparison WCA Vs PSO					
Optimization Technique	**Base Case without DG (kW)**	**1 DG Case (kW)**	**3 DGs Case (kW)**	**% decreased with 1 DG case**	**% decreased with 3 DGs case**
WCA	202.677	105.637	76.807	47.879%	62.104%
PSO	202.677	105.637	77.823	47.879%	61.602%

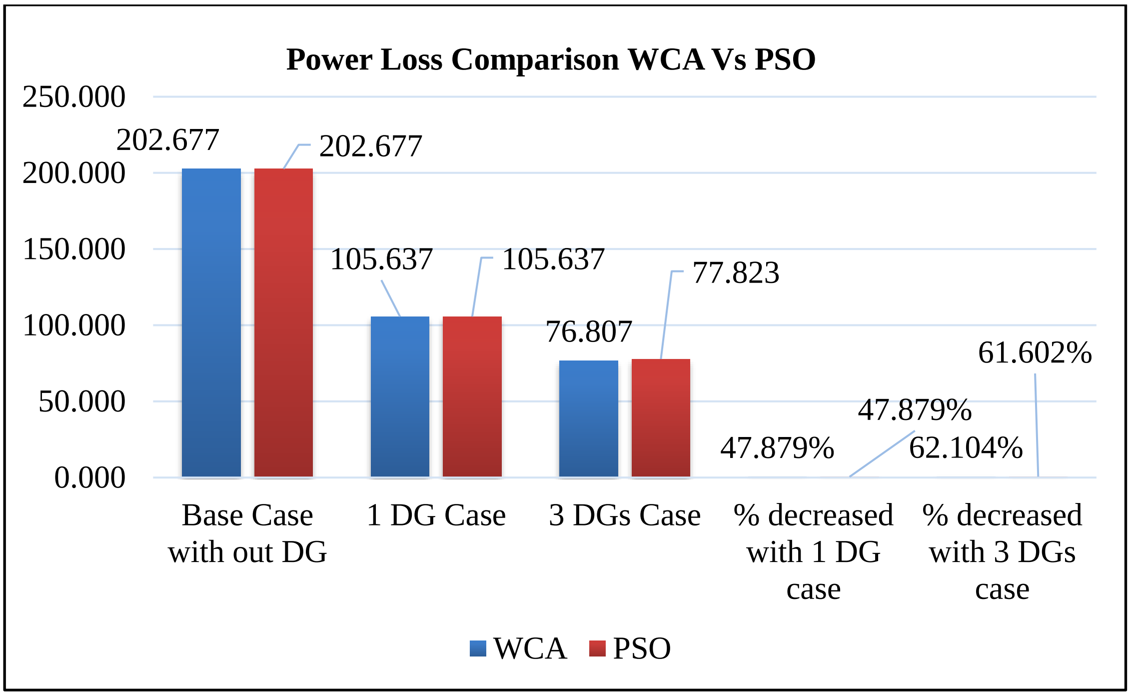

Figure 4.2: Power Loss Comparison WCA Vs PSO

Here, total loss for the base case is 202.677 kW and total loss of the network in single DG case and three DGs case are found to be 105.637 kW and 76.807 kW respectively with WCA optimization and 105.637 kW and 77.823 kW respectively with PSO optimization. From the results, in single DG case both optimization techniques have same result of total loss but WCA performs better to achieve the objective function as compared to the PSO optimization technique if we increased the number of DGs in the same network. The percentage decrease in loss with comparison to base case is found to be 62.104% and 61.602% form WCA and PSO when there are three DGs respectively. Hence, Power Loss decreased by 1.02kW (1.31%) with WCA optimization as compared to PSO.

4.2.3 Objective function convergence graph WCA Vs PSO

The convergence of the objective function can be illustrated in figure 4.3, 4.4, 4.5 and 4.6.

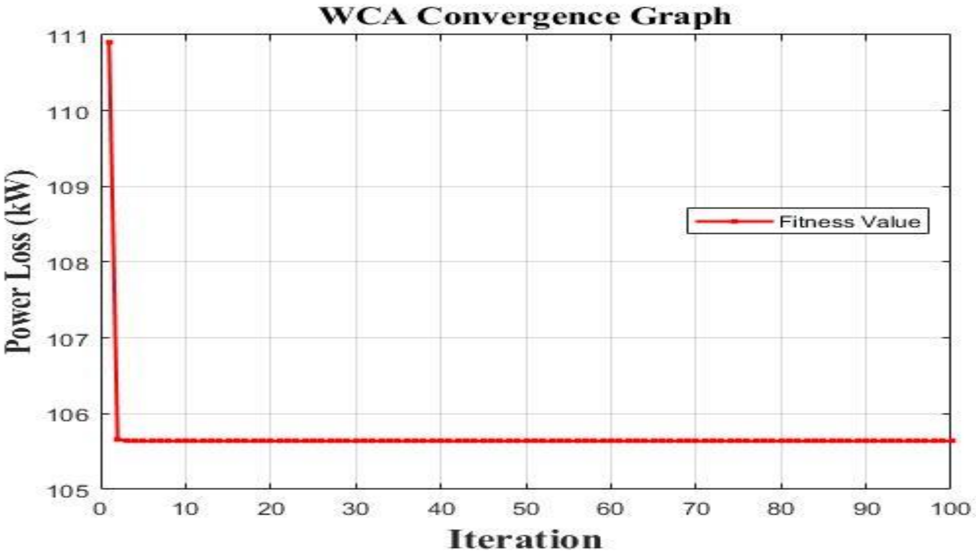

Figure 4.3: Objective function convergence graph for single DG with WCA

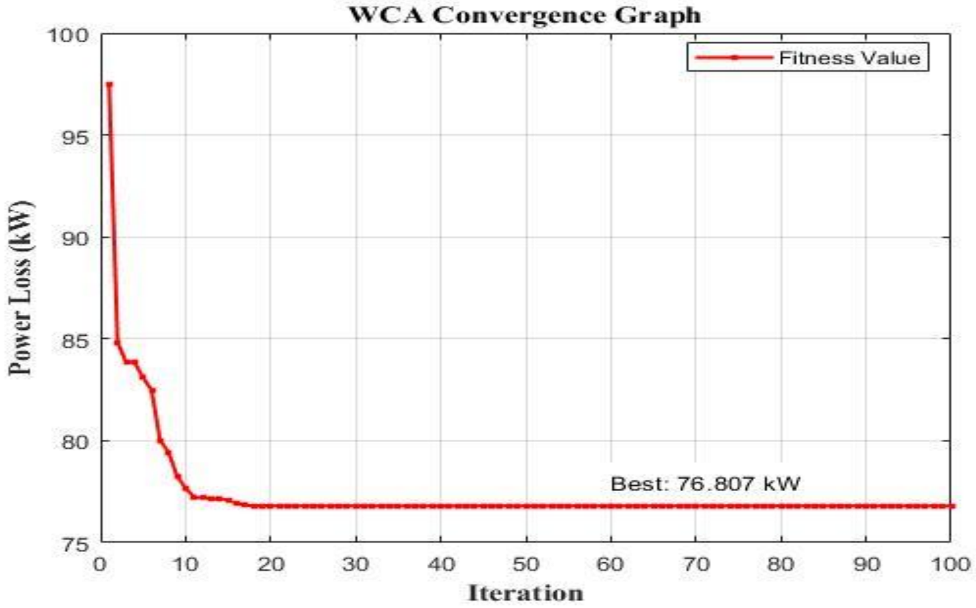

Figure 4.4: Objective function convergence graph for three DGs with WCA

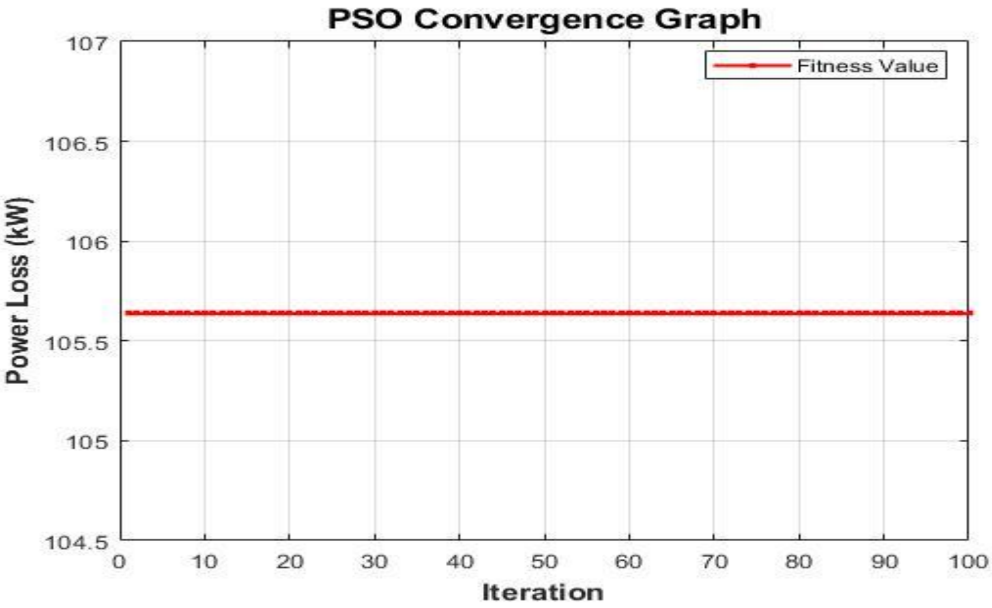

Figure 4.5: Objective function convergence graph for single DG with PSO

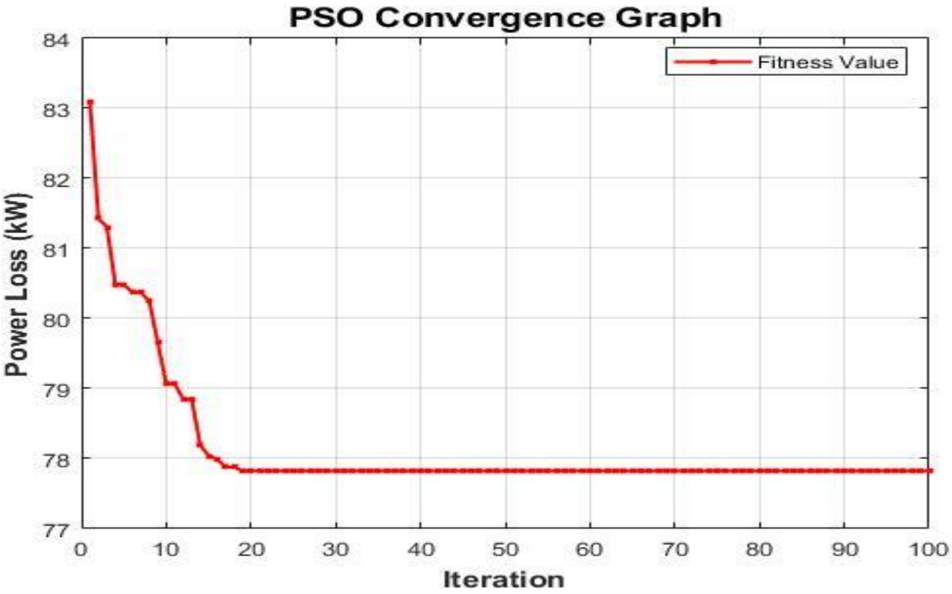

Figure 4.6: Objective function convergence graph for three DGs with PSO

Form above convergence graph, the objective function value is found to be 105.637 kW at 2 iterations in single DG case and for three DGs case the objective function value is found to be 76.807 kW at 20 iterations with the WCA. Similarly, the objective function value is found to be 105.637 kW at 1 iteration in single DG case and for three DGs case the objective function value is found to be 77.823 kW at 34 iterations with the PSO. Hence, with increased in the population size and complexity of the system, the WCA performs effectively reducing the number of iterations and improved objective function.

4.2.4 Voltage comparison

Similarly, the voltage profile along the line before and after DGs placement is compared for both single and three DGs cases with the base case and comparison is performed with WCA and PSO optimization.

4.2.4.1 Voltage comparison at single DG case with WCA Vs PSO

The comparison between bus voltages for base case and after placing the one DG at optimal place is shown in figure 4.7 and data are listed in ANNEX D.

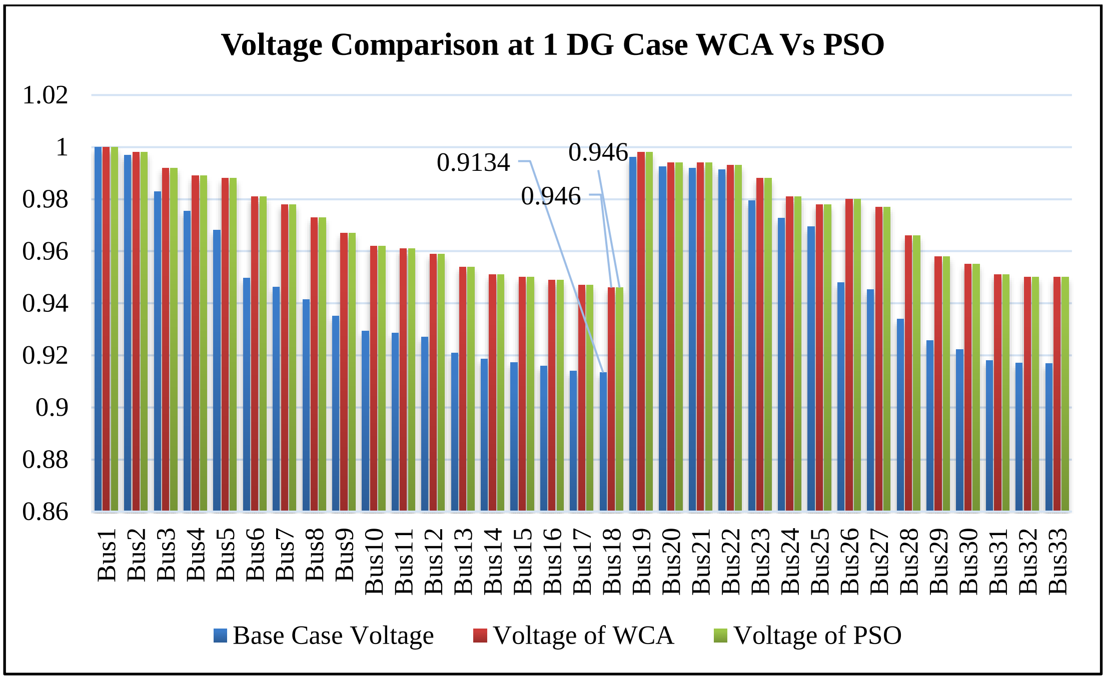

Figure 4.7: Bus Voltage comparison at single DG case WCA Vs PSO

From the above figure 4.7, it is obvious that the voltage at every bus has been improved after the installation of DG at bus 6. It is seen that the minimum voltage before DG placement is 0.913 pu at bus number 18 which has been improved to 0.946 pu so it is clear that voltage is well improved with same value in both optimizations' technique.

4.2.4.2 Voltage comparison at three DGs case

Similarly, the comparison between bus voltages for base case and after placing the three DGs at optimal places is shown in figure 4.8. data are listed in ANNEX E.

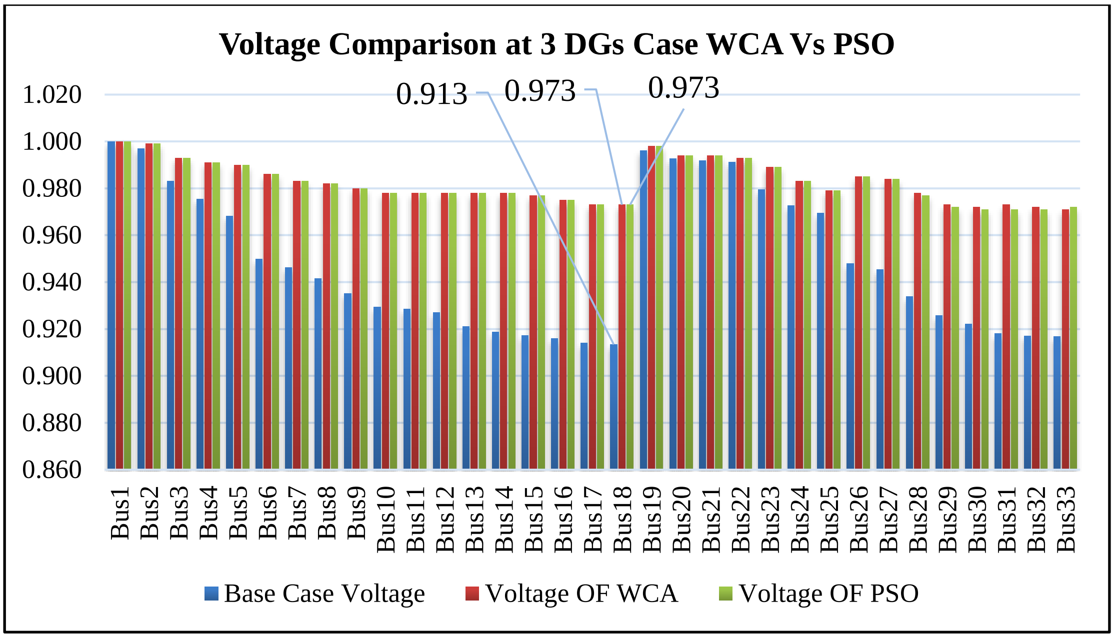

Figure 4.8: Bus Voltage comparison before and after three DGs placement

From the figure 4.8, it is clear that the voltage at every bus has been improved after the installation of DG at optimal location. It is seen that the minimum voltage before DG placement is 0.913 pu at bus number 18 which has been improved to 0.973 pu so it is clear that voltage is well improved with same value in both optimizations' technique

4.3 ETAP model for different case scenarios

In this study, best solution is used among the two-optimization technique WCA and PSO. Here, WCA performs better to find the objective function of total system loss with the increased number of DGs in the same network so after finding the optimal location and sizing of DGs for single and three DGs cases from WCA, the model has been developed in ETAP for the minimum short circuit analysis to obtain the fault current through the Recloser and Fuses at different case scenarios like base case without DGs, single DG case and three DGs case. The single line diagram of developed model is shown in figure 4.9.

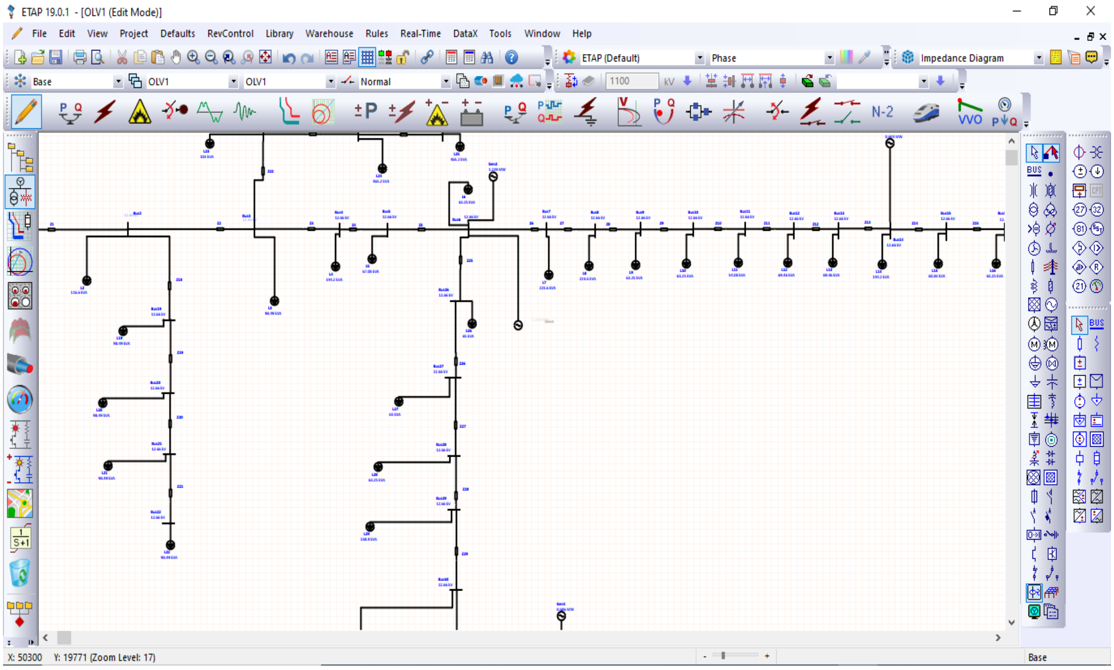

Figure 4.9: ETAP model for short circuit analysis at different case scenario

The line and load data for this system is available in [24]. The above model is simulated on ETAP to find the fault currents by short circuiting each bus except the bus 1. At first, the node 2 is short circuited and short circuit analysis has been done and fault currents through the Recloser and Fuses are noted towards the faulted section. The same procedure is repeated by short circuiting all the nodes up to 33 at different case scenarios like at base case without DGs, single DG case and three DGs case. The outputs of this data are listed in ANNEXES F, G, H.

4.4 Placement for Recloser Fuse and operating sequence

After obtaining the fault currents from ETAP simulation, outputs of the ETAP simulation are used as input for the coding of MATLAB program to find the best coordination of Recloser Fuse. In this study, there is only one Recloser and six Fuses which provide complete protection for the entire network. However, the number of Fuses can be increased but it makes system costlier and maintenance difficulties so at the sending end Recloser is placed that provides complete protection of entire network from any kind of faults at anywhere in the system. In case of temporary fault and permanent fault Recloser must operate first to provide overall backup for rest of the Fuses. The Fuses are located downstream to the Recloser so the placement of Recloser and Fuse can be illustrated in the figure 4.10 and table 4.3 below.

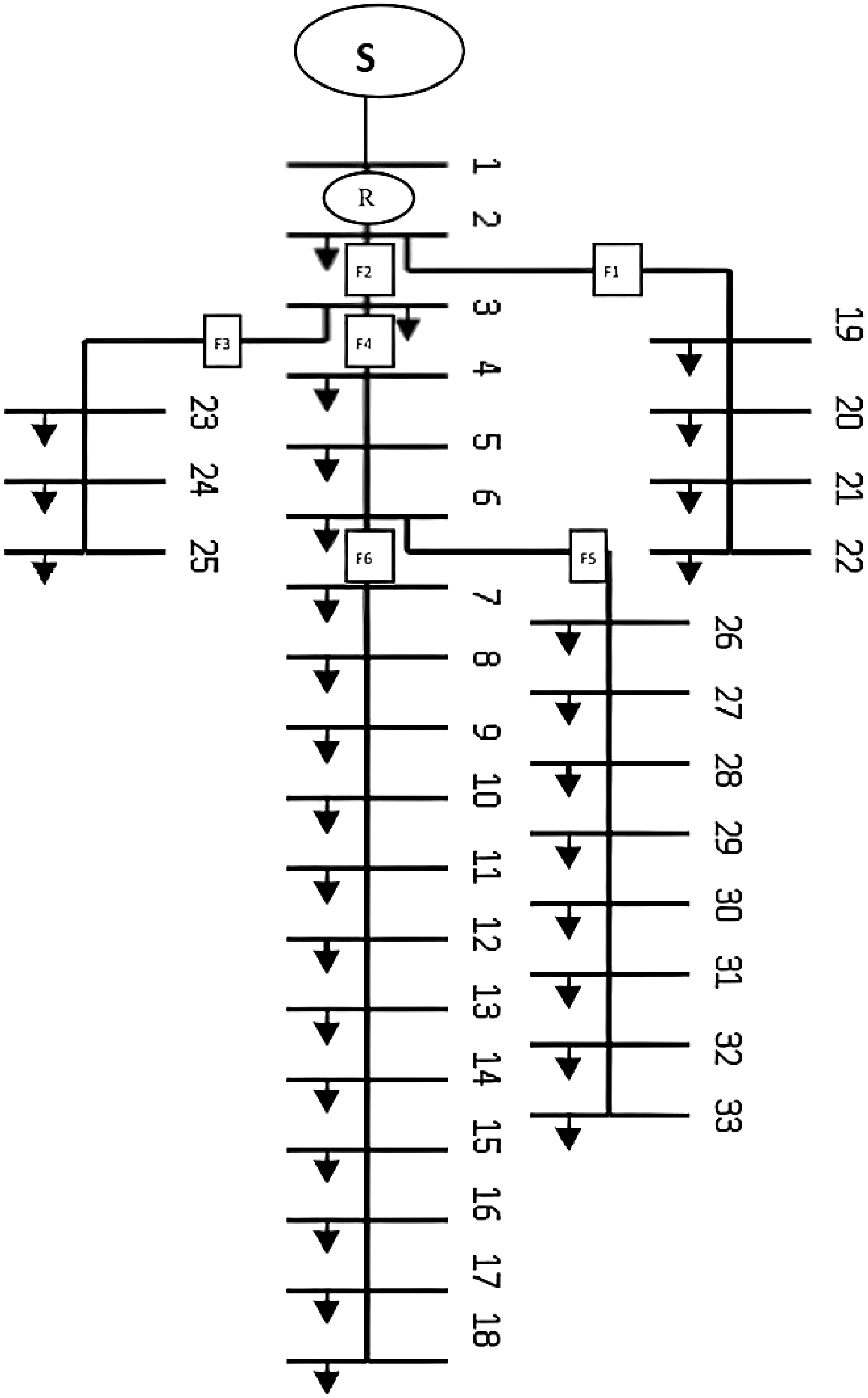

Figure 4.10: Recloser and Fuse Position

Table 4.3: Recloser Fuse Position

Branch	No. of Recloser	No. of Fuse	Name
1 to 2	1	0	Recloser
2 to 19	0	1	Fuse 1
2 to 3	0	1	Fuse 2
3 to 23	0	1	Fuse 3
3 to 4	0	1	Fuse 4
6 to 26	0	1	Fuse 5
6 to 7	0	1	Fuse 6

For the IEEE 33 bus system and the above position of Recloser and Fuses there are seven operating sequences of the Recloser Fuses combination which provide the complete Recloser Fuses coordination whenever the fault occurs at anywhere in the system. The sequence of operation of the combination is well dependent on the location of the fault in the system which is given the following table 4.4.

Table 4.4: Operating sequence of Recloser Fuses combination

S.N.	Fault location	Operating sequence
1	Between Recloser and bus 2	RFM-RSM
2	After the bus 2 upto bus 22	RFM-F1-RSM
3	Between bus 2 and bus 3	RFM-F2-RSM
4	After the bus 3 upto bus 25	RFM-F3-F2-RSM
5	Between bus 2 to bus 6	RFM-F4-F2-RSM
6	After the bus 6 upto bus 33	RFM-F5-F4-F2-RSM
7	After the bus 6 upto bus 18	RFM-F6-F4-F2-RSM

Here, the RFM and RSM are the Recloser fast and slow mode operation and F1, F2, F3, F4, F5 and F6 are the number of Fuses in the network. The operating sequence indicates that the operation of Fuses should lies between the two-mode operation of Recloser for optimal coordination.

4.4.1 Result obtained in the base case

4.4.1.1 Optimum settings for the base case

Without the placement DG at base case, fault analysis is done in ETAP by short circuiting each bus except bus 1 at a time and corresponding fault current is noted in the Recloser and Fuses towards the faulted path. Thus, obtain fault current at base case is further used to find the optimal TDS value of the Recloser and Fuse constant a & b and the value of the objective function by using WCA algorithm in MATLAB. The output for the characteristic constants without DG is shown in table 4.5 below.

Table 4.5: Output for characteristic constants without DG

Fuse No.	a	b
1	-1.3162	10.934
2	-1.3162	10.7955
3	-1.3162	10.1217
4	-1.3162	10.4192
5	-1.3162	9.7553
6	-1.3162	10.2823
TDS fast mode = 0.50000, TDS slow mode = 4.09950		
Minimum Objective Function Value = 769.935		

The value for the constant a for all Fuses is same because it is assumed that all Fuses are made up of same materials. The values of constant b for the Fuses along the faulted path are found to be higher towards the Recloser, that shows the upstream Fuses acts as back up for downstream Fuses. For example, for any kind of fault occurs at bus 18, initially the fast mode of Recloser activated. If faults persist for longer duration, the Fuse F6 must operate to isolated the fault. However, F6 fails to operate then Fuse F4 must operate that acts as a backup protection for Fuse F6. Similarly, if Fuse F4 fails to operate then the backup Fuse F2 must operate and finally slow mode of Recloser must activated to provide overall backup for rest of the system and Fuses. Hence, Fuses are responsible to provide the primary protection for any kind of permanent fault that might occurs at anywhere in the system.

4.4.1.2 Recloser-Fuse coordination characteristic curve for base case

The output characteristic curve for the base case is plotted in MATLAB which is given in the figure below 4.11.

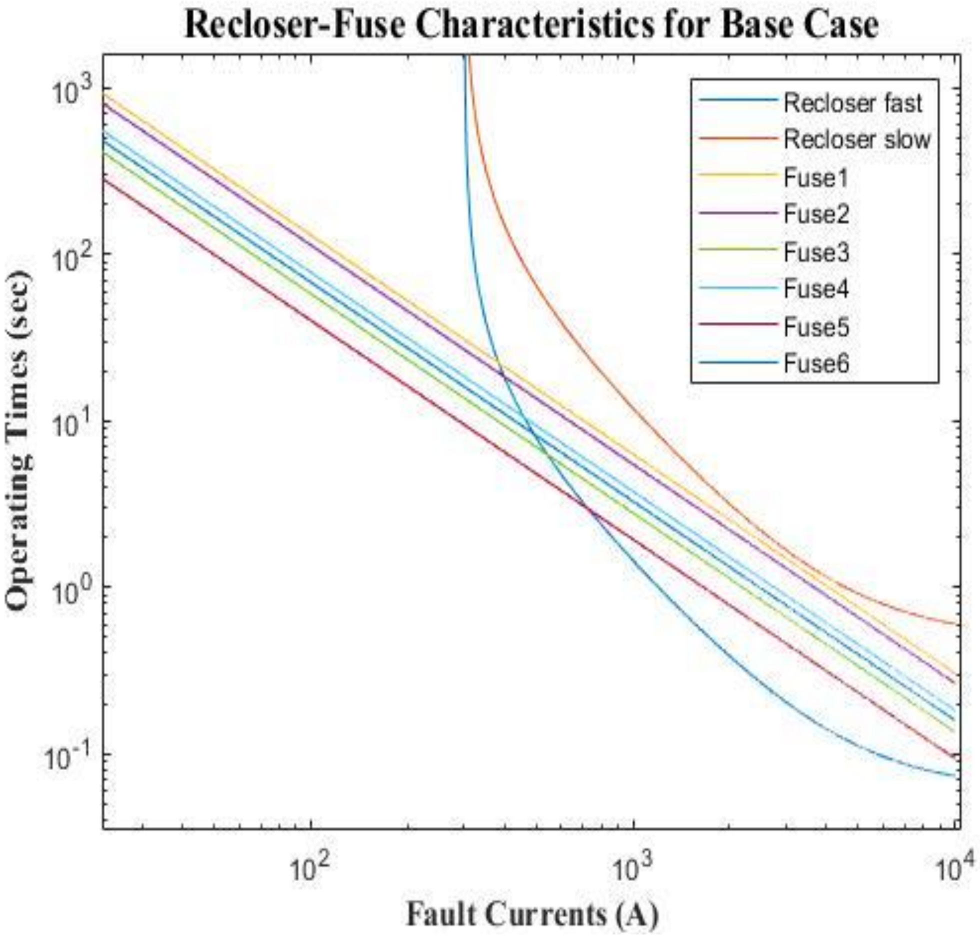

Figure 4.11: Characteristic curve of Recloser Fuse for base case

From the above curve it is clearly seen that the characteristics curve of all Fuses lies within the characteristics curve of the Recloser's slow and fast mode which indicated the optimal coordination between Recloser and Fuses at base case.

4.4.2 Result obtained in the single DG case

4.4.2.1 Optimum settings for the single DG case

Similarly, with the placement of single DG, fault analysis is done in ETAP by short circuiting each bus except bus 1 at a time and corresponding fault current is noted in the Recloser and Fuses towards the faulted path. Thus, obtain fault current at single DG case is further used to find the optimal TDS value of the Recloser and Fuse constant a & b and the value of the objective function by using WCA algorithm in MATLAB. The output for the characteristic constants is shown in table 4.6 below.

Table 4.6: Output for characteristic constants with single DG

Fuse No.	a	b
1	-1.2351	10.1621
2	-1.2351	9.9187
3	-1.2351	9.3727
4	-1.2351	9.4457
5	-1.2351	8.7809
6	-1.2351	8.9027
TDS fast mode = 0.50050, TDS slow mode = 6.41340		
Minimum Objective Function Value = 513.458		

Similarly, the value for the constant a for all Fuses is same because it is assumed that all Fuses are made up of same materials. The values of constant b for the Fuses along the faulted path are found to be higher towards the Recloser, that shows the upstream Fuses acts as back up for downstream Fuses. Hence, the values of characteristic coefficient of Fuses obtained in base case cannot be used for single DG case that causes miscoordination of Recloser and Fuses.

4.4.2.2 Recloser-Fuse coordination Characteristic curve for single DG case

The output characteristic curve for the single DG case is plotted in MATLAB which is given in the figure 4.12.

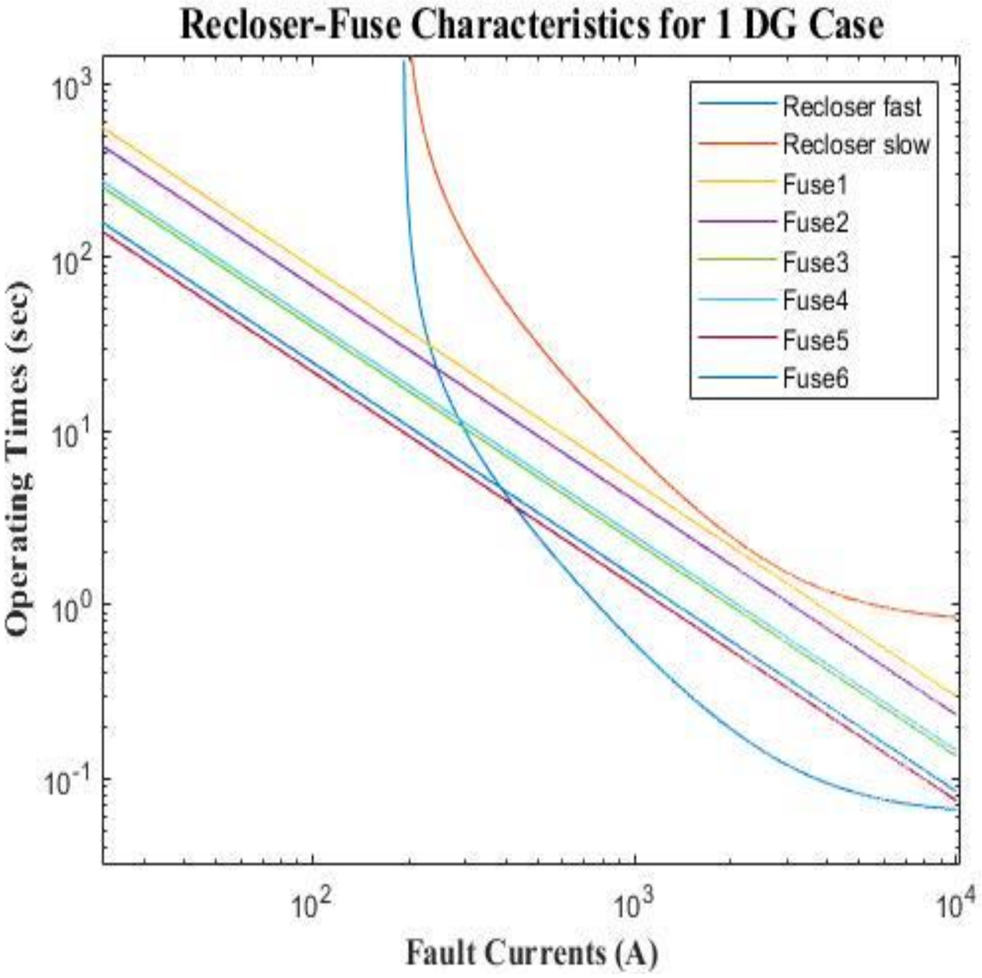

Figure 4.12: Characteristic curve of Recloser Fuse for single DG case

From figure it is seen that, likewise in the base case, the characteristics curve of all Fuses lies within the characteristics curve of the Recloser's slow and fast mode.

4.4.3 Result obtained in the multiple DGs case

4.4.3.1 Optimum settings for the three DGs case

Similarly, with the placement of three DGs, fault analysis is done in ETAP by short circuiting each bus except bus 1 at a time and corresponding fault current is noted in the Recloser and Fuses towards the faulted path. Thus, obtain fault current at three DGs case is further used to find the optimal TDS value of the Recloser and Fuse constant a & b and the value of the objective function by using WCA algorithm in MATLAB. The output for the characteristic constants is shown in table 4.7 below.

Table 4.7: Output for characteristic constants with three DGs case

Fuse No.	a	b
1	-0.9853	7.8943
2	-0.9853	7.8271
3	-0.9853	7.2513
4	-0.9853	7.3789
5	-0.9853	6.7930
6	-0.9853	7.2329
TDS fast mode = 0.50000, TDS slow mode = 5.28570		
Minimum Objective Function Value = 378.327		

Similarly, the values of constant b for the Fuses in the faulted path are found to be higher towards the Recloser, that shows the upstream Fuses acts as back up for downstream Fuses along the faulted path. Hence, the values of characteristic coefficient of Fuses obtained in base case and single DG cannot be used for three DGs case that causes miscoordination of Recloser and Fuses. Also, the value of objective function goes on decreasing from the base case with the placement of number of DGs in the network. It is because of the contribution of fault current by the DGs towards the faulted path.

4.4.3.2 Recloser-Fuse coordination Characteristic curve for three DGs case

The output characteristic curve for the three DGs case is plotted in MATLAB which is given in the figure 4.13 below.

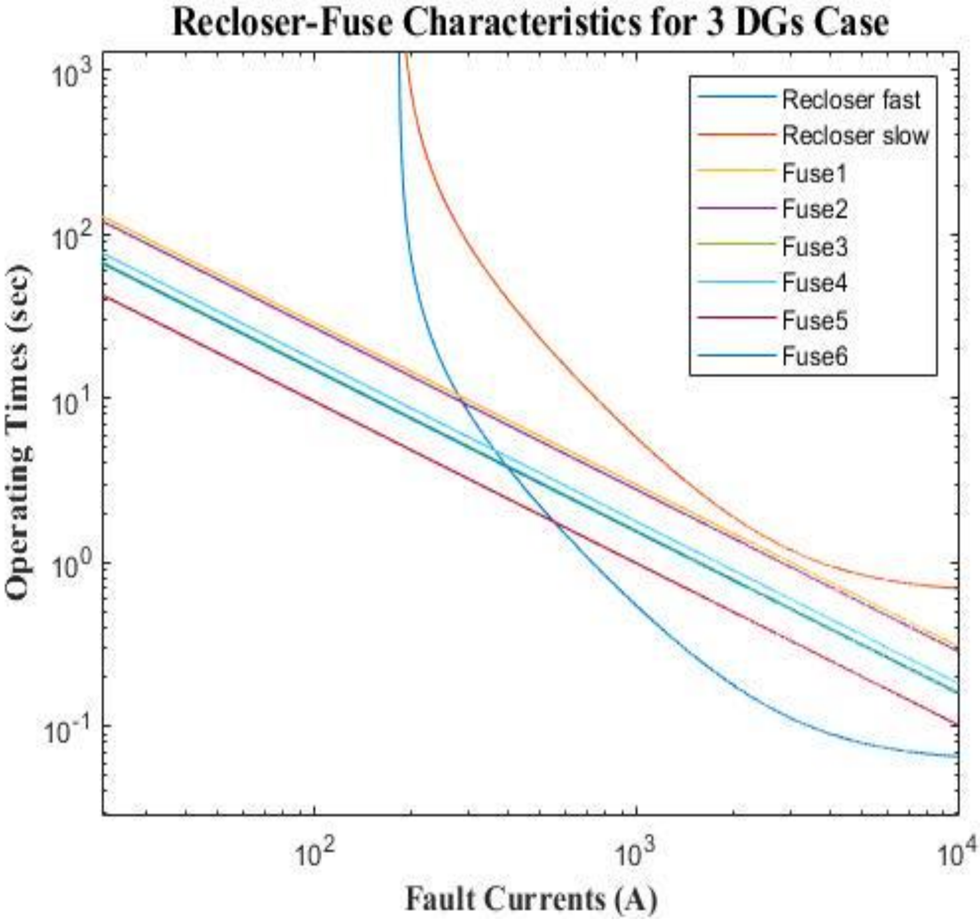

Figure 4.13: Characteristic curve of Recloser Fuse for three DGs case

In this case also, the characteristics curve of all Fuses lies within the characteristics curve of the Recloser’s slow and fast mode which indicated the optimal coordination between Recloser and Fuses at three DGs case.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Recloser-Fuse coordination for standard IEEE 33 bus system is performed and analyzed for base case, single DG case, and multiple DG case. At first, the optimal size and location of DG was found using WCA and PSO algorithm in MATLAB for single and three DGs. After that comparative analysis among the optimization technique has been perform and the best solution is further used to find fault current by minimum short circuit analysis in the ETAP for different case scenarios (i.e. base case, single DG case, and three DGs case). And finally, the optimized operating time for Recloser-Fuse combination is achieved using WCA in MATLAB.

The subsequent conclusions can be derived from this research:

- For the single DG case, the optimal location has been found at bus 6, with size 2.229 MW form both optimization technique. However, for three DGs case, from WCA the optimal location has been found at bus 6, 14, and 31 with sizes 1.229 MW, 0.604 MW, and 0.686 MW respectively and from PSO the optimal location has been found at bus 6, 14, and 33 with sizes 1.311 MW, 0.604 MW, and 0.606 MW respectively.
- In single DG case both optimization techniques have same result of total power loss but WCA performs better to achieve the objective function as compared to the PSO optimization technique if we increased the number of DGs in the same network. The percentage decrease in loss with comparison to base case is found to be 62.104% and 61.602% form WCA and PSO in case of three DGs respectively. Power Loss decreased by 1.02kW (1.31%) with WCA optimization as compared to PSO with few numbers of iterations that shows the WCA optimization technique outperformed for optimal multiple DGs placement and sizing than PSO optimization technique. Voltage profile is well improved to the significant level with similar values in both optimizations.
- Faults currents are obtained from ETAP simulation at different case scenario like in base case, single DG case and three DGs case which is used input for the coding of MATLAB program to find the best coordination of Recloser Fuse. In this study, there is only one Recloser and six Fuses which provide complete protection for the entire network. However, the number of Fuses can

be increased but it makes system costlier and maintenance difficulties so at the sending end Recloser is placed that provides complete protection of entire network from any kind of faults at anywhere in the system. In case of temporary fault and permanent fault Recloser operate first to provide overall backup for rest of the Fuses. Similarly, the value for the constant a for all Fuses is same because it is assumed that all Fuses are made up of same materials. The values of constant b for the Fuses in the faulted path are found to be higher towards the Recloser, that shows the upstream Fuses acts as back up for downstream Fuses along the faulted path. Hence, the values of characteristic coefficient of Fuses obtained in base case, single DG case and three DGs case so that the one case scenario cannot be used for another case that causes miscoordination of Recloser and Fuses. Also, the value of objective function goes on decreasing from the base case with the placement of number of DGs in the network. It is because of the contribution of fault current by the DGs towards the faulted path.

Thus, this research concludes that optimal multiple DGs placement and Recloser-Fuse coordination in the IEEE 33-bus radial distribution system can be effectively achieved using the Water Cycle Algorithm (WCA).

5.2 Recommendation

Due to time limitation and unavailability of sufficient data of real world this research was carried out and implemented with the standard IEEE 33 bus system only. Thus, this research can be further extended by taking real field data of existing distribution network. Distributed generations (DGs) are the important part of the smart grid for energy mix technologies so the penetration of DGs to the distribution network along with the Recloser Fuses coordination is very crucial part as Nepal is heading to the smart grid with the automation in near future.

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ANNEXES

ANNEX A: Line Data of IEEE 33 Bus System

S.N	Line Data of IEEE 33 Bus System				Z_base = (basekV^2) / baseMVA	
					R_ohm = R_pu * Z_base	
	Base MVA = 100		Base Voltage (kV) = 12.66		X_ohm = X_pu * Z_base	
	From bus number	To bus number	Resistance (p.u.).	Reactance (p.u.).	Resistance (ohm)	Reactance (ohm)
			R_pu	X_pu	R_ohm	X_ohm
1	1	2	0.0575	0.0293	0.0922	0.047
2	2	3	0.3076	0.1567	0.493	0.2511
3	3	4	0.2284	0.1163	0.366	0.1864
4	4	5	0.2378	0.1211	0.3811	0.1941
5	5	6	0.511	0.4411	0.819	0.707
6	6	7	0.1168	0.3861	0.1872	0.6188
7	7	8	0.4439	0.1467	0.7114	0.2351
8	8	9	0.6426	0.4617	1.03	0.74
9	9	10	0.6514	0.4617	1.044	0.74
10	10	11	0.1227	0.0406	0.1966	0.065
11	11	12	0.2336	0.0772	0.3744	0.1238
12	12	13	0.9159	0.7206	1.468	1.155
13	13	14	0.3379	0.4448	0.5416	0.7129
14	14	15	0.3687	0.3282	0.591	0.526
15	15	16	0.4656	0.34	0.7463	0.545
16	16	17	0.8042	1.0738	1.289	1.721
17	17	18	0.4567	0.3581	0.732	0.574
18	2	19	0.1023	0.0976	0.164	0.1565
19	19	20	0.9385	0.8457	1.5042	1.3554
20	20	21	0.2555	0.2985	0.4095	0.4784
21	21	22	0.4423	0.5848	0.7089	0.9373
22	3	23	0.2815	0.1924	0.4512	0.3083
23	23	24	0.5603	0.4424	0.898	0.7091
24	24	25	0.559	0.4374	0.896	0.7011
25	6	26	0.1267	0.0645	0.203	0.1034
26	26	27	0.1773	0.0903	0.2842	0.1447
27	27	28	0.6607	0.5826	1.059	0.9337
28	28	29	0.5018	0.4371	0.8042	0.7006
29	29	30	0.3166	0.1613	0.5075	0.2585
30	30	31	0.608	0.6008	0.9744	0.963
31	31	32	0.1937	0.2258	0.3105	0.3619
32	32	33	0.2128	0.3308	0.341	0.5302

ANNEX B: Load flow Bus Data of IEEE 33 Bus System

Load flow Bus Data of IEEE 33 Bus System						
Bus Number	Voltage		Generation		Load	
	Mag(pu)	Ang(deg)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)
1	1	0	3.92	2.44	-	-
2	0.997	0.014	-	-	0.1	0.06
3	0.983	0.096	-	-	0.09	0.04
4	0.975	0.162	-	-	0.12	0.08
5	0.968	0.228	-	-	0.06	0.03
6	0.95	0.134	-	-	0.06	0.02
7	0.946	-0.096	-	-	0.2	0.1
8	0.941	-0.06	-	-	0.2	0.1
9	0.935	-0.133	-	-	0.06	0.02
10	0.929	-0.196	-	-	0.06	0.02
11	0.928	-0.189	-	-	0.04	0.03
12	0.927	-0.177	-	-	0.06	0.04
13	0.921	-0.269	-	-	0.06	0.04
14	0.919	-0.347	-	-	0.12	0.08
15	0.917	-0.385	-	-	0.06	0.01
16	0.916	-0.408	-	-	0.06	0.02
17	0.914	-0.485	-	-	0.06	0.02
18	0.913	-0.495	-	-	0.09	0.04
19	0.997	0.004	-	-	0.09	0.04
20	0.993	-0.063	-	-	0.09	0.04
21	0.992	-0.083	-	-	0.09	0.04
22	0.992	-0.103	-	-	0.09	0.04
23	0.979	0.065	-	-	0.09	0.05
24	0.973	-0.024	-	-	0.42	0.2
25	0.969	-0.067	-	-	0.42	0.2
26	0.948	0.173	-	-	0.06	0.03
27	0.945	0.229	-	-	0.06	0.03
28	0.934	0.312	-	-	0.06	0.02
29	0.926	0.39	-	-	0.12	0.07
30	0.922	0.496	-	-	0.2	0.6
31	0.918	0.411	-	-	0.15	0.07
32	0.917	0.388	-	-	0.21	0.1
33	0.917	0.38	-	-	0.06	0.04
Total			**3.92**	**2.44**	**3.720**	**2.30**

ANNEX C: Load Flow Branch Data of IEEE 33 Bus System

Load Flow Branch Data of IEEE 33 Bus System

S. N	From Bus	To Bus	From Bus Injection		To Bus Injection		Loss (I^2 * Z)	
			P (MW)	Q (MVAr)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)
1	1	2	3.92	2.44	-3.91	-2.43	0.012	0.01
2	2	3	3.44	2.21	-3.39	-2.18	0.052	0.03
3	3	4	2.36	1.68	-2.34	-1.67	0.02	0.01
4	4	5	2.22	1.59	-2.2	-1.58	0.019	0.01
5	5	6	2.14	1.55	-2.11	-1.52	0.038	0.03
6	6	7	1.1	0.53	-1.09	-0.52	0.002	0.01
7	7	8	0.89	0.42	-0.89	-0.42	0.005	0
8	8	9	0.69	0.32	-0.68	-0.32	0.004	0
9	9	10	0.62	0.3	-0.62	-0.29	0.004	0
10	10	11	0.56	0.27	-0.56	-0.27	0.001	0
11	11	12	0.52	0.24	-0.51	-0.24	0.001	0
12	12	13	0.45	0.21	-0.45	-0.21	0.003	0
13	13	14	0.39	0.17	-0.39	-0.17	0.001	0
14	14	15	0.27	0.09	-0.27	-0.09	0	0
15	15	16	0.21	0.08	-0.21	-0.08	0	0
16	16	17	0.15	0.06	-0.15	-0.06	0	0
17	17	18	0.09	0.04	-0.09	-0.04	0	0
18	2	19	0.36	0.16	-0.36	-0.16	0	0
19	19	20	0.27	0.12	-0.27	-0.12	0.001	0
20	20	21	0.18	0.08	-0.18	-0.08	0	0
21	21	22	0.09	0.04	-0.09	-0.04	0	0
22	3	23	0.94	0.46	-0.94	-0.46	0.003	0
23	23	24	0.85	0.41	-0.84	-0.4	0.005	0
24	24	25	0.42	0.2	-0.42	-0.2	0.001	0
25	6	26	0.95	0.97	-0.95	-0.97	0.003	0
26	26	27	0.89	0.95	-0.88	-0.95	0.003	0
27	27	28	0.82	0.92	-0.81	-0.91	0.011	0.01
28	28	29	0.75	0.89	-0.75	-0.88	0.008	0.01
29	29	30	0.63	0.81	-0.62	-0.81	0.004	0
30	30	31	0.42	0.21	-0.42	-0.21	0.002	0
31	31	32	0.27	0.14	-0.27	-0.14	0	0
32	32	33	0.06	0.04	-0.06	-0.04	0	0
Total:							**0.203**	**0.14**

ANNEX D: Voltage Comparison with one DG case WCA Vs PSO

Voltage Comparison at 1 DG case			
Bus ID	**Base Case Voltage**	**Voltage of WCA**	**Voltage of PSO**
Bus1	1	1	1
Bus2	0.997	0.998	0.998
Bus3	0.983	0.992	0.992
Bus4	0.9755	0.989	0.989
Bus5	0.9682	0.988	0.988
Bus6	0.9498	0.981	0.981
Bus7	0.9463	0.978	0.978
Bus8	0.9415	0.973	0.973
Bus9	0.9352	0.967	0.967
Bus10	0.9294	0.962	0.962
Bus11	0.9286	0.961	0.961
Bus12	0.9271	0.959	0.959
Bus13	0.921	0.954	0.954
Bus14	0.9187	0.951	0.951
Bus15	0.9173	0.95	0.95
Bus16	0.916	0.949	0.949
Bus17	0.914	0.947	0.947
Bus18	0.9134	0.946	0.946
Bus19	0.9962	0.998	0.998
Bus20	0.9926	0.994	0.994
Bus21	0.9919	0.994	0.994
Bus22	0.9913	0.993	0.993
Bus23	0.9794	0.988	0.988
Bus24	0.9727	0.981	0.981
Bus25	0.9694	0.978	0.978
Bus26	0.9479	0.98	0.98
Bus27	0.9453	0.977	0.977
Bus28	0.9339	0.966	0.966
Bus29	0.9257	0.958	0.958
Bus30	0.9222	0.955	0.955
Bus31	0.918	0.951	0.951
Bus32	0.9171	0.95	0.95
Bus33	0.9168	0.95	0.95

ANNEX E: Voltage Comparisons with three DGs case WCA Vs PSO

Voltage comparison at 3 DGs case			
Bus ID	**Base Case Voltage**	**Voltage of WCA**	**Voltage of PSO**
Bus1	1.000	1.000	1.000
Bus2	0.997	0.999	0.999
Bus3	0.983	0.993	0.993
Bus4	0.976	0.991	0.991
Bus5	0.968	0.990	0.990
Bus6	0.950	0.986	0.986
Bus7	0.946	0.983	0.983
Bus8	0.942	0.982	0.982
Bus9	0.935	0.980	0.980
Bus10	0.929	0.978	0.978
Bus11	0.929	0.978	0.978
Bus12	0.927	0.978	0.978
Bus13	0.921	0.978	0.978
Bus14	0.919	0.978	0.978
Bus15	0.917	0.977	0.977
Bus16	0.916	0.975	0.975
Bus17	0.914	0.973	0.973
Bus18	0.913	0.973	0.973
Bus19	0.996	0.998	0.998
Bus20	0.993	0.994	0.994
Bus21	0.992	0.994	0.994
Bus22	0.991	0.993	0.993
Bus23	0.979	0.989	0.989
Bus24	0.973	0.983	0.983
Bus25	0.969	0.979	0.979
Bus26	0.948	0.985	0.985
Bus27	0.945	0.984	0.984
Bus28	0.934	0.978	0.977
Bus29	0.926	0.973	0.972
Bus30	0.922	0.972	0.971
Bus31	0.918	0.973	0.971
Bus32	0.917	0.972	0.971
Bus33	0.917	0.971	0.972

ANNEX F: Fault Current at Base Case through Recloser and Fuses

Fault Current at Base Case							
Faulted Node	**Recloser Current**	**Fuse 1 Fault Current**	**Fuse 2 Fault Current**	**Fuse 3 Fault Current**	**Fuse 4 Fault Current**	**Fuse 5 Fault Current**	**Fuse 6 Fault Current**
2	13103						
3	7071		7071				
4	5134		5134		5134		
5	2917		2917		2917		
6	2376		2376		2376		
7	1952		1952		1952		1952
8	1460		1460		1460		1460
9	1164		1164		1164		1164
10	1129		1129		1129		1129
11	1067		1067		1067		1067
12	838		838		838		838
13	763		763		763		763
14	704		704		704		704
15	647		647		647		647
16	546		546		546		546
17	510		510		510		510
18	502		502		502		502
19	9523	9523					
20	2651	2651					
21	2158	2158					
22	1603	1603					
23	4658		4658	4658			
24	2697		2697	2697			
25	1898		1898	1898			
26	2222		2222		2222	2222	
27	2035		2035		2035	2035	
28	1461		1461		1461	1461	
29	1205		1205		1205	1205	
30	1105		1105		1105	1105	
31	916		916		916	916	
32	864		864		864	864	
33	806		806		806	806	

ANNEX G: Fault Current at one DG Case through Recloser and Fuses

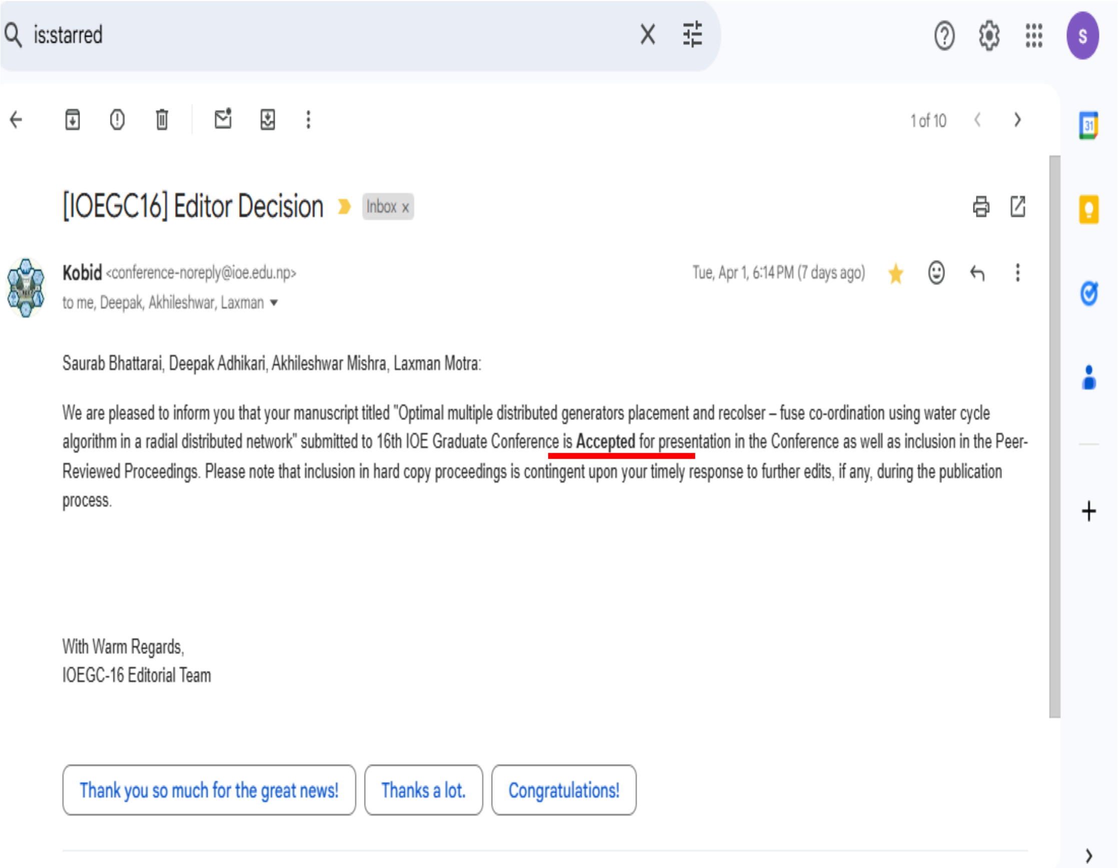
Fault Current at 1 DG Case							
Faulted Node	**Recloser Current**	**Fuse 1 Fault Current**	**Fuse 2 Fault Current**	**Fuse 3 Fault Current**	**Fuse 4 Fault Current**	**Fuse 5 Fault Current**	**Fuse 6 Fault Current**
2	13103		332		332		
3	7071		7071		336		
4	5134		5134		5134		
5	2917		2917		2917		
6	2376		2376		2376		
7	1925		1925		1925		2159
8	1405		1405		1405		1576
9	1103		1103		1103		1237
10	1068		1068		1068		1198
11	1007		1007		1007		1130
12	782		782		782		877
13	708		708		708		794
14	652		652		652		731
15	597		597		597		699
16	500		500		500		561
17	467		467		467		524
18	460		460		460		515
19	9463	9496	239		239		
20	2600	2664	66		66		
21	2115	2167	54		54		
22	1570	1608	40		40		
23	4604		4604	4783	219		
24	2637		2637	2739	125		
25	1847		1847	1919	88		
26	2210		2210		2210	2478	
27	2010		2010		2010	2254	
28	1403		1403		1403	1573	
29	1142		1142		1142	1280	
30	1043		1043		1043	1169	
31	855		855		855	959	
32	805		805		805	903	
33	748		748		748	839	

ANNEX H: Fault Current at three DGs Case through Recloser and Fuses

Fault Current at three DGs Case							
Faulted Node	**Recloser Current**	**Fuse 1 Fault Current**	**Fuse 2 Fault Current**	**Fuse 3 Fault Current**	**Fuse 4 Fault Current**	**Fuse 5 Fault Current**	**Fuse 6 Fault Current**
2	13103		360		360	96	84
3	7071		7071		366	98	85
4	5134		5134		5134	99	86
5	2917		2917		2917	103	89
6	2376		2376		2376	106	92
7	1929		1929		1929	86	2128
8	1412		1412		1412	63	1558
9	1111		1111		1111	50	1226
10	1077		1077		1077	48	1188
11	1015		1015		1015	45	1120
12	789		789		789	35	871
13	715		715		715	32	789
14	659		659		659	29	727
15	599		599		599	27	661
16	495		495		495	22	546
17	460		460		460	21	508
18	452		452		452	20	499
19	9456	9711	260		260	69	60
20	2595	2665	71		71	19	17
21	2111	2168	58		58	15	13
22	1566	1609	43		43	11	10
23	4597		4597	4796	238	63	55
24	2630		2630	2743	136	36	32
25	1842		1842	1921	95	25	22
26	2212		2212		2212	2431	86
27	2014		2014		2014	2213	78
28	1413		1413		1413	1553	55
29	1153		1153		1153	1267	45
30	1053		1053		1053	1157	41
31	866		866		866	951	34
32	811		811		811	891	32
33	749		749		749	823	29

PUBLICATION

The paper has been published in 16th IOE Graduate Conference, Conference ID A3-2 and Submission ID 377 in the name of “Optimal multiple distributed generators placement and Recloser – Fuse co-ordination by using Water Cycle Algorithm in a radial distributed network". The authors for this paper are Saurab Bhattarai, Deepak Adhikari, Akhileshwar Mishra, Laxman Motra.



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We are pleased to inform you that your manuscript titled "Optimal multiple distributed generators placement and recolser – fuse co-ordination using water cycle algorithm in a radial distributed network" submitted to 16th IOE Graduate Conference is Accepted for presentation in the Conference as well as inclusion in the Peer-Reviewed Proceedings. Please note that inclusion in hard copy proceedings is contingent upon your timely response to further edits, if any, during the publication process.

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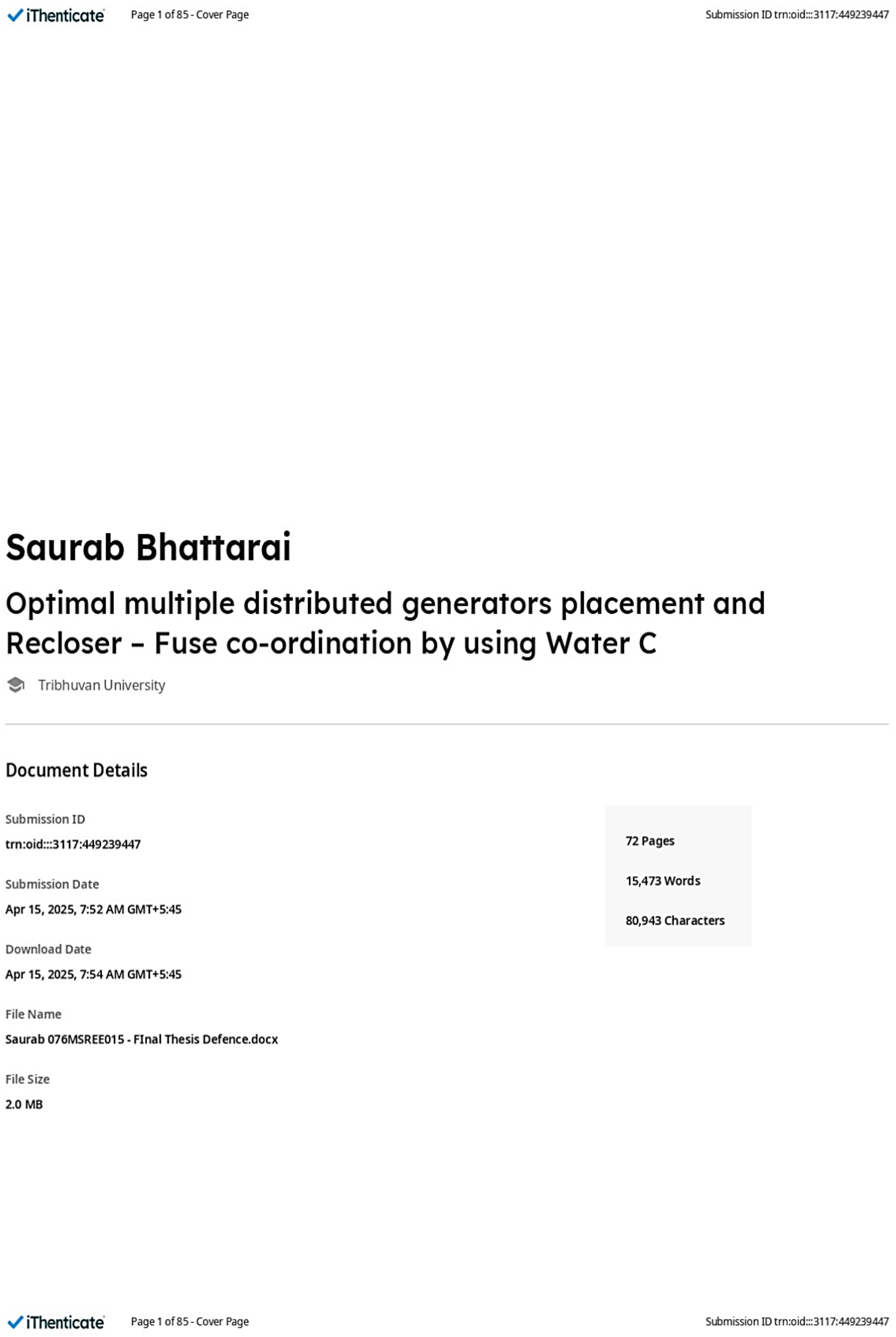

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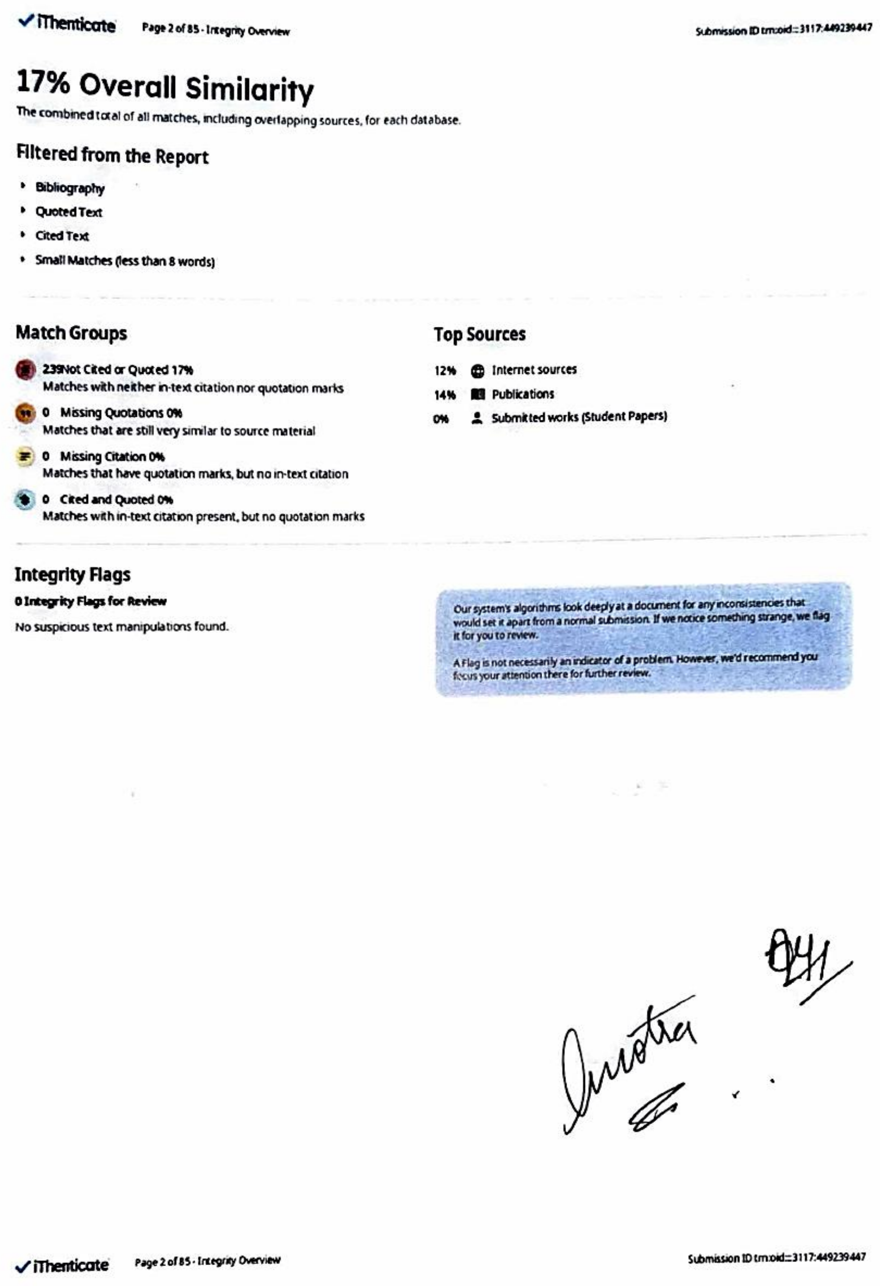

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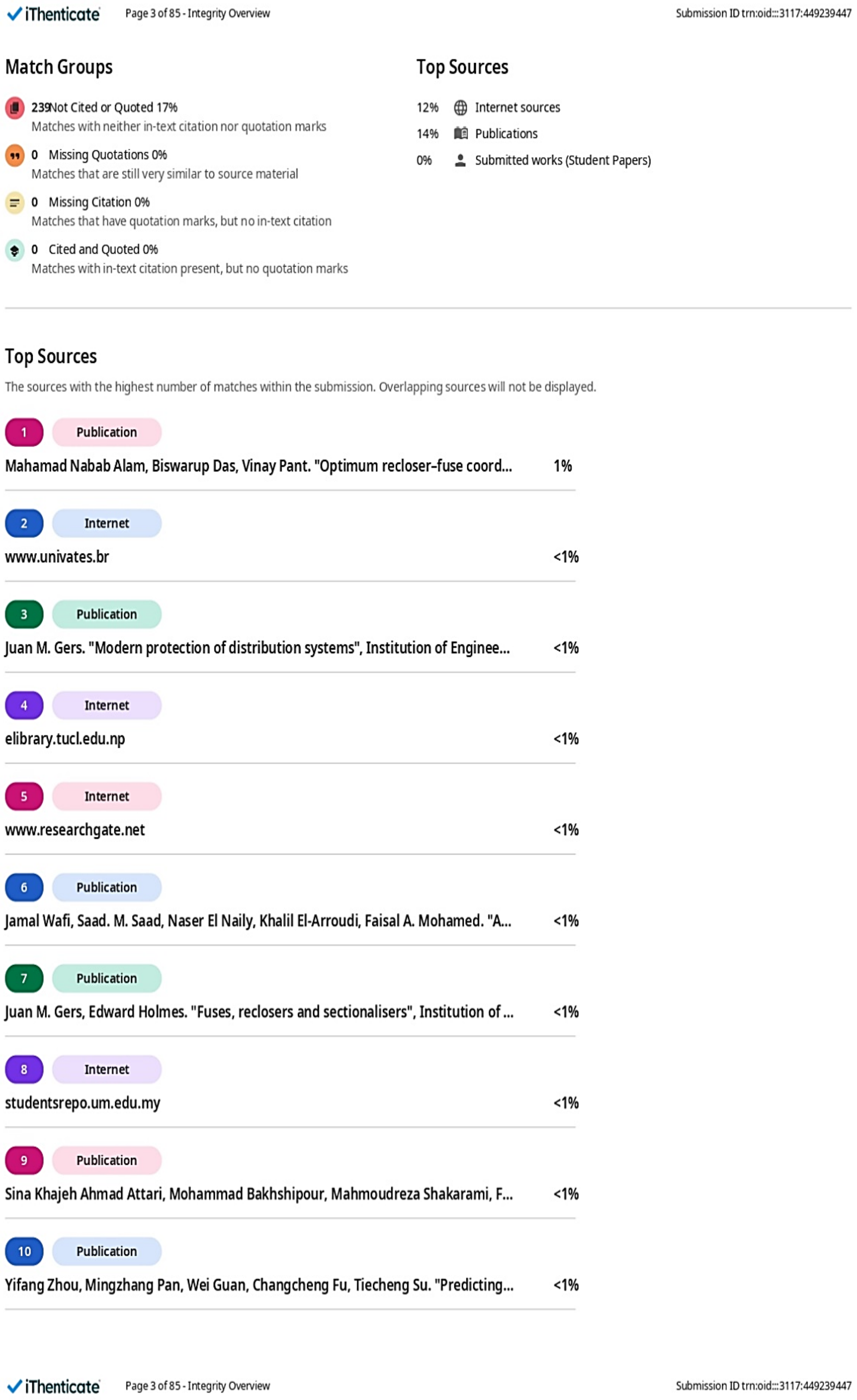

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