UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING

# NON-TECHNICAL POWER LOSS REDUCTION AND FAULT MANAGEMENT USING OPTIMAL RECLOSER PLACEMENT

By

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A Thesis submitted in Partial Fulfilment of Requirement for Award of Degree of the Master of Science (Electrical and Electronics Engineering) in the Department of Electrical and Information Engineering in the

University of Nairobi

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This thesis is my original work and has not been presented for an award in any other Institution.

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# DEDICATION

I would like first to dedicate this thesis to God the Almighty and all those who may find this work useful to them. I significantly recognize the assistance given by African Development Bank (AfDB) and University of Nairobi grant organizers, for my scholarship funding. I am constantly humbled to recall my better half Florence Odongo, and youngsters Joshua Ajode and Patience Akinyi, for giving me ample time and condition to settle down calmly and accomplish my work.

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I would like to begin by officially taking positively the commitments of numerous lecturers and course Professors from the University of Nairobi, for their support towards my further Studies. By and large, this research work moved to its final conclusion through keen supervision of Dr. Peter Musau and Dr. Abraham Mutunga Nyete.

I cannot likewise forget about my kindred researchers Benson Onyango and Paul Muia for their mutual and moral support towards this work.

# ABSTACT

Nowadays, it is rare for a power distribution system to run without a unique protective device to handle transients produced by energy theft, lightning, falling trees, and animals such as monkeys, among other things. Researchers employing reclosers to regulate transients have previously examined reliability needs. Non-technical power loss and cost reduction, on the other hand, have not been adequately addressed in order to improve high-quality power supply. As a result, customers have always had to pay extra for system losses. This thesis discusses optimal reclosing, cost of energy not served, and the firefly algorithm strategy to combat this threat.

In the event of temporary faults, reclosers are employed to temporarily or permanently lock out the distribution system, preventing damage to system apparatus. The distribution system successfully functions on computerized intelligent settings, based on predefined transient faults in high-risk locations, with appropriate reclosing. Recloser's accurate reactions in diverse situations are intelligently determined. This thesis built an intelligent system that uses the firefly algorithm to install reclosers at specific points along distribution lines, as well as manage and monitor transient faults. As a result, utilizing the optimal reclosing technique, energy not served (ENS) and associated costs are minimized. The results and analysis of the used method show a cost reduction of sixty-one (61%) on energy not served (ENS) during transient. This saving is made feasible by the recloser's optimal placement and reaction time. Other than the Firefly algorithm, the radial distribution system used to assess this can be replaced with a closed network and another new optimization method.

**Key Words: Loss Reduction, Recloser, Stability, Transient, Non-Technical Optimal Placement**

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# CHAPTER 1: INTRODUCTION

The major purpose for conducting research is introduced in this section of the thesis. Similarly, this Chapter 1 outlines and explains the essential parts of the problem being addressed. More crucially, the solution to the challenge of conveying the purpose to organizations is discussed, as well as how to cope with the power system. This chapter is divided into sub-sections namely: research background, problem statement, research objectives, justification of the study, scope of work, research contribution and Thesis organization for the succeeding chapters.

## 1.1 Background

Consumers and industries, in particular, are subjected to frequent power outages [1]. Numerous power consumers, particularly in underdeveloped nations like Kenya, experience losses, according to peer-reviewed research. Similarly, the Republic of Congo's distribution system had suffered huge losses as a result of a lack of metering infrastructure, theft, and fraud by non-genuine consumers, among other factors [1],[2]. Basically, if power system stability is not effectively maintained and controlled, it can be quite costly. To re-establish system stability in a power distribution system with limited information on transients, an adaptive reclosing method was used [3]. Based on these findings, a modern microprocessor-based relay and recloser control system was employed to record distribution line oscillator performance during faults [4]. This was intended to allow operators to determine the true source of line interruption, and then build a fuse-saving scheme and high-speed sensitivity at the sacrifice of system security during inrush. Another advancement used a multi-objective for the combination of "electricity levels" and "reliability in communication channels," as well as formulations to locate reclosers ideally using a genetic algorithm. GA [5]. The first objective was to reduce recloser investment costs, while the second was to increase reliability. Other studies developed a modeled MATLAB-SIMULINK simulation based on the adaptive reclosing technique (ART) principle [6][7]. In power distribution, a solid-state power controller (SSPC) will replace the traditional electromechanical circuit breaker; was designed to distribute power and safeguard it from the impacts of varied loads. This technique has the following advantages: enhanced transient stabilization; advanced reclosing scheme implementation; computer-based implementation was achievable due to less mathematical calculations. A flow chart with Monte Carlo convergence was formerly the norm developed to randomly manage the faults [8]. Hitherto, the operation of recloser and settings depended on historical data of transients [7]-[8]. The model was capable of offering kVA *t which withheld energy not serve caused by succeeding faults. Drastic actions showed that, four ways of assignment of reclosers for optimal operation can be developed [9]. In this thesis, methods applied were; Ant Colony Algorithm, Enhanced Network Genetic algorithm without dominated sorting, sectionalized schemes with network loop automation, and CENS-cost of energy not served [10].

## 1.2 Problem Statement

Electrical power has undoubtedly become a need in every sector of the economy, as well as for residential use. New connections are gradually expanding and will not be able to halt anytime soon, particularly in developing countries.

Meanwhile, a more serious state of power supply is the cause of frequent power outages, which result in the disruption of industrial activities and home power supplies. Research into the causes has revealed that power theft has become a threat due to the short circuit transients it creates in distribution lines. According to studies [3,] the number of power customers grew at the same rate as electrical energy theft.

Non-technical power loss reduction and related research projects have remained stagnant in recent years, focusing solely on increasing the reliability concept of power supply and quality. More power producers may decide to cut off supplies to locations where power theft is common. Following this, the Kenya Power and Lighting Company (KPLC) shut down transformers in the Kibera neighborhood due to unlawful connections, according to a report published by Kenya News Agency (KNA) on August 24, 2019. The study looked at non-technical loss reduction approaches and used the reclosing cycle model (RCM) to describe the topic in this thesis.

## 1.3. Objectives

### 1.3.1 Overall objective

The overall goal of optimal reclosing was to reduce the cost of energy not used by regulating the recloser's ideal location while maintaining system security.

### 1.3.2. Specific Objectives

The particular goals were:

1. i) To reduce non-technical power losses in distribution due to unlawful power line connections; by reducing non-technical power losses in transmission.
2. ii) To model and simulate recloser switching for optimal performance; reduce power loss due to faults.
3. iii) To analyse and verify results using Firefly Algorithm.

## 1.4 Justification of Study

As ealier explained in the introduction, electricity theft, transients on transmission power line such as lightning, animals like birds and monkeys touching on power line and amid others are issues of great interest which this thesis seek to solve. Introduction of optimal reclosing devices in power distribution system; creates an increase in constant power supply with reduced outages. The Nairobi region electrical power system, being entirely dependent on reliable power supply; consequently requires automatic reclosing device to reduce frequent power outage and also save energy losses during that reclosing operation. There is no adequate recent study that has been done, to observe the effect of optimal reclosing service and its impact on voltage stability. Even though reclosers interupts power supply, this reaction deliberately reduced and optimised reclosers placement.

## 1.5 Scope of Work

This study is limited to the following:

1. i) Modeling and simulation of optimal recloser placement, for non-technical loss reduction which is relevant to all grid networks; for power loss reduction and transient stability.
2. ii) Coding contemporary intelligent algorithm to simulate the modeled network; which is supposed to optimally place recloser, to manage energy loss during transients in power distribution systems.
3. iii) This thesis did not come up with practical installation of recloser for simulation.

iv) This thesis did not put up a complete protection system for simulation; other than just study recloser on distribution system and their effects during transients.

## 1.6 Thesis Contribution

The ability of the recloser response time has been improved, and its best placement within power distribution system has been determined. The research discovered a controlled power distribution system that achieved balance in the period of temporary power interruptions. There was a 61% realization of energy savings during recloser operation. The higher financial savings would enhance more investment and boost productivity over a longer term.  The power producers would eventually reduce the cost of energy charged on consumers. Some of these consumers who will benefit, are those who steal electricity because now they will pay what is avoidable to them.

## 1.7 Organization of the Thesis

Moving forward from Chapter 1, this thesis is organized into a number of chapters namely:

- Literature review: Research gap, problem (statement and formulations) is generated by the reviewed work of the most recent literature
- Research methodology: Research methodology, basically assembles materials and skills required to tackle the problem and how the method required solving it and filling the gap.
- Results and analysis: Similarly, results narrate the findings without interpretation; and analysis organizes the results and reports them in an organized manner.
- Conclusion/ recommendation: Lastly, conclusion and recommendations interpret results and brings out a clear opinion that supports the findings.
- Appendices: Finally, the appendix which presents the code that was utilized, the published articles and similarity index of plagiarism.

# CHAPTER 2: LITRATURE REVIEW

## 2.1 Introduction

Literature reviews are an important part of every research undertaking foundation, since they help to fill in the gaps in knowledge. This Chapter is divided into five sections, as follows: introduction, reviewed work, reviewer's summary, formulation of problem, and conclusion.

The operation of transmission and distribution networks has been shown to be troubled with problems, particularly in terms of transients and their effects on network stability. Work on the same subject had been reviewed in order to: determine how stability may be increased in order to overcome network gaps. One of the solutions pursued by this thesis was: the development of a recloser technology as a supplement to the distribution system. Unscrupulous customers would necessitate the implementation of a recloser robust approach to handle transients resulting from unlawful power tapping. Various studies have been conducted in the past on how to protect power systems against non-technical losses. To prevent distribution system failures, new technological advancements such as computer programming (CP) were developed. This thesis was created with the goal of not only studying but also implementing a technical framework for the best usage of recloser to handle a variety of situations.

## 2.2 Reviewed Research Work

[2] Developed a sophisticated microprocessor-based relay and recloser control to record distribution line oscillator performance during faults. This was supposed to allow operators to: determine the true source of a failure and then build a fuse-saving system; and achieve high-speed sensitivity at the expense of security during an inrush. However, the effort failed to account for the savings generated by the model once it was applied.

[11] Two formulations were modelled: Recloser's combination of "electricity levels" and "reliability in communication channels" has a multi-objective. The former became the first goal in determining recloser investment expenses, while the latter became the second goal in terms of reliability. “A multi-objective optimization method was adopted, and the execution was simple.” The MICRO-GA, which was based on genetic algorithms (GA) [11], appeared to offer little. The findings revealed that mathematics may be used to solve problems; by placing normally closed Recloser (N-C-R) and

ordinarily open Recloser (N-O-R) for fault isolation efficacy as a statement and the models used to address the problem. Non-technical loss cost reductions, on the other hand, were overlooked.

[4][12][13][14] Adaptive recloser approach was used to present a transient stability enhancement. The system under study's oscillations were eventually reduced using the modeled strategy. This technology could only work with limited data, and the authors projected that it would be practical in a real-world power system. This technique had the following advantages: improved transient stability and adaptiveness.

[15] The Monte Carlo method of convergence was used, which was predicated on the likelihood of a fault occurring. The method relied on historical data of occurrences to map different types of faults and their likelihood. To manage fault kinds at random, a flow chart was created. Power loss expressions were used to compute the cost of each type of fault. Power loss expressions were used to compute the cost of each type of fault. For setting the operation of a recloser, the same Monte Carlo method was utilized. This approach, on the other hand, was not intelligent enough to allow for fuse and relay coordination during power outages.

[16] Revolutionized a modest algorithm for selecting a minimized amount of electricity theft. To overcome transient fault-related losses, an Analytical Hierarchy Process grid with a diversified format and customer features was used in this study, which had an exceptional strategy. The work chose a test feeder with significant costs and failures to evaluate the model, but it did not solved it by illustrating values of power savings.

[17] A fault search strategy model was used. The authors examined fault hunting strategies and demonstrated how to interrupt such faults utilizing a stand-alone (sectionalized switches or recloser system) paired with a communication system. SMART or programmable switches were eventually developed by the authors, who used all of the devices in a fault hunting method using SCADA for control objectives. When compared to the old way, the SMART switches were more expensive. The model, on the other hand, was an improvement, but the authors were unable to optimize and offer an intelligent solution. There was no cost-cutting analysis or acknowledgment of the model's agility in responding to consumer interruption.

[18][19][20][21][22][23][24] Reclosers can be placed in four different ways for best performance. He divided the approaches he used into four categories: Ant colony algorithm, Enhanced network Genetic algorithm without dominating sorting, sectionalized schemes with network loop automation, and CENS-cost of energy not served savings at the power point.

[9] To replace traditional electromechanical circuit breakers in power distribution, a modelled solid-state power controller was developed. The technology was able to distribute power while also safeguarding it from diverse loads. Current-squared-time ($I^2t$) induced by instantaneous faults were protected using the model. He did not, however, use artificial intelligence in his research.

### 2.3. Summary of Literature Review.

Table 2.1 shows the previous research work which were relevant for this study. The subject areas provided within the literature review is researcher's methodologies applied in solving a similar problem and the gaps therein.

**Table 2.1 Summary of Literature Review**

| Ref | Reclosing Technologies | Candidate for Recloser Placement | Optimization Method | Tests for Validity | Gaps |
|---|---|---|---|---|---|
| [1] | Non reclosing technique other than copper and iron loss reduction technologies | Technical and non-technical loss reduction | Used models that foresee the system circumstance in a general manner and determined and calculated loss of power for 10kV, 20kV links and 6.6 kV even on transformer | Used10kv, 20kv links and 6.6 kV lines to analyze system copper and transformer iron losses intelligent tools | Limited solution and lesser intelligent technique on power loss reduction |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| [2] | A simplified computer-based algorithm. | Used a test grid, in which costs were extremely high, and a Case study on cost benefit analysis was conducted | Cost analysis | Interchanged grid structure and one and a half percent (1.5%) in overall loss reduction were approximated | Reclosing technique was taken into account to solve transients and technical and non-technical loss reduction |
| [14] | Optimized reclosing technology | Critical clearing angle “the load angle at which the fault will be cleared and the system becomes stable | Simulated studies to calculate optimal reclosing time | MATLAB/ SIMULINK | Model lacked integration for both transients and non-technical loss reduction caused by transients |
| [4] |  | Enhanced transient stability, minimum power cost | A multi-objective optimization method | Showed improvement as compared with fixed recloser time. ART can be | Generator transient but lacked bearing towards system |

| | | | | | |
|---|---|---|---|---|---|
| | | and ENS loss. | | applied to real situation. | distribution transients' stability |
| [2] | Modern digitized reclosing technique | Fault detection and blocking | Digital programmable recloser logic (DPRL) | Modern digital recloser controls offered a fine-tune fast curve timing to enable the control inrush | Failure to compare the results with other tools to show their validity |
| [20] | Smart auto-recloser | Fast control of circuit breakers (CBs) during transients | NI7851_Card With Lab-view technology support | Validity test was Simulink MATLAB | Did not consider non-technical loss reduction |
| [17] | Zoning or Sub-divided supply feeders using new Smart Switches | Reduced customer interruptions | Switches "smart" were increased in number to intensify system security | Power system simulators were used but lacked validations comparison with other | Lacked integration of transients and non-technical loss reduction. |
| [11]<br>[19] | Multi-objective for the communication channels of recloser | Efficient recloser placement of N-C-R and N-O-R short circuit | A MICRO-GA multi-objective optimization method | Tests showed non-technical, technical and investment costs among others | Human factors such as theft of electricity |

| | | | | | |
|---|---|---|---|---|---|
| | | clearing on main line and beginning of each section feeders | | were well articulated | was not studied |
| This Thesis | Presents an Intelligent reclosing technique | Main line and secondary feeder branches | Firefly algorithm for recloser placement and MATLAB Simulation | To Validate using PSO and BAT algorithm | Expected to fill the existing research Gap |

## 2.4 Existed Gaps

Some of the existed gaps that were fulfilled are as follows:

i) Increased utilization of distribution resources, by automating recloser with the ability to trip in all directions.

ii) Increased distribution system (DS) performance at all levels, by equipping recloser with performance-based monitoring to save power from losses.

iii) Provided recloser with success of reclosing sequences; such that utilities are provided with information to monitor faults.

iv) Made a recloser flexible and more intelligent using data; so as to be predictive on future control event before it happens.

## 2.5 Auto- Recloser Philosophies

An auto recloser was fixed; to auto reclose twice in attempt to reconnect power [21][20] [22]. When fault persisted even after the second attempt of its three-cycle logic, The recloser had been programmed to lock out any additional efforts at reconnecting.

Network faulted part was then isolated, leaving the other parts operational. The lock out meant that, the fault was permanent and a follow up by technician was required for fault physical repair work. Although the fact that the line would be inspected beyond the position of the recloser, it would be time-consuming exercise.

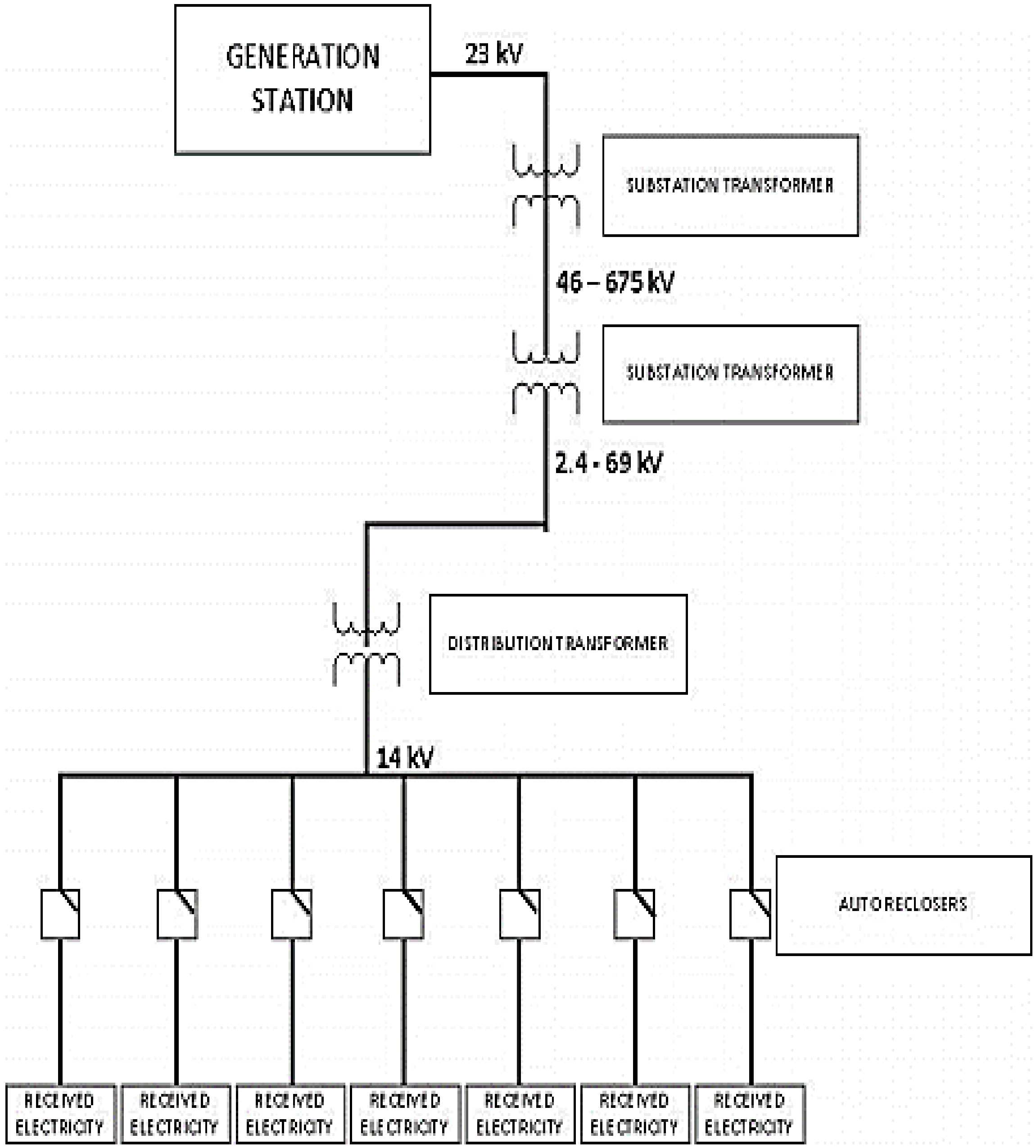
According to an auto reclose philosophy of three-cycle logic was assumed [23]. The implication to the feeders was that, they were exposed to permanent fault up to the time recloser locked out. Feeder conductors heat dissipation was assumed to be considerably high, within that short time span of recloser deadtime. The kind of heat dissipation experienced by feeders during persistent power interruption; As a result, the temporary interruptions is cleared in the third reclosing trial before recloser lockout. Successful rate for the first shot was estimated at 89%, 5% second and 1% for the third. First trip to the last expose the network to overcurrent. During the first trip, 89% of fault was cleared, then 5% and 6% in the second and third trip respectively [24]. This assumption could be used to calculate energy exposure at specific point of the network as follows:

$$\mathrm{Eh} = 100\% * kVA * \mathrm{t}_1 + (100 - 89)\% * \mathrm{kVA} * \mathrm{t}_2 + (100 - 94)\% * \mathrm{kVA} * \mathrm{t}_3$$

$$\mathrm{Eh} = \mathrm{kVA} * \mathrm{t}_1 + 0.11 * \mathrm{kVA} * \mathrm{t}_2 + 0.06\mathrm{kVA} * \mathrm{t}_3 \qquad (3.1)$$

Where $\mathbf{E_h}$is the network energy exposition, with $\mathbf{t_n}$ and kVAtransformer rating for a given radial network zone. The trip cycles n being 1, 2 and 3 respectively.

### 2.5.1 Block Diagram of Reclosers in a Distribution System



Source: Smart_Recloser_2011.pdf (wpi.edu)

Figure 2.1: Reclosers in a Distribution System

Normally, there is no way to tell if the attempt to reconnect the circuit occurs after the fault has cleared or not when reclosers operate mechanically. The power distribution system illustrated in

### 2.6 Fault Mitigation Strategy

The action of reducing the amount of power outages and voltage sags would result in the disruption outcome being mitigated. The following were some of the activities that could be taken:

i) the addition of a line recloser. More downstream reclosers are installed to coordinate with upstream reclosers [17][25].

ii) Coordinate the fast tripping of reclosers and circuit breakers [26]. This is done in order to reduce customer interruptions by at least 50%.

iii) Increase the protection speed. This was accomplished by adopting a steeper TCC curve to quickly eliminate faults [27].

iv) iv) Reducing the dead-time of the recloser. The standard dead-time is 1.5 to 2 seconds. To facilitate immediate reclosing, this would be made to be between 20 and 30 cycles (0.03 to 0.05s). Single-phase tripping: It was preferable to employ a recloser with single-phase tripping and three-phase lockout to prevent damage to three-phase loads [28].

v) Loops schemes that are improved. To boost reliability, one feeder is replaced with two parallel feeders [14].

vi) Changing the design of the feeder Increase feeder impedance and reduce voltage sag by changing feeder pathways and cross-section. The first five actions would make it simple to implement overcurrent protection. Faults that commonly occur along electricity lines were divided into two categories: temporary and permanent. The former type could self-clear, and power would be restored in one to four times, whilst the latter would necessitate line staff labor [24].

### 2.7 Categorization of Optimizing Technique

The algorithms can be classified as either probability based or non-probability-based models as follows [15]:

#### 2.7.1 Non-Probability Based Models

In every implementation venture of a probability calculation, all considerations needed one approach. On the other hand, if there was no real way to continue; the calculation had ended.

In this category, rule of thumb was used for the algorithm to progress, if not it would terminate. In most cases, the values fed at the input of the program-generated outcomes, which were similar. Therefore, when a choice was made on how to progress, every time the output data did not change.

A probability-based model, agreed to a strategy in which, the variables are always in a certain state. Result of a probability modeling, was resolved by the initial states and parameters of a variable. Any moment the model was executed with the same initial states, equal results were received. A probability-based model was developed applying first principal equations. It was also referred to as white box model [29].

#### 2.7.2 Probability Based Model

There could be a likelihood that non-probability-based model refused to optimize for a realistic result. If at all the comparison between the contending solutions “aptness” was not straight forward, with respect to dynamics that were complex, the range of exploration span got large. In that perspective, the non-probability-based model fell, became less effective and often unattainable. In all considerations, specific algorithms were more proficient compared to non-probability-based models in all domains.

Non-Probability based models suffered drawbacks; because of not being able to generate consistent outcomes. Then, probability based optimization algorithms came into play. A randomized (or probabilistic or stochastic) algorithm included at least one instruction that acted on the basis of random numbers. In other words, a probabilistic algorithm violated the constraint of determinism.

In many domains, precise algorithms may be far more efficient than probability based. The probability based algorithms also had the issue of not being deterministic, which meant that even for the same input, the outputs would vary. There were several optimizations approaches available, and they all assisted in achieving the best or optimal response to power system operation issues. Main categories of the methods are listed as follows:

#### 2.7.2.1 Conventional Optimization Methods

In this situation, mathematical models were used for solutions, when described and developed from the principle of the problem. The key concerns when using these methods, are the mathematical properties of the objective function, constraints and decision variables. They were mostly applicable in providing solutions to less complicated scales of work, as they converged to solutions quickly. These strategies consist of:

i) Interior point (IP) methods
ii) Linear programming (LP)
iii) Mixed-integer programming (MIP)
iv) Network flow programming (NFP)
v) Newton method
vi) Nonlinear program
vii) Quadratic programming (QP)
viii) Unconstrained optimization approaches

#### 2.7.2.2 Intelligence Search Methods

Complicated nature of electrical power systems, had made use of artificial intelligence to solve problems. Artificial intelligence tended to mimic human behaviour. Human and social intelligence was based on memory of the past findings, and artificial intelligence did analyze their performance, and readily graphed their next move. These methods includes:

#### 2.7.2.3 Non-Quantitative Approaches

They address uncertainties in objectives and constraints.

These include:

i) Analytic hierarchical process (AHP)

ii) Fuzzy set applications

iii) Probabilistic optimization

### 2.7.2.4 Hybrid Methods

As problems get complicated, single methods suffer limitations and hybrid techniques are better placed to overcome such. Hybridization combined two or more optimization algorithms; and output would depend on the best qualities of the combined methods. The goal of the hybrid technique was to maximize on the pros and improve the quality of the solution by speeding up convergence [30]. The following are the examples of hybrid techniques:

i) Artificial Bee Colony – Particle Swam Optimization (ABC-PSO)

ii) Bacterial Foraging – Differential Evolution (BF-DE)

iii) Evolutionary Programming –Efficient Particle Swam Optimization (EP-EPSO)

iv) Fuzzified Artificial Bee Colony (FABC)

v) Fuzzy Adaptive -Particle Swarm Optimization (FA-PSO)

vi) Genetic Algorithm -Particle Swarm Optimization (GA-PSO)

vii) Simulated Annealing – Cloned Selection Algorithm (SA-ASA)

### 2.7.2.5 Genetic Algorithm (GA)

In nineteen seventies (1970s), John Holland and close associates invented the genetic algorithm. The model used Darwin's principle of nature and it's selective characteristics; with an abstraction of natural evolution [31]. This inventor became the initiator that implemented the use of crossover and recombination, mutation, and choice in adaptive and synthetic structures. Genetic set of rules had the functionality of accepting numerous varieties of optimization, but no longer withstands the objective (fitness) features, be it non-changing or changing, linear or non-linear optimization. This versionis confined by non-linear optimization. Genetic algorithms additionally have a few fatalities. The machine fitness feature uses populace length and choose the most beneficial analytical parameters; that involves mutation and crossover. The selection criteria of new population need to be carefully done. Any wrong preference will be seem hard for the set of guidelines, to converge or it correctly yields meaningless effects.

#### 2.7.2.6 Neural Networks

It is among the already available and use artificial intelligence and machine learning tools and is popularly known as Artificial Neural Network (ANN)[32]. Being simple to study and understandable algorithms, it can manage to use multi-layer (frequently three) of neurons and interconnection to form a network that simulate machines' output from the stimuli. Speech reputation and adaptive control are some of the very many applications using ANN.

#### 2.7.2.7 Firefly Algorithm.

In the year 2008, Xin-She Yang at Cambridge University developed the Firefly algorithm which falls under the category of meta-heuristic optimization [33].

The flashing illuminations and conduct of fireflies inspire this algorithm. Under special instances, it was able to lessen either to a random search or particle swarm optimization. Preliminary research showed that it's far greater effective than PSO (Particle Swam Optimisation).

##### 2.7.2.7.1 Advantages of Firefly Algorithm (FA)

i) FA finds its supremacy because it deals with highly non-linear, multi-modal global optimization problem [34].

ii) Is also simple and has flexibility of integrating with other optimization techniques to form hybrid tools.

iii) Do better in the energy-efficiency maximization problem.

iv) Does not depend on an excellent preliminary solution to start the iterations.

##### 2.7.2.7.2 Applications of FA

Firefly algorithm has been frequently used in Engineering and other fields to help in the following undertakings:

i) Feature selection and fault detection

ii) Antenna design

iii) Structural design

iv) Scheduling process

v) Dynamic problems

## 2.8 Electrical Power Losses

Distribution power losses by definition, is simply the difference between that energy delivered to the network from the power generators and the actual energy available for real consumption [1]. Power losses within the distribution network traditionally classified into two categories:

- Losses caused by technical issues/ Technology based
- Losses caused by non-technical issues/ non-technology based

### 2.8.1 Technology based Losses

The design of an electrical system involves the use of electrical lines, transformers, measurement facilities and other support equipment that carry energy. These physical devices directly dissipate power in form of lost energy in the system. Therefore, energy or lost power related to the system design; is broadly regarded as technical loss (TLs), which must occur within the system as power is being delivered to the customers. Customers normally incur more cost or charged more fees to cater for the losses [35]. Otherwise, such losses are experienced as noise along the line as well as heat on the devices.

### 2.8.2 non-Technology based Losses

The definition for technical losses (TLs) simply gives an overview, to broadly define non-technical power losses (NTLs)[32]**.** In line with technical losses, not that entire energy supplied to the consumer and measured can be accounted for. All unaccounted-for energy are losses caused by unidentified consumers**.** The non-technical losses are caused by deliberate acts by consumers, whose actions are external to power systems**.** They allude to cost of energy; that is not identifiable to the transportation of electricity. More explanation regarding NTLs is that; even though actual losses increase when undetected load is joined into the system but the expected loss based on record of utilities remain the same. This kind of loss will appear on the consumer's accounts because costs will be passed along to the customer. Examples of NTLS are:

- Illegal connections
- Meter bypass

- Tapping of power lines
- Frauds
- Customers without contracts – unknown delivery points
- Illegal reconnections of disconnected lines

Power firms suffer financial losses as a result of power system failures. These costs can be broken down into three groups:

a) **Price** of installation of faulty component(s) and repair (direct costs).
b) **Supplier** if it is contracted, reimbursements for loss compensations to the consumer (indirect costs).
c) **Revenue:** Electricity is not sold or delivered; hence it is lost (indirect costs).

Category a) depends on the type and location of fault component and it can be hard to make an exact assessment.

Category b) depends on the legislative, power supply contracts points, open electricity markets offers and consumer status based on power consumption per year

NTLs = Total losses – Technical losses.

## 2.9 Problem Formulation

Three formulations featured separately, then combined for an overall objective function for the problem.

### 2.9.1 Objective function for Optimal Recloser Time

I. Brief shut down is improved in several ways, including the following:

i) Reduce faults - such as tree lowering, tree line, creatures' movements, arresters, tour duties, and so on.

ii) Reclosing quickly.

iii) Reduce the number of consumers' disturbance, by using downstream recloser.

II. Distribution Circuits with Line Reclosers

In this kind of recloser arragement, the strategy is to minimize recloser time; because it is based on the time delay required to extinguish the fault.

Table 2.2 shows the dead time in line with typical settings range, for an auto-recloser alongside. The dead time interval for initial trip is 0 to 5 seconds, second trip is 10-20 seconds whereas third trip which is also last is 10-30 seconds. The maximum time takes up to the last trip 55 second.

**Table 2.2: Auto reclosing Dead-time intervals**

| **Intervals of Dead-time** | **Range of common settings (seconds)** |
|---|---|
| $R_{T1}$ is the initial trip of reclosing. | 0-5.0 |
| $R_{T2}$ is the 2nd trip of reclosing | 10.0-20.0 |
| $R_{T3}$ is the 3rd trip of reclosing | 20.0-30.0 |

Source: IEEE std C37.104-2012

### III. Considering Current time characteristics

$$T_i = \left[\frac{A}{(M)^p - 1} + B\right] TDS \tag{2.1}$$

$$M = \left(\frac{I}{I_S}\right) \tag{2.1a}$$

$$TT = \frac{0.14\ TMS}{\left[\frac{I_{fault}}{I_{PU}}\right]^{0.02} - 1} \tag{2.1b}$$

Where, $T_i$ is Inverse characteristic equation for the recloser (Recloser for optimum operation could only be set to very inverse value), TT is trip time or recloser reference time in sec, I is Fault current, M is recloser' multiple pickup current (M > 1), $TDS_j$ or TMSj = Time dial setting or time multiple setting, $0.5s \leq TDS \leq 1.5s$ and PMS = Plug setting Multiplier ($1.0 \leq PMS \leq 1.50$).

NI (normal inverse) characteristics are used. The trip time (TT) of the NI curve was determined by the Equation 2.1b. [15].

### 2.9.2 Objective function for Non-Technical Loss Reduction

Considering the costs of transient and permanent faults or "non-technical power". The objective cost function of transient faults were calculated as:

$$\mathrm{w_{ENS}} = \min \sum_{\mathrm{r}=1}^{\mathrm{n}} \mathrm{P_r\,T_r C_r} \tag{2.3}$$

Where $\mathrm{P_r}$, $\mathrm{T_r}$ and $\mathrm{C_r}$ are utilized power, power recovery time and energy cost for load in that order. r,is utilities head count that had been interrupted during brief failure. The spending during long-lasting interruption or permanent fault was also evaluated (Equation 2.4) as

$$\mathrm{w_{ENS}} = \min \sum_{\mathrm{r}=1}^{\mathrm{n}} \mathrm{P_r\,T_r C} \tag{2.4}$$

Where C is the electricity charges subject to recloser settings and brief power cut off caused by the operation [35]:

$$\mathrm{PMS_{jmin}} \leq \mathrm{PMS_j} \leq \mathrm{PMS_{jmax}} \tag{2.5a}$$

$$\mathrm{TDS_{jmin}} \leq \mathrm{TDS_j} \leq \mathrm{TDS_{jmax}} \tag{2.5b}$$

Where PMS and TDS are the plug and time multiple settings of the protection device within a specific location j.

### 2.9.3 Objective function for electricity consumption

This research modelled an objective function, to reduce the cost and increase the system reliability; with recloser' optimization model given by Equation 2.6.

The total electricity consumption for a given distribution system in a given power outage is given in the following Equation:

$$\mathrm{E_h} = \sum_0^9 kVA_I * t_r = \mathrm{P*t} \tag{2.6}$$

Where, $\mathrm{E_h}$, Un-served Energy in kWsec, I, fault current, P was power supplied by the system at time $\mathrm{t_r}$ in seconds of the recloser operation.$\mathrm{kVA} * \mathrm{t_r}$is the thermal energy required to melt a specific fuse element; Given that the recloser dead-time was approximated as 2 cycles or seconds (0.04s)

Equation. (2.5), used reclosing philosophy as shown in eq. 2.6b

$$E_h = kVA * \mathrm{t}_1 + 0.01 * \mathrm{kVA} * \mathrm{t}_2 + 0.06 * \mathrm{kVA} * \mathrm{t}_3 \qquad (2.6b)$$

Considering single recloser device, the total everyday device operation and maintenance cost is given by:

$$\mathrm{C_{rom}} = \xi * \mathrm{CENS} \qquad (2.7)$$

Where, $\xi$ is operation and maintenance costs coefficient on the investment.

Considering operation and maintenance cost $\mathrm{C_{rom}}$ at time t, the energy consumptionwas represented as:

$$\xi * \mathrm{CENS} = \left(\mathrm{f}(\mathrm{C_{rom}})\right) \qquad (2.8)$$

The objective function, derived from the objective of minimizing the non-technical and transient energy cost, was thus, based on installing recloser.

Objective function :

$$\mathrm{f(x)} = \xi * \mathrm{CENS} = \min\left(\mathrm{f}(\mathrm{C_{rom}})\right) \qquad (2.9)$$

Subject to:

$$\mathrm{R(t)} \geq \mathrm{R_0} \ \rightarrow \text{Considering failure rate of the feeder line} \qquad (2.10)$$

$$\mathrm{ENS_{min}} \leq \mathrm{ENS} \leq \mathrm{ENS_{max}} \qquad (2.11)$$

Thus R_(t) was the probability of success (reliability) index of a distribution system, under a given recloser constraints.  Ro (t) is the occurrence or reliability index projection compels and RT is scheduled reliability level.

Energy not supplied is constrained, where; ENSmax is the highest outage and expressed as:

$$\mathrm{ENSmax} = \ 8760(1 - \mathrm{R_T})\mathrm{P_L} \qquad (2.12)$$

$$\mathrm{ENS} = \left[\sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{P_r\, T_r C_r}\right] \qquad (2.13)$$

Considering recloser operation, fault location time was calculated as:

$$\text{Fault location time} = \frac{x_1}{x_1 + x_2} * \text{Recloser standard sensing Time} \tag{2.13b}$$

Where, $x_1$ and $x_2$ are downstream and upstream distances to the faulted area.

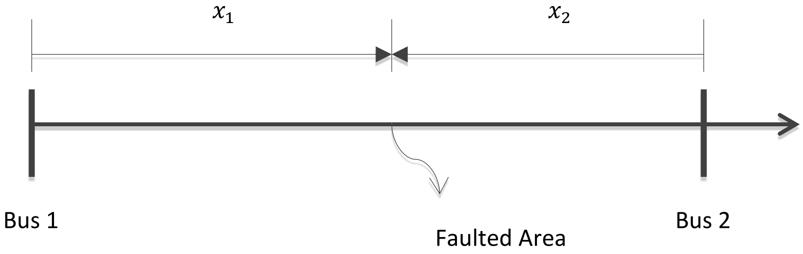


Figure 2.2: Power Line Faults Location

Fault location is the place where a short circuit current occur. The distance is measured from the sub-station recloser position. Fault location time for faulted area was calculated using equation (2.13b) with reference to Figure 2.3

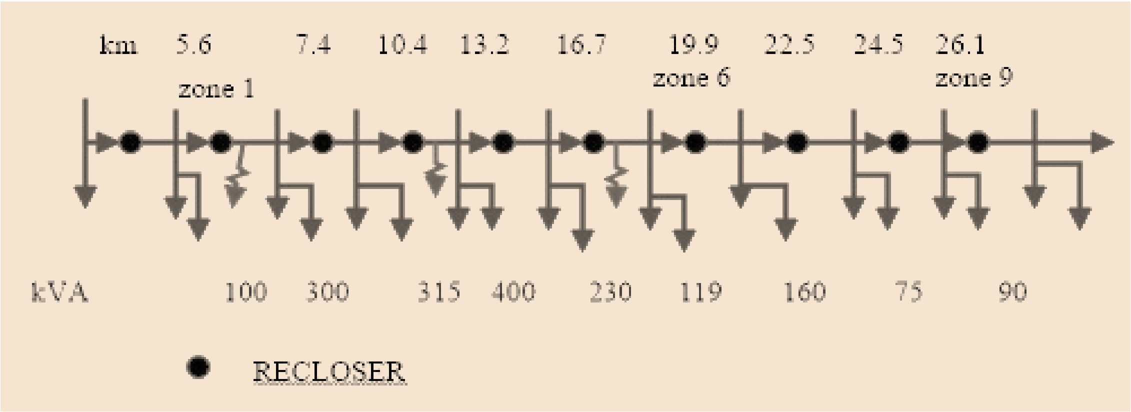


Figure 2.3: Fault Location along the proposed System Network

### 2.9.4 Total Cost Savings Objective Function

Transformers in this thesis were assumed to spread across the distribution lines, along feeders and loads; branched to 9 zones considering the zoning policy. Therefore, the circuit breakers and one recloser does the optimization of recloser location - allocation. This was based on their zone protection distance.

Using assumption that recloser are placed at the end or centers of the feeder line, the total cost of energy not served due to reclosing action was formulated as follows:

The savings in the total costs can be expressed as:

$$\text{Minimize } f(x) = d_i t_1 + d_i t_2 + d_i t_3 \tag{2.14}$$

Where, $d_i$ is the power demand downstream in kVA and t (1, 2 and 3) are the reclosing durations designated to identify whether fault is temporary or permanent. The recloser will cut of the line at the time, $t_{3,}$ thus indicating that fault is permanent awaiting service from the technical personnel.

$$\text{Where } d_i = D_j F_k L_m R(t) C C_r \tag{2.15}$$

This objective function subject to the following constraints:

$$0.50 \leq t_r \leq 45.90;$$

$$75.0 \leq D_j \leq 400.0;$$

$$0 \leq F_k \leq 1.0;$$

$$R[(t)] \geq R_0;$$

$$\text{CENSmin} \leq \text{CENS} \leq \text{CENSmax}$$

The cost of energy not supplied to the consumer as a result of the reclosing, which is done to protect the feeder line and power apparatus, is denoted by CENS.

$D_i$ = Upstream load allocation,

Lm= Line length downstream,

$\boldsymbol{t_r}$= Recloser time setting,

*C*= cost of a recloser for the entire review period (including maintenance and operation)

$\boldsymbol{C_r}$ = Cost of energy outage per hour

R(t) =Rate of expected interruptions based on probability

### 2.9.5 Criteria for Recloser time coordination

Between the recloser's operations, coordination time is the shortest time required. The gap between the operation times of the two reclosers must be less than or equal to the CTI (coordination time criteria).

### 2.9.6 Recloser Characteristics

The recloser's response time should be swift in order to identify the defect quickly. As seen in Table 2.3, a time constraint is implemented.

**Table 2.3: Operating Time of Recloser**

| A | Operating Time (s) | |
|---|---|---|
| | 3-phase reclosing, shot 1 | 0-5 |
| | 3-phase reclosing, shot 2 | 10-20 |
| | 3-phase reclosing, shot 3, 4 | 20-30 |
| | Reclaim time settings | 10-180s in steps of 1s |
| B | Fixed Settings | |
| | Reclosing pulse | 0.2 s (0.20 0.22 s) |
| | Interruption at new trip | Minimum duration of 50ms |
| | Reset of time blocking input | 5 s |
| | Condition “CB closed” min time | 5 s |
| | “Synchro-check” signal | 5 s |
| **C** | **Typical Error Limit** | |
| | Time up to 2s | 0 – 0.02 s |
| | Time above 2s | 0- 0.10 s |

**Source**: https://pacbasics.org/how-do-reclosers-work-setting-and-operation/#2-recloser-settings-34

### 2.9.7 Determining the Optimum Location of a Recloser

Firefly algorithm (FA) is one of the meta-heuristics swam intelligent optimization; which was employed based on its advantages, as compared to other artificial intelligent methods. The optimal value of recloser placement to minimize cost of energy not served; from the objective function in equation (2.14), was determined by the value of brightness of the firefly.

Reclosers are known to be versatile in handling protection of power distribution lines. The need to make recloser intelligent enough, was the major objective of this research. The number of recloser put along distribution line, to safe guard any eventualities; depended on the reliability of the line from transients.

Populated areas in the cities and where there are lower class dwellers; posed a threat to reliability of the line. This had been caused by the probability of, slum dwellers using power without; getting normal connections done by the authority in charge. Whenever such connection came up, power outage was to be experienced almost hourly.

## 2.10 Conclusion

In order to safe guard the lines during unprecedented power failures; power supply authority need to employ devices which are able to sense, disconnect and reconnect power immediately to avoid inconveniencing consumers. Recloser in this case is able to determine through computer coding, the kind of decisions to take and hence minimize the cost of power outage.

In conclusion, auto-reclosing philosophies, fault mitigation strategies, categories of optimization techniques and firefly algorithm were the main areas studied in this section.

Many of FA advantages are it’s supremacy, that makes it deal with highly non-linear multi-modals; global optimization problem and simplicity, flexible in integrating with other optimization techniques to form hybrid tools, better in the energy-efficiency maximization problem, and finally does not depend on an excellent preliminary solution to start the iterations.

Apart from these methods, auto-reclosing philosophies study; helped in realizing data for running the firefly algorithm. In other words, the three-shot principle of the recloser reaction was key; to optimization technique as far as this thesis is concerned. Mitigation strategy study played a major role, in designing ways of locating recloser along the radial system network.

# CHAPTER 3: RESEARCH METHODOLOGY

## 3.1 Introduction

Transients are linked to instability in power systems, according to theoretical evidence and methodologies provided in this thesis. There are three ways that can be used to overcome transients and establish stability:

- using a device for power protection,
- identifying their capital investment and
- establishing cost minimization of the strategy based on cost-benefit analysis.

This section provides details of the materials, equipment, and tools, which were necessary for an appropriate and accurate solution to the transients caused by transients. Consequently, mapping of the method and pseudo code  generated.

In this regard, it was necessary to develop this chapter to cover areas such as: introduction, review of previous methods, summary of the reviewed methods, mapping the method to the problem and finally modeling and coding of the chosen method to generate results for analysis.

## 3.2 Previous Methods Applied to solve the Problem

Table 3.1 shows the preceding methodologies employed by researchers. The purpose in this table shows the reason for methodology. The candidate for recloser placement indicates the main work done by the recloser. Optimisation method is the tool which was used and its contribution to the objective function [36]. The last section of the table shows, the data needed to manage the objective function variables.

**Table 3.1: Preceding Method Employed on the Problem**

| **Ref.** | **Purpose** | **Candidate for Recloser Placement** | **Optimization Method** | **Contribution to Objective Function** | **Data Needed to Manage Variable** |
|---|---|---|---|---|---|
| [2] | Detect faults and manage them | Recorded data on oscillatory performance of distribution line during faults | Simulated studies to calculate optimal reclosing time | Reaction time of recloser<br>Duration of faults<br>Causes of faults | Probability of faults on section of feeder<br>Cost of outage depending on cable span<br>Network layout<br>Cost of recloser |
| [3] | Modeled for the location of optimized recloser in the distribution system | Binary variable that determined the various paths of communication channels | Mathematical model and vector codification | Investment cost<br>Cost of outages | cost reduction saving on power loss due to faults |
| [6] | Presents auto-recloser algorithm to control recloser to manage faults and improve on reliability | Main line and branching point of feeders | NI Lab VIEW FPGA module | Data processing<br>Timing control and sequencing of data transfer | Data acquisition card NI |
| [7] | Developed Recloser location on | Changed grid structure and placed recloser | Monte Carlo and simulations | MAIFI<br>SAIDI<br>SAIFI | Reliability failure rates<br>Repair times |

| Ref. | Purpose | Candidate for Recloser Placement | Optimization Method | Contribution to Objective Function | Data Needed to Manage Variable |
|---|---|---|---|---|---|
| | distribution feeders | along main line and junction points of secondary feeders | | | Investment cost<br>Maintenance cost |
| [8] | Reliability in communication channels of recloser | Devised a method for a most efficient recloser placement N-C-R and N-O-R short circuit clearing | A MICRO-GA multi-objective optimization method | Non-technical, technical and investment costs among others were well articulated | Communication channels<br>Investment cost<br>Reliability<br>Maintainability |
| In this Thesis | Provides Intelligent reclosing technique | To provide transient stability and saving strategy of Energy not served during reclosing | Firefly optimisation technique through MATLAB coding | Electricity theft control, mitigation of transient currents and ultimately saving of energy not served during transients. | Radial network data such as downstream load demands, reliability of the system and recloser settings and |

## 3.3 Vectorization of the Model and Problem Formulation

Vectorization is a way of expressing calculations, in terms of matching similar operations on vectors of data [33]. Vectorization would be able to relate variables that should be used, as inputs and outputs for the developed model.

based on radial network considered the following vector equations:

I: Set vector parameters: time, distance, current and power and equate them as follows:

$$\mathrm{x}_1 = \text{Location time per km in seconds} \tag{4.7}$$

$$\mathrm{x}_2 = \text{Line length downstream of i km } = \textstyle\sum_{i=1}^{9} L_i \tag{4.8}$$

$$L_i = [5.6\ ,7.4, 10.4, 13.2\ ,16.7, 19.9, 22.5\ ,24.5\ ,26.1]$$

$$\mathrm{x}_3 = \text{Line length Upstream of j in km } = \textstyle\sum_{i=1}^{9} L_j \tag{4.9}$$

$$L_j = [26.1, 25.4.22.5\ ,19.9\ .16.7\ ,13.2, 10.4, 7.4\ ,5.6]$$

$$\mathrm{g}_1 = \text{Fault location time} \tag{4.10}$$

Therefore:

$$\mathrm{x}_1 = 2\ \text{sec/km fault detection time per km along the feeder}$$

II: Switching time for the feeder

$$\mathrm{g}_1 = \frac{\mathrm{x}_2}{\mathrm{x}_2 + \mathrm{x}_3}\mathrm{x}_1 \tag{4.11}$$

III: Fault clearing time of the feeder is given by:

$$\mathrm{g}_2 = \mathrm{g}_1 + 15\ \text{sec} \tag{4.12}$$

IV: Fault clearing time of the feeder is given by:

$$\mathrm{g}_3 = \mathrm{g}_2 + 30\ \text{sec} \tag{4.13}$$

V Energy not supplied due to outage based on demand (D) downstream is given by:

$$\mathrm{g}_4 = \sum_{I=1}^{9} 1.17 g_1\, D_i \tag{4.14}$$

VI: Failure rate of the Zonal line per km is given by:

$$\mathrm{g}_5 = 0.008 kVA_{\mathrm{i}} \tag{4.15}$$

VII: Operational and Maintenance expense of the protective device is given by:

$$\mathrm{g}_6 = \$\frac{0.008}{kVA_i} \tag{4.16}$$

VIII: Energy outage cost per kW is given by:

$$\mathrm{C}_{\mathrm{r}} = \$\frac{1}{kVA_i} \tag{4.17}$$

IX: Savings on the cost of Energy not used in given as:

$$\mathrm{CENS} = \min\left(C_r * \sum (g_1 g_2 g_3 g_4 g_5 g_6)\right) \tag{4.18}$$

## 3.4 Recloser Optimization Method

### 3.4.1 kVA Cost Method

This method is used to determine the number of recloser equipment and its location, in order to mitigate the customer's inconvenience [13][1]. The kVA cost (CENS) rating is specified at each measurement point; as the product of the line energy consumption of the network and it's cost of maintenance and operation during mitigation [14]. Once the ratings of kVA cost for all the measuring points are calculated, the position that prescribes to the large value is chosen; as the position of the device [14].

### 3.4.2 Data for the Formulated Model Simulation

The data for the firefly algorithm coding utilized the radial network in Fig. 2.2. This network has values including: downstream load power demands symbolized as d, distances where transformers are placed and their kVA values, the reliability ratings of each line and is based on power demand of the section.

#### 3.4.2.1 Network Zones and Parameters

For each of the nine zones, three parameters are considered for data inputs, as tabulated in table 3.2. These include maximum kVA, downstream network length (km) and line failure rates

**Table 3. 2: Network zones and their parameters**

| ZONES | Demand kVA | Fault Clearing Time (s) | Failure rate per zone a (constant) | Maintenance and operation costs ($) | Distance along the line from Sub-station (km) |
|---|---|---|---|---|---|
| 1 | 100 | 45.4 | 0.7143 | 25 | 5.6 |
| 2 | 300 | 45.5 | 0.5405 | 75 | 7.4 |
| 3 | 315 | 45.6 | 0.3846 | 78 | 10.4 |
| 4 | 400 | 45.8 | 0.3030 | 100 | 13.2 |
| 5 | 230 | 46 | 0.2395 | 57 | 16.7 |
| 6 | 110 | 46.2 | 0.2010 | 27 | 19.9 |
| 7 | 160 | 46.4 | 0.1778 | 40 | 22.5 |
| 8 | 75 | 46.5 | 0.1633 | 18 | 24.5 |
| 9 | 90 | 46.6 | 0.1533 | 22 | 26.1 |

**Source**: MATLAB simulation variables

Table 3.2 Values were used to develop matrices for reclosing coefficient. Reclosing coefficient values were useful for optimization technique, developed in firefly algorithm. Basically, all the zones' distances are stretched for different kilometers along the network.

Fault location and clearing time are solved using equation (4.11) and (4.13) respectively. At first, fault location and clearing times are shorter and increases downstream. As long as the recloser is closer to the upstream distribution system, it is made to have a shorter time to locate and clear the fault; once it occurs along the proposed radial line.

## 3.5 Solution of the Model Problem Formulation

### 3.5.1 Firefly Algorithm

To reduce the amount of energy not served during the reclosing period, a Firefly modeled algorithm was devised. The methodology's goal was to keep the blackout costs as low as possible as a result of the reclose mitigation process. A recloser's ideal setup comprises factors of arbitrary nature, such as faulty area and fault kind (transient or permanent). This information, must be dependent on recorded ones.

Such information was a waste of time in this routine study. The information flaws are neglected, but the exposures are dealt with using a stochastic (random process or possibility estimates) technique. The firefly technique (a computerized calculation) relied on repeatedly and irregularity checking to obtain numerical outcomes in order to limit weaknesses. Of which was used in the approach that was devised.

The ideal settings for a recloser, were accomplished through the accompanying advances and the flowchart developed appropriately.

Table 4.2 provides a summary of techniques that were relevant and adequate for the solution. The areas for optimization and the convergence rate, served as a means to guide in choosing the most appropriate method.

### 3.5.2 Presentation of FA

FA, a nature-inspired kind of algorithm; related to the behaviour of fireflies from which, its fly was attracted to the fly, which emits light [37]. The brightest fly attracts the rest in its direction. This behaviour was described as both stochastic and a population-based multimodal characteristic. The FA approach was robust, in providing solution to optimization problems. Areas such as engineering, robotic technology, combinatorial optimization uses the FA.

In FA, space distance two fireflies i and j at $x_i$ and $x_j$,in that order could be equated to the length of the distance travelled, $r_{ij}$ giving:

$$r_{ij} = \|x_i - x_j\| = \sqrt{\sum_{d=1}^{D_m} \left(x_{i,d} - x_{j,d}\right)^2} \tag{4.1}$$

Thus, $D_m$ being dimensional optimized value for the case that seeks a solution. Definitely, if the distance$r_{ij}$was large illumination was minimized and making it hard for the flies to find each other. Appropriately, the situation occurred vital to define singularly decreasing functions for illumination strength and the fly attracting level, in that order. This is shown in equation(4.2 and 4.3)

$$I(r) = I_O \, e^{-\gamma^{r^2}} \tag{4.2}$$

$$\beta(r) = \beta_O \, e^{-\gamma^{r^2}} \tag{4.3}$$

Thus$\beta_0$ taken to be a fixed, illumination strength at r = 0 the fly motion I and attracting level to change position to a different but greater attracting (high illumination) fire flying j value was generated by eqn.

$$\Delta x_i(t) = \beta.\left(x_i(t)\right) - x_j(t)) + s\,(g_t - h) \tag{4.4}$$

Thus h, a non-varying vector$[0.4, 0.4, 0.4 \ldots]^{D_m}$and$t_m$ being the duration interval the time step, $g_t$ gotten from probability distribution curve N (0,1). Δx, being the time interval $i_m$ the fly runs around. Two terms existed in this case, whereby, the initial one was inward drawing power from jth fly, and the next term was the chance coordinated by s, a fixed value ranging from [0,1]. Hence the renewed position of ith fly was equated as:

$$x_i(t+1) = x_i(t) + \Delta x_i \tag{4.5}$$

The Equations, (4. 4 &4.5) shows the ith fly travelling in the direction of the jth that has a better attracting power.

### 3.5.3 Pseudo Code for the Adopted Firefly Algorithm

The code for FA is as follows:

```
Step 1:   Initiate algorithm
Step 2:   Develop initial population using equation $X_{j,i} = X^{L}_{j.i} + rand\ (X^{U}_{j,i} + X^{L}_{j,i})$
          (where j = 1,2...n, i=1,2...N and N is the number of decision variables)
Step 3:   Calculate objective function $f(X), X = (x_1, \ldots x_N)^T$
Step 4:   Define parameters for the algorithm ( $\gamma$ - light absorption coefficient, $\alpha$ -
          randomization parameter and $\beta$ - attractiveness)
          While (iter < max_Iteration)
            for j=1:n all n firefly
              for k=1:j all n firefly
                Light intensity Ia at xa is decided by f (xa)
                if ( Ia < Ib )
Step 5:           Shift firefly a towards the direction of firefly b (shift towards brighter one)
                  Attractiveness varies according to distance $d_{a,b}$ via exp [$-\gamma d^2_{a,b}$]
Step 6:         Create and calculate new solutions and update light intensity
              end for k loop
            end for j loop
Step 7:     Put limits for equality and inequality constraints violations
Step 8:     Rate the fireflies, and find the best currently available
          end while
Step 9:   Post results
Step 10:  Display the highest light intensity firefly among all the fireflies, which is the optimum
          solution
Step 11:  Plot the light intensity versus time/iterations
Step 12:  End of algorithm
```

## 3.6 Mapping Problem to Firefly Algorithm

Using FA, this research aimed to minimize the cost of the fuel; while at the same time meeting the constraints of equality and inequality [38]. Implementation of the work would involve MATLAB coding and FA to provide optimized post-convergence solutions. The FA parameters are:

- **Population**: This was possible combination of vector parameters: time, distance, current and power.
- **Number of generations (N):** These are numbers of fault locations within feeder line,
- social component (location) or finite distance from the light source. Actual time to locate fault in a specific zone (sec).
- **Absorption coefficient of the least intensity firefly (γ):** Zonal switching time after fault, cognitive component or initial attractiveness between two flies: Line energy intensity during fault clearing reclosing operation (ENS).
- Inertia weight or fitness value for each fly (w):Cost objective function.
- **Randomization parameter (α):**Failure rate/km for the line.

### 3.6.1 Mapping Problem to Firefly Algorithm:

Table 3.3: Mapping Problem to Firefly Algorithm

| Parameters for FA | Optimization Mapping |
|---|---|
| i) Flies (population) parameters | Create vector parameters: time, distance, current and power and equate them as<br>$x1$= Time for interruptions location per km in seconds<br>$x2 =$ = kVA values<br>Li= Distance downstream of i km<br>$Lj$= Distance upwards radial line of j in km |

| | |
|---|---|
| | $Di$= Line loads upstream of i |
| ii) No of generations (N) | Number of fault locations |
| iii) Social component (location) or finite distance from the light source (r) | Actual time to locate fault in a specific zone (sec) |
| iv) Absorption coefficient of the least intensity firefly ($\gamma$) | Zonal switching time after fault |
| v) Cognitive component or Initial attractiveness between two flies | Line energy intensity during fault clearing reclosing operation (ENS) |
| vi) Inertia weight or fitness value for each fly (z) | Cost objective function |
| vii) Randomization parameter ($\alpha$) | Failure rate/km for the line |

Table 3.3 shows how the problem is mapped to the tool of optimisation. This is a procedure for problem solving to manage clarity so that answers can be reached easily especially in MATLAB coding

## 3.7 Optimal Reclosing Flow Chart

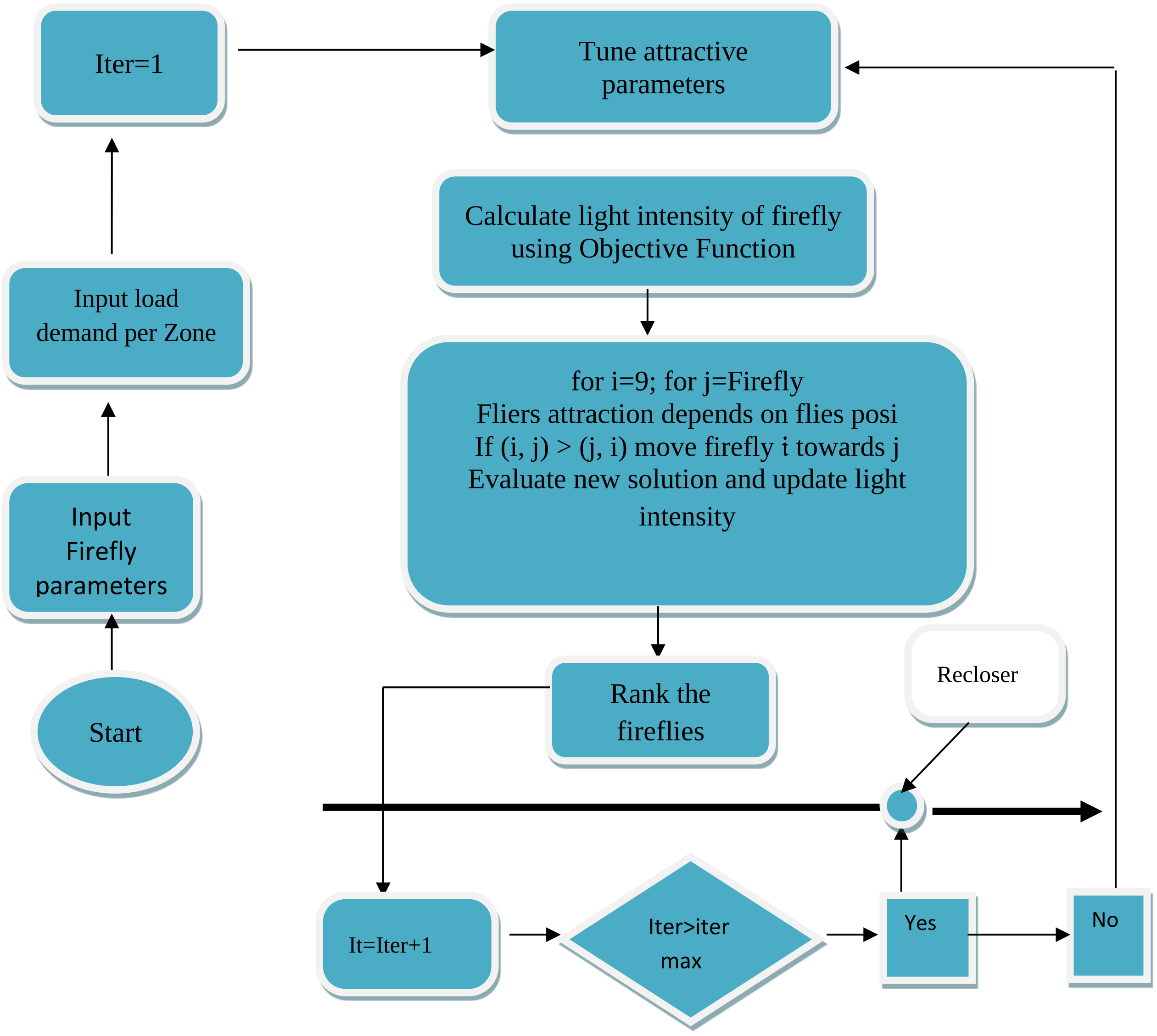


Figure 3.1: Flow Chart for Firefly Algorithm

### 3.8 Developed MATLAB Simulation Code

The FA was implemented in MATLAB R2017a, according to the code attached in Appendix A. MATLAB has a streamlining tool kit, which gives capacities to acquiring parameters that either limit or boost on targets, while satisfying the given requirements. This tool was suitable for solving various optimization problems including linear, non-linear, quadratic, and integer ones. It exhibited high-performance when doing technical computation. It was important in establishing optimal solutions; to either continuous or discrete problems with the help of mathematical formula. The MATLAB code developed is in append

### 3.9 Validation Technique

A similar work and method to test the tool, can be described as the validation technique. The tool used in this work shall be bench marked to another problem(s) a researcher used a recloser technology. Their work on the cost of energy not served should be an overall objective.

This work benched marked on cost benefit analysis, of a recloser with respect to the amount of energy saved; by employing various number of reclosers installed on the distribution lines of power systems.

The steps of simulation in respect to the firefly was as depicted in Figure 3.1. The solution technique assigned the firefly algorithm's initial parameters, then set limitations and uploaded data to the system [39]. When the algorithm was tuned and executed, it generated values for the feeder radial system's responses during faults or line disruptions. The algorithm was created with the intention of automating the process.

# CHAPTER 4: RESULTS AND ANALYSIS

The algorithm was implemented in Firefly and the converging time was 1.3 seconds. The description of experimental parameters are in Table 4.1. Feeder system kVA data values were for simulation of power transmitted along the feeder. Line length per feeder zone was measured in kilometres. Fault location times were calculated based on the principle of fault location in Equation.4.7. Reclosing coefficient was gotten from Equation. 4.9. Failure rate of the Feeder line was gotten from the expression in Equation 4.10, at a rate proportion to kVA values. Total cost, sum of total costs and the Firefly simulation generated optimized costs as it searched for optimal solutions.

## 4.1 Firefly Algorithm Convergence

Computation for the time taken by the firefly algorithm to converge at its optimal point was included in the code. The firefly algorithm parameters are tabulated in Table 4.1. the values given for each parameter are step size factors and are for practical appliacation of firefly algorithm. Simulation parameters such as Alpa, Beta and Gamma are always available in standard values recommended for the Algorithm.

**Table 4.1: Firefly Algorithm Parameters**

| **Simulation Parameters** | **Set values** |
|---|---|
| Number of running | 10 |
| Population size | 9 |
| Number of Iterations | 100 |
| Alpha | 0.5 |
| Number of zones in the Radial system | 9 |
| Number of recloser | 1 |
| Betamin | 1.0 |
| Gamma | 0.6 |

**Source**: MATLAB simulation variables

## 4.2 Objective Function

Figure 4.1 depicts an objective function fitness curve. As illustrated by the curve for analysing fits and outputs; a simple fit was performed here by showing a decreasing curve performing a minimize () function. It had taken an objective funtion to calculate the array to be minimized. The firefly algorithm, which was the minimizer helped in running optimisation problem [40].

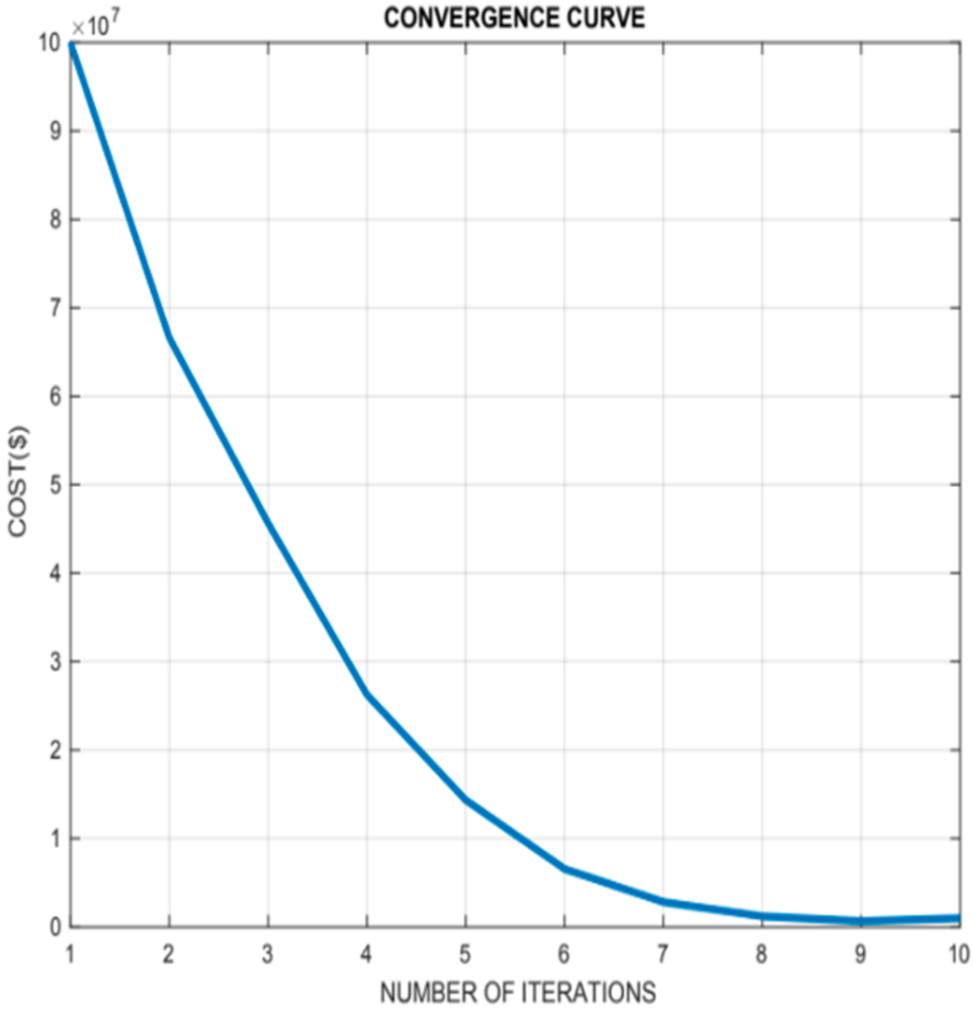


Figure 4.1: Simulation Fitness Curve

## Table 4.2 Function Values for Optimal Saving of ENS

| | **ZONES** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Function values of kVA during simulation** | **Before** | 88 | 283 | 303 | 288 | 218 | 98 | 148 | 63 | 78 |
| | **After** | 87.75 | 287.75 | 302.75 | 387.75 | 217.75 | 97.75 | 147.75 | 62.75 | 77.75 |
| | **Best** | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 |
| | **Best position** | Zone 1 “is the Best Location for a Recloser” | | | | | | | | |

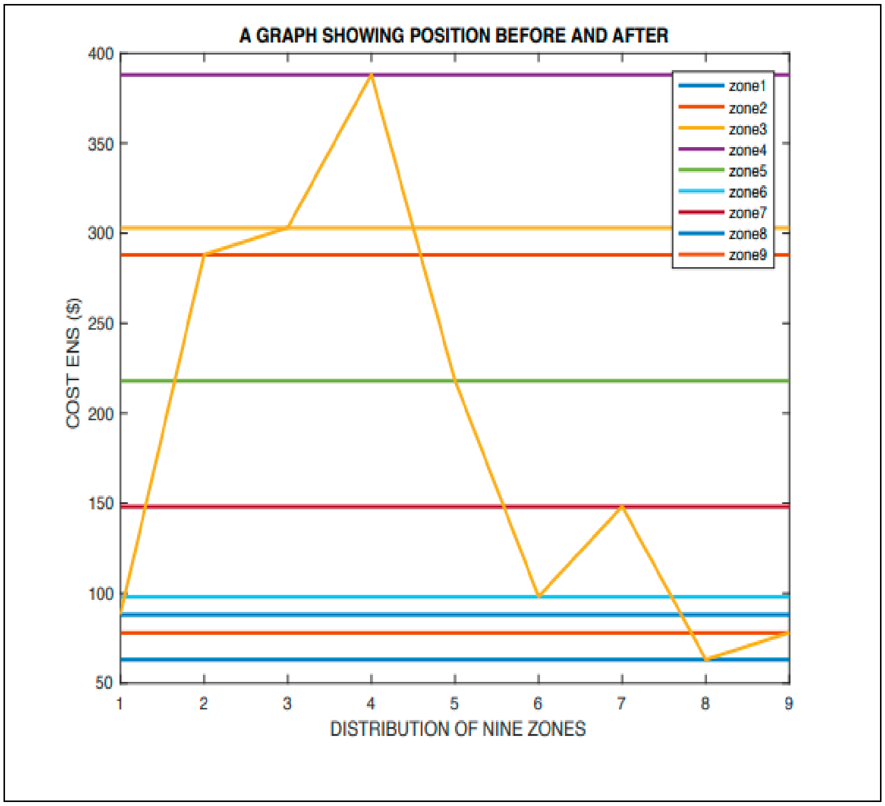


Figure 4.2: Profile of ENS Positions before and After Optimal reclosing

Figure 4.3 provides a realization that; minimization of energy not served during reclosing, was conducted throughout the nine zones of the radial line. The amounts of energy not served were predominant in zone 3, 4 and 5. These zones were equally having large amount of load ratings in terms of kVA values. Minimization of ENS as can be observed from Fig 4.3 can be used to select the best position of loading of radial line. From Table 4.2, loading for optimal placement indicated that 88 kVA, was the best for all sections of the 9 zones.

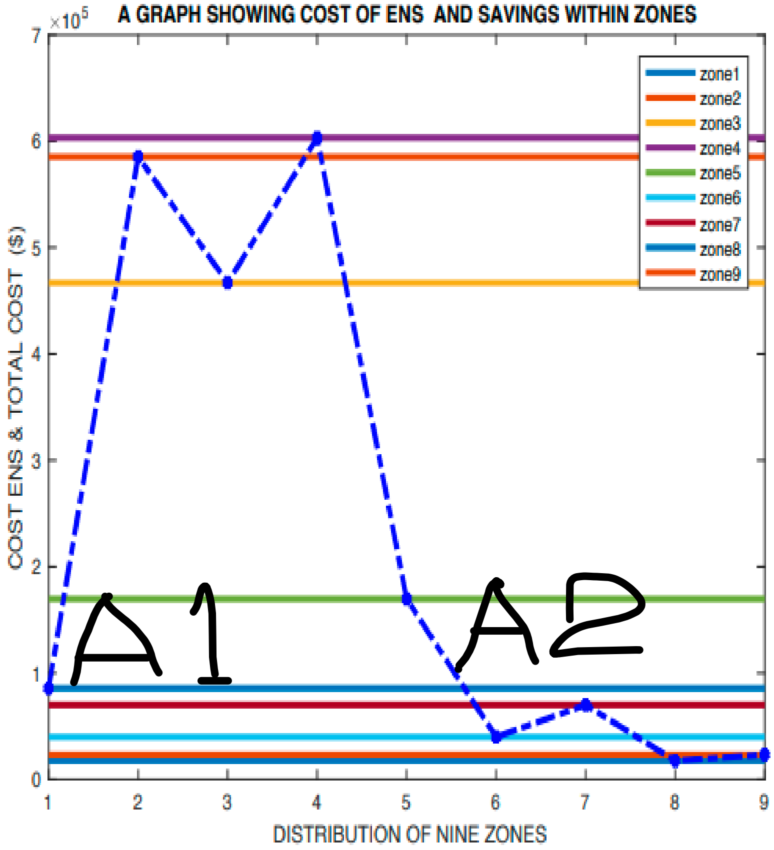


Figure 4. 3: Profile of Minimum Cost of Energies not supplied

### 4.3 Mean Savings of power losses

**Table 4.3: Mean Savings of costs for Recloser operation**

| **ZONES** | **TOTAL COST OF ENS VALUES ($) x $10^6$** | **MINIMUM ENS VALUES ($) x $10^6$** | |
|---|---|---|---|
| **1** | 2.061 | 2.061 | |
| **2** | 1.0 | 2.061 | |
| **3** | 2.061 | 2.061 | |
| **4** | 1.0 | 2.061 | |
| **5** | 2.061 | 2.061 | |
| **6** | 1.0 | 2.061 | |
| **7** | 1.0 | 2.061 | |
| **8** | 1.0 | 2.061 | |
| **9** | 1.0 | 2.061 | |
| | | | |
| | **Total cost of various energies not used in the re-closing process is Area 2** | **Reclosing minimum total cost of various energies not served is Area 1** | **Savings** |
| | Area 2 = 6.0 e+5*9 =5400000 | Area1=trapz(cost_ENS) | A 2 - A 1 |
| | 5.4 x $10^6$ | 2.061 x $10^6$ | 3.390e +06 |
| | | | [A 2 - A 1/A2] x 100 |
| | | | =61% |

In Table: 4.2 and 4.3 simulations generated types of data; amongst which are the total cost of energy not served together with the its minimum value. Minimization of the energy not served, similarly reduced total cost of energy. Reclosing integration with costs of energy supply, was to reduce the cost of energy not served.

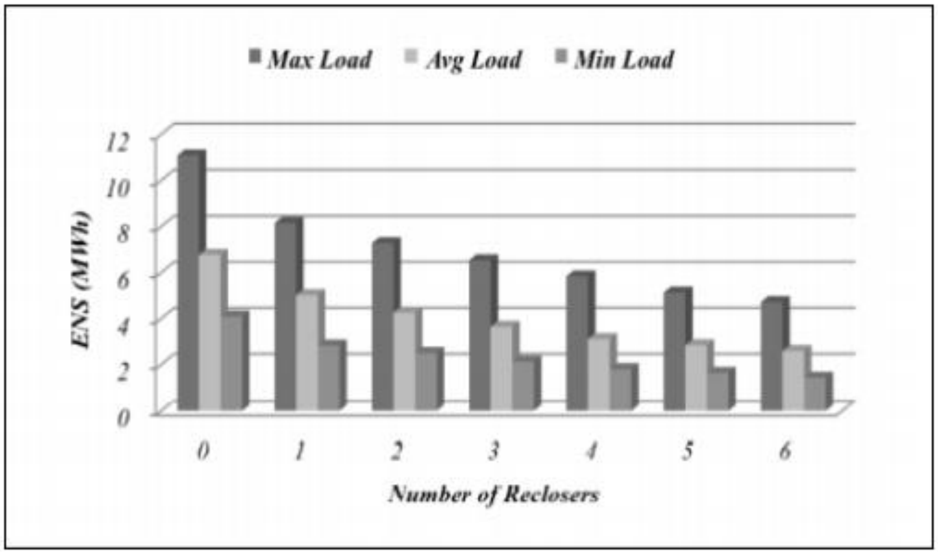
The Firefly algorithm was meant to perform energy cost minimization process, through optimal operation. The area of total energy losses during reclosing has been given by area A1 (this area is covered by the rectangle). The other area under consideration was area A2 (the area is covered by a trapezium). By minimizing area A2 increases area A1, which meant an increase of energy served or reducing outages.

What reclosers do is that, instead of having 100 interruption per year, you will likely have only 39. The two measurements in Table 4.3 observed for 64% power distributed to some of the areas in the distribution lines.

## 4.4 Validation of Results

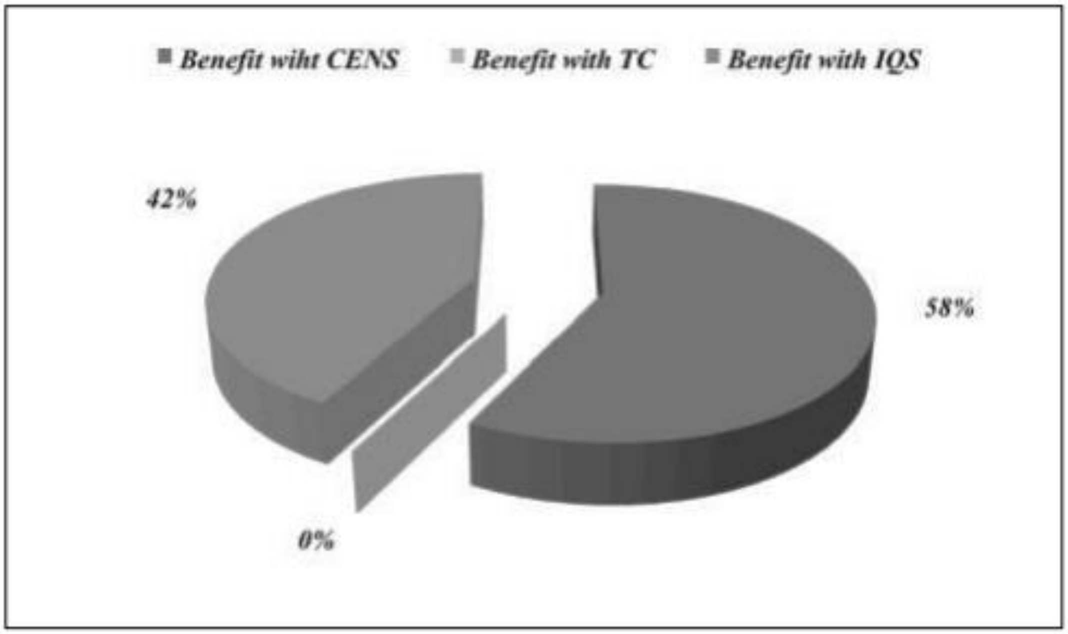
Fig 4.4 and 4.5 are collections of similar previous work [15][18]. The method was to evaluate economic paybacks of positioning reclosers; in overhead distribution network, permitting self-healing approaches.

The technical of valuation of facility restoration through network reconfiguration was based on cost benefit assessment (CBA). An actual distribution network defined the optima reclosers numbers required for reliability enhancement and total savings effectiveness. Figure 4.4 shows evolution of number of reclosers against the ENS (MWhr). The observation indicated that ENS decreased as reclosers numbers increased in the network. Figure 4.5 shows contribution for the total economic benefits achieved in the 1st year with the optimal solution.



**Source: doi: 10.1109/ENERGYCON.2016.7513983**

Figure 4.4 Recloser Versus Energies Saved



**Source: doi: 10.1109/ENERGYCON.2016.7513983**

Figure 4.5 Reclosers' Economic Benefits

### 4.5 How Overall Objective Was Achieved

The Overall objective of best reclosing was, to reduce the charge of energy not served; by managing  recloser optimal location while keeping the security of the sytem. These are the steps performed to meet this objective:

- Formulation of the problem was done.
- Objective function developed.
- Formulated problem was mapped to Firefly algorithm.
- MATLAB coding was performed based on the mapping above.

MATLAB simulation generated the values as shown:

- Unserved energy during reclosing.
- Reduced CENS.
- Best kVA values for optimum reclosing strategies.
- Total savings during optimum reclosing strategy.

### 4.6 In Conclusion

The aim was to see the effect of proposed power loss reduction in a radial system. From the tabular and graphical results, we conclude that the objectives were met. We have seen that as we increased optimisation of distribution of power, minimization of energy not served and costs were observed to reduce as expected.

Non- technical loss reduction studies are important for planning for future protection and expansion of power system at the distribution levels. From the findings, it is concluded that optimisation has both the positive and negative effects on the system.

Table 4.2. indicates that for the best operation of reclosing techniques, line loading should be equal in sizes for proper management of power losses. The best value of optimisation is 88 kVA. This value was observed only at Zone 1. This means optimal location of the recloser should be the one adjacent to the sub-station.

# CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusions

In this thesis, recloser placement framework for a radial distribution was one with line faults. The conventional recloser placement problem formulations were originally based on two tiers. First tier looked at minor areas of the feeder line and provided estimates for the SAIFI. The second-tier perfected location using simulation technique. This work on allocation strategy, analyzed the cost benefit effect on installing reclosers on the main feeder line based on CENS saving using simulation technique [19]. The hypothetical radial feeder employed was typical and assumed to have the following features:

a) Feeder had nine zones of which each had different transformer kVA ratings.

b) Time and place of fault was based on the distance between the substation and the customer

c) Reclosing was based on 3 shots timing.

Again, CENS was based on kVA protection technique, the evaluation of the problem and solution was primarily established using the above statements and eventually led to the following Cconclusions:

i) Reclosing the feeder has a comparable effect on cost. As you travel away from the substation, costs decrease, unless when maintenance and operating costs are lower than the next zone, as demonstrated in zones 8 and 9.

ii) CENS reductions can be realized by reducing the number of zoning zones to avoid multiple interruptions.

iii) Reclosers could be used instead of fuses and switches (the latter results in long time interruptions and an increase in CENS).

iv) Satisfactory recloser allocation and placement can be achieved with the firefly algorithm simulation and an optimal reclosing technique.

v) CENS savings were realized as planned. The gap between the lowest total cost or fees charged and the lowest CENS value was the most effective way to save money.

vi) Using this strategy for recloser placements will assist the company, as will boosting performance targets on their distribution networks.

vii) The percentage of energy saved can be increased to 39 percent. Customers will have access to sixty-one percent (61%) of real power as a result of this. This was conceivable due to a power outage that was not served; it was reduced to allow places that require constant power supply to remain unaffected.

vii) The business will benefit by using this method for recloser placements; on their distribution networks by improving the performance targets.

vii) The sum of energy savings can also be improved to be 39 percentage. This would mean, sixty-one percent (61%) of real power will be available to the customers. This had been possible because power outage and not served; had been minimized to enable areas which requires continuous power supply are not interrupted.

## 5.2 Recommendations.

Proposed FA with hard constraints such as non-radial network topology, can also be pursued in future. Applicability of FA can also be examined; using a different meta-heuristic or parameter tuning approach to improve on FA.

The future will need more energy from past years trends on demand today. In fact, every new technology in power systems may have to meet a challenge arising at that very time. Firefly algorithm has proved to be robust and fast in solving problems as compared to other available techniques. I then may recommend the following:

a) A more complicated network than the radial proposed in this work and compare on how much savings accrued

b) Firefly technique being very advanced in integrating and solving problems should be studied further in areas of cost analysis which is nightmare in power generation and distribution costing

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# APPENDIXA: MATLAB Code

**Firefly Algorithm Code for Reclosing Technique for Non-Technical Power Loss Reduction**

```
clear all;
clc;
tic;
%% EARLY INITIATION
alpha = 0.5; % parameter ()
betamin = 1.0; % parameter ()
gamma = 0.6; % parameter ()
firefly = 9;% firefly
it = 1; %Initial iteration%
iteration_max = 10; % iteration
%% RADIAL kVA RATINGS
D_Zonemin_max = [100 100;300 300;315 315;400 400; 230 230;160 160;110 110;75 75;90 90];
%%SYSTEM VECTORS INPUT VALUES
Downstream_Length_data = [5.6 7.4 10.4 13.2 16.7 19.9 22.5 24.5 26.1]';%i%gotten from the line current tension during fault  s%
Upstream_Length_data =[26.1 23.6 20.5 18.7 15.7 12.9 9.4 6.2 3.6]';
f=[26.1 24.5 22.5 19.9 16.7 13.2 10.4 7.4 5.6];
kVA=[100 300 315 400 230  110 160  75 90];
Demand_upstream=[100 300 315 400 230  110 160  75 90];
h=2;
u=[5.6 7.4 10.4 13.2 16.7 19.9 22.5 24.5 26.1];%gotten from the cummulative sum ofupsteam length
Fault_location_Time=  (u./(u+f))*h; % is obtained from the formula g1=x3*x1/x4
Line_switching_time_after_fault = Fault_location_Time+15;
Fault_clearing_time = Line_switching_time_after_fault+30;
```

```
% is obtained from the formula  0.0008*Downstream_Length_data%
Failure_rate_of_the_line =4*1./u'; %gotten from the inverse of downstream commulative sum
%[0.1888    0.3528    0.5000    0.6280    0.7296    0.8048    0.8544    0.8832    0.8960];%obtained
from 0.0008*Downstream_Length_data%
Maintenance_and_Investment_Cost =0.25.*kVA;% gotten from $0.25 *kVA or $0.25/kWh
%% DEVELOPING MATRICES FROM VECTOR INPUTS
A=[45.35;45.46;45.63;45.79;46;46.20;46.36;46.53;46.64];
B=[25 75 78 100 57 27 40 18 22];
C=[ 0.7143 0 0 0 0 0 0 0 0
    0 0.5405 0 0 0 0 0 0 0
    0 0 0.3846 0 0 0 0 0 0
    0 0 0 0.3030 0 0 0 0 0
    0 0 0 0 0.2395 0 0 0 0
    0 0 0 0 0 0.2110 0 0 0
    0 0 0 0 0 0 0.1778 0 0
    0 0 0 0 0 0 0 0.1633 0
    0 0 0 0 0 0 0 0 0.1533];
matrix_E=A*B*C;
G=kVA*matrix_E;
%INITIATE PARTICLE EARLY POSITION
for interval =1
for i = 1:9 % i = row 1 to 30
     for j = 1:firefly % j = columns 1 to 30 (number of firefly)
      starting_position(j,i)=(D_Zonemin_max(i,2)-
D_Zonemin_max(i,1))*rand+D_Zonemin_max(i,1);  %(i,2)=(rows,column)
     end

end
end
sum_p = sum ('starting_ position'); %  starting position in all totals
```

```
for K = 1:firefly
    if sum_p<1780
   corrector(K) = ((1780-sum_p)/9);
         starting_position(K,:) = starting_position (K,:)+corrector(K);
    elseif(sum_p>1780)% if the kVA initial position is more than 1780 MW then:
         corrector(K) = ((sum_p-1780)/9);
         starting_position(K,:) = (starting_position (K,:)-corrector(K));
         end
end
%% INITIATE POSITIONS OF FIREFLIES IN ZONES
 D_Zone1 = starting_position(:,1);   % power demand upstream_data1
 D_Zone2 = starting_position(:,2);   % power demand upstream_data1
 D_Zone3 = starting_position(:,3);   % power demand upstream_data1
 D_Zone4 = starting_position(:,4);   % power demand upstream_data1
 D_Zone5 = starting_position(:,5);   % power demand upstream_data1
 D_Zone6 = starting_position(:,6);   % power demand upstream_data1
 D_Zone7 = starting_position(:,7);   % power demand upstream_data1
 D_Zone8 = starting_position(:,8);   % power demand upstream_data1
 D_Zone9 = starting_position(:,9);   % power demand upstream_data1
 D_Zone  =[D_Zone1 D_Zone2 D_Zone3 D_Zone4 D_Zone5 D_Zone6 D_Zone7 D_Zone8
D_Zone9];
 Coeff_REC= Fault_clearing_time;

%% COSTING THE ENERGY NOT SERVED PER ZONE
 cost_ENS1 = matrix_E(9,1)*D_Zone1 + matrix_E(9,1)*D_Zone1*0.11+
matrix_E(9,1)*D_Zone1*0.06; % enters the formula
 cost_ENS2 = matrix_E(9,2)*D_Zone2 + matrix_E(9,1)*D_Zone2*0.11+
matrix_E(9,1)*D_Zone2*0.06;
 cost_ENS3 = matrix_E(9,3)*D_Zone3 + matrix_E(9,1)*D_Zone3*0.11+
matrix_E(9,1)*D_Zone3*0.06;
```

```
 cost_ENS4 = matrix_E(9,4)*D_Zone4 + matrix_E(9,1)*D_Zone4*0.11+
matrix_E(9,1)*D_Zone4*0.06; % enters the formula
 cost_ENS5 = matrix_E(9,5)*D_Zone5 + matrix_E(9,1)*D_Zone5*0.11+
matrix_E(9,1)*D_Zone5*0.06;
 cost_ENS6 = matrix_E(9,6)*D_Zone6 + matrix_E(9,1)*D_Zone6*0.11+
matrix_E(9,1)*D_Zone6*0.06;
 cost_ENS7 = matrix_E(9,7)*D_Zone7 + matrix_E(9,1)*D_Zone7*0.11+
matrix_E(9,1)*D_Zone7*0.06; % enters the formula
 cost_ENS8 = matrix_E(9,8)*D_Zone8 + matrix_E(9,1)*D_Zone8*0.11+
matrix_E(9,1)*D_Zone8*0.06;
 cost_ENS9 = matrix_E(9,9)*D_Zone9 + matrix_E(9,1)*D_Zone9*0.11+
matrix_E(9,1)*D_Zone9*0.06;
 cost_ENS  =
[cost_ENS1,cost_ENS2,cost_ENS3,cost_ENS4,cost_ENS5,cost_ENS6,cost_ENS7,cost_ENS8,cos
t_ENS9];
 total_cost = cost_ENS1 +cost_ENS2 +cost_ENS3 +cost_ENS4+cost_ENS5+cost_ENS6+...
     cost_ENS7+cost_ENS8+cost_ENS9;
inequal=[D_Zone1>100 D_Zone1<100 D_Zone2>300 D_Zone2<300 D_Zone3 >315
D_Zone3<315 D_Zone4 >400 D_Zone4<400 D_Zone5 >230 D_Zone5<230 D_Zone6>110
D_Zone6<110 D_Zone7>160 D_Zone7<160 D_Zone8>75 D_Zone8<75 D_Zone9>90
D_Zone9<90];
inequality = sum(inequal');
 clear j
   for j=1:firefly
      if inequality(j)>0
          total_cost(j)=100000000;
      end
  end
 [lambda, In] = min (total_cost); % minimum fee
  lightbest (it) = lambda;
```

```
  Position_best (1,:) = starting_position(In, :);
 clear j i
  position_firefly = starting_position;

for ikj=1:firefly  % Parameter Attractiveness flies : beta=exp(-gamma*r);%

for jkj=1:firefly
 r = sqrt (sum ((position_firefly (ikj,:) - position_firefly (jkj,:)).^ 2));
%% UPDATE THE MOVEMENT OF FIREFLIES
    if (total_cost (ikj)> total_cost (jkj))% Is brighter and attractive
          beta0 = 0.5;
             beta = (beta0) * exp (-gamma * r ^ 2);
             tmpf = alpha.* ((rand (1,1)) - 0.5);
 position_firefly(ikj,1) = position_firefly (ikj, 1).* (1-beta) + (position_firefly (jkj, 1).* beta) +
tmpf;
 position_firefly(ikj,2) = position_firefly (ikj, 2).* (1-beta) + (position_firefly (jkj, 2).* beta) +
tmpf;
 position_firefly(ikj,3) = position_firefly (ikj, 3).* (1-beta) + (position_firefly (jkj, 3).* beta) +
tmpf;
 position_firefly(ikj,4) = position_firefly (ikj, 4).* (1-beta) + (position_firefly (jkj, 4).* beta) +
tmpf;
 position_firefly(ikj,5) = position_firefly (ikj, 5).* (1-beta) + (position_firefly (jkj, 5).* beta) +
tmpf;
 position_firefly(ikj,6) = position_firefly (ikj, 6).* (1-beta) + (position_firefly (jkj, 6).* beta) +
tmpf;
 position_firefly(ikj,7) = position_firefly (ikj, 7).* (1-beta) + (position_firefly (jkj, 7).* beta) +
tmpf;
 position_firefly(ikj,8) = position_firefly (ikj, 8).* (1-beta) + (position_firefly (jkj, 8).* beta) +
tmpf;
 position_firefly(ikj,9) = position_firefly (ikj, 9).* (1-beta) + (position_firefly (jkj, 9).* beta) +
```

```
tmpf;
    end
end
end
while it <iteration_max
      it = it + 1;
end

%% REPOSITION FIRELIES
 D_Zone1 = position_firefly(:,1);   % power demand upstream_data1
 D_Zone2 = position_firefly(:,2);   % power demand upstream_data1
 D_Zone3 = position_firefly(:,3);   % power demand upstream_data1
 D_Zone4 = position_firefly(:,4);   % power demand upstream_data1
 D_Zone5 = position_firefly(:,5);   % power demand upstream_data1
 D_Zone6 = position_firefly(:,6);   % power demand upstream_data1
 D_Zone7 = position_firefly(:,7);   % power demand upstream_data1
 D_Zone8 = position_firefly(:,8);   % power demand upstream_data1
 D_Zone9 = position_firefly(:,9);   % power demand upstream_data1

 %% REPEAT THE COSTING OF ENERGY NOT SERVED
 cost_ENS1 = matrix_E(9,1)*D_Zone1 + matrix_E(9,1)*D_Zone1*0.11+
matrix_E(9,1)*D_Zone1*0.06; % enters the formula (C_r*??(g1g2g3g4g5g6 )
 cost_ENS2 = matrix_E(9,2)*D_Zone2 + matrix_E(9,1)*D_Zone2*0.11+
matrix_E(9,1)*D_Zone2*0.06;
 cost_ENS3 = matrix_E(9,3)*D_Zone3 + matrix_E(9,1)*D_Zone3*0.11+
matrix_E(9,1)*D_Zone3*0.06;
 cost_ENS4 = matrix_E(9,4)*D_Zone4 + matrix_E(9,1)*D_Zone4*0.11+
matrix_E(9,1)*D_Zone4*0.06;
 cost_ENS5 = matrix_E(9,5)*D_Zone5 + matrix_E(9,1)*D_Zone5*0.11+
matrix_E(9,1)*D_Zone5*0.06;
```

```
 cost_ENS6 = matrix_E(9,6)*D_Zone6 + matrix_E(9,1)*D_Zone6*0.11+
matrix_E(9,1)*D_Zone6*0.06;
 cost_ENS7 = matrix_E(9,7)*D_Zone7 + matrix_E(9,1)*D_Zone7*0.11+
matrix_E(9,1)*D_Zone7*0.06; % enters the formula
 cost_ENS8 = matrix_E(9,8)*D_Zone8 + matrix_E(9,1)*D_Zone8*0.11+
matrix_E(9,1)*D_Zone8*0.06;
 cost_ENS9 = matrix_E(9,9)*D_Zone9 + matrix_E(9,1)*D_Zone9*0.11+
matrix_E(9,1)*D_Zone9*0.06;
 total_cost = cost_ENS1 +cost_ENS2 +cost_ENS3+cost_ENS4+cost_ENS5+cost_ENS6+...
     cost_ENS7+cost_ENS8+cost_ENS9; %
    s=total_cost;
    v=min(s);
 inequal=[D_Zone1>100 D_Zone1<100 D_Zone2>300 D_Zone2<300 D_Zone3 >315
D_Zone3<315 D_Zone4 >400 D_Zone4<400 D_Zone5 >230 D_Zone5<230 D_Zone6>110
D_Zone6<110 D_Zone7>160 D_Zone7<160 D_Zone8>75 D_Zone8<75 D_Zone9>90
D_Zone9<90];
 clear j
   for j=1:firefly
      if inequality(j)>0
          total_cost(j)=1000000000;
      end
  end
 [lambda, In] = min(total_cost); % minimum fee
 lightbest (it) = lambda;
 Position_best (1,:) = position_firefly (In);

 clear j i
  before = position_firefly;
for ikj = 1:firefly
% Firefly Attractiveness Parameters: beta = exp (-gamma * r)
```

```
for jkj = 1:firefly
            r = sqrt (sum ((position_firefly (ikj,:) - position_firefly (jkj,:)).^ 2));
%% UPDATE THE MOVEMENT OF FIREFLIES
   if total_cost (ikj)> total_cost (jkj)% Is brighter and more attractive
              beta0 = 0.5;
              beta = (beta0) * exp(-gamma*r^ 2);
              tmpf = alpha.* ((rand(1,1))- 0.5);
%xn (ikj,:) = xn (ikj,:).* (1-beta) + nso (jkj,:).* beta + tmpf;
 position_firefly(ikj,1) = position_firefly (ikj, 1).* (1-beta) + (position_firefly (jkj, 1).* beta) +
tmpf;
 position_firefly(ikj,2) = position_firefly (ikj, 2).* (1-beta) + (position_firefly (jkj, 2).* beta) +
tmpf;
 position_firefly(ikj,3) = position_firefly (ikj, 3).* (1-beta) + (position_firefly (jkj, 3).* beta) +
tmpf;
 position_firefly(ikj,4) = position_firefly (ikj, 4).* (1-beta) + (position_firefly (jkj, 4).* beta) +
tmpf;
 position_firefly(ikj,5) = position_firefly (ikj, 5).* (1-beta) + (position_firefly (jkj, 5).* beta) +
tmpf;
 position_firefly(ikj,6) = position_firefly (ikj, 6).* (1-beta) + (position_firefly (jkj, 6).* beta) +
tmpf;
 position_firefly(ikj,7) = position_firefly (ikj, 7).* (1-beta) + (position_firefly (jkj, 7).* beta) +
tmpf;
 position_firefly(ikj,8) = position_firefly (ikj, 8).* (1-beta) + (position_firefly (jkj, 8).* beta) +
tmpf;
 position_firefly(ikj,9) = position_firefly (ikj, 9).* (1-beta) + (position_firefly (jkj, 9).* beta) +
tmpf;
   end
end
end
%% FIND THE LAST POSITIONS OF THE FIREFLIES
```

```
after= position_firefly(ikj,:);
  it;

%% PLOT THE BEST POSITION
plot(lightbest)
after;
toc;
%polar(cost_ENS)
%xlabel('DOWNSTREAM FIREFLY POSITION');
%ylabel('COST OF ENERGY NOT SERVED ($)');
%title('COST OF ENERGY NOT SERVED DOWNSTREAM ');
%legend('Zone1','Zone2','Zone3','Zone4','Zone5','Zone6','Zone7','Zone8','Zone9')
%q=smooth(lightbest);
%k=smooth(q);
%w=smooth(k);
%e=smooth(w);
%plot(e,'LineWidth',3)
%xlabel(' POSITION MOVEMENTS BY FIREFLY');
%ylabel('DEMAND DOWNSTREAM VALUES GENERATED  ');
%title(' A LINE  GRAPH  SHOWING DEMAND DOWNSTREAM WITH FIREFLY
MOVEMENT ')
%grid on
%xlabel(' DEMAND UPSTREAM (kVA)');
%ylabel(' COST OF ENERGY SERVED UPSTREAM ($)');
%title(' COST OF ENERGY NOT SERVED WITH INCREASE OF DEMAND UPSTREAM')
 %polar(lightbest)
%q=smooth(ES_Zone);
%plot(REC_TIME,ES_Zone,'k','LineWidth',3)
%area(q')
%xlabel(' TIME-EQUIVALENT TO DEADTIME OF RECLOSER (Sec)');
```

```
%ylabel('ENERGY SERVED (kWs)');
%title('NORMAL ENERGY SERVED WITHOUT TRRANSIENTS')
%%
%startingf=smooth(lightbest);
%plot(lightbest,'LineWidth',3)
%xlabel('NUMBER OF ITERATIONS');
%ylabel('COST($)');
%title('CONVERGENCE CURVE')
%%
%plot(min(cost_ENS))
%hold on
%bar(min(total_cost))
%colormap([1 0 0; 0 0 1]); %
%hold off
%xlabel('RADIAL LINE-COST OF ENERGY NOT SERVED');
%ylabel('COST OF (TOTAL) and  min(ENS)($)');
%title('COST OF ENERGY NOT SERVED AND TOTAL COST CHARGED')
%legend('min ENS','min TOTAL COST')

%grid on    min ENS
+
0.1,
0,
'Critical
n
%%
%ENS_zone=[483 1670 1220 469 1357 1990 1324 1171 322];
%grid on
%plot(cost_ENS,'LineWidth',3);
%xlabel('DOWNSTREAM DISTANCE FIREFLY POSITION');
```

```
%ylabel('COST OF ENERGY NOT SERVED PER ZONE($)');
%title('COST OF ENERGY NOT SERVED DOWNSTREAM ');
%legend('Zone1','Zone2','Zone3','Zone4','Zone5','Zone6','Zone7','Zone8','Zone9')
%loglog(lightbest,'LineWidth',2);
%semilogy(lightbest,'LineWidth',3);
%c=smooth(lightbest);
%k=smooth(c);
%l=smooth(k);
%plot(l,'LineWidth',3)
%xlabel('Number of Iterations');
%ylabel('GLOBAL FITNESS VALUE');
%title( 'Cost of energy not serve "convergence curve"')
%histogram(Demand_upstream)
%area(cost_ENS,'LineWidth',2)
%xlabel('ENERGY DOWNSTREAM');
%ylabel('COST OF ENERGY');
%title('GRAPH SHOWING COST OF ENERGY NOT SERVED DURING TRANSIENTS');
%bar(cost_ENS9,'LineWidth',1)
 %hold on
%bar(cost_ENS8,'LineWidth',1)
%hold off
%xlabel('FIREFLIES SEARCH');
%ylabel('ENERGY NOT SERVED DURING SWITCHING OPERATION ');
%title('ENERGY NOT SUPPLIED IN THREE SHOTS OF RECLOSING')
%legend('zone1','zone2','zone3','zone4','zone5','zone6','zone7','zone8','zone9')
%contourf(starting_position)
%xlabel('No of Fireflies');
%ylabel('starting positions');
%title('A GRAPH SHOWING FIREFLY MOVEMENTS TOWARDS OPTIMAL VALUE')
%%
```

```
%plot(Fault_location_Time,'LineWidth',2)
%hold on
%plot(Line_switching_time_after_fault,'LineWidth',2)
%hold on
%plot(Fault_clearing_time,'LineWidth',2)
%hold off
%xlabel('FEEDER ZONES');
%ylabel('TIME (sec)');
%title('A GRAPH SHOWING RECLOSING TIME')
%legend('Fault clearing time','Line switching time','Fault location time')
%%
%surf(cost_ENS)
%surf( D_Zone)
%xlabel('ZONES ');
%ylabel('FIREFLIES MOVEMENTS');
%zlabel('COST($)')
%title('SURFACE PLOT SHOWING COST OF ENERGY SUPPLIED WITHIN
NODES','FontSize', 12)
%legend('Zone9','Zone8','Zone7','Zone6','Zone5','Zone4','Zone3','Zone2','Zone1')
%hold on
%plot(Maintenance_and_Investment_Cost)
%hold of'
%stairs(u,'LineWidth',2)
%xlabel('FEEDER ZONES');
%ylabel('FEEDER LENGTH(km)');
%title('A GRAPH SHOWING STAIRCASE COMMULATIVE LENGTH FEEDER
DOWNSTREAM ')
%legend()
%figure
%area('LineWidth',2)
```

```
%xlabel('ZONES');
%ylabel('TIME (s)');
%title('A GRAPH SHOWING FAULT CLEARING TIME')
%legend('Zone1','Zone2','Zone3','Zone4','Zone5','Zone6','Zone7','Zone8','Zone9')
%area(total_cost)
%xlabel('FIREFLY OPTIMISATION');
%ylabel('TOTAL COST ($)');
%title('A GRAPH SHOWING TOTAL COST MINIMISATION')
%legend('Zone1','Zone2','Zone3','Zone4','Zone5','Zone6','Zone7','Zone8','Zone9')
% on
%plot(cost_ENS,'LineWidth',3)
%hold on
%plot(min(cost_ENS),'*-.b','LineWidth',3)
%hold off
%xlabel('DISTRIBUTION OF NINE ZONES');
%ylabel(' COST ENS & TOTAL COST  ($)');
%title('A GRAPH SHOWING COST OF ENS  AND SAVINGS WITHIN ZONES')
%legend('zone1','zone2','zone3','zone4','zone5','zone6','zone7','zone8','zone9')
%plot(min(cost_ENS))
%hold on
%plot(cost_ENS1)
%hold on
%plot(cost_ENS2)
%hold on
%plot(cost_ENS3)
%hold on
%plot(cost_ENS4)
%hold on
%plot(cost_ENS5)
%hold on
```

```
%plot(cost_ENS6)
%%hold on
%plot(cost_ENS7)
%hold on
%plot(cost_ENS8)
%hold on
%plot(cost_ENS9)
%hold off
%plot3(D_Zone1,cost_ENS1,total_cost,'k','LineWidth',0.5)
%hold on
%plot3(D_Zone9,cost_ENS9,total_cost,'m','LineWidth',0.5)
%hold off
%xlabel('Radial line Demand Distributed values');
%ylabel('Cost ENS($)');
%zlabel('Total Cost')
%title('Distrubuted "Power Demand","cost(ENS)","Total Energy Cost"','FontSize', 14')
%set (gca, 'FontSmoothing', 'off')
%legend('node1','node2','node3','node4','node5','node6','node7','node8','node9')
%legend('Recloser1','Recloser9')
%X = [6.6713;5.1339;3.6186;2.8776;2.2647;1.9166;1.6547;1.5407;1.4621];
%labels={'ENS1','ENS2','ENS3','ENS4','ENS5','ENS6','ENS7','ENS8','ENS9'};
%pie(X,labels)
%title('COST OF ENERGY NOT SERVED PER ZONALS')
%
%x = [83385,621062,489978,630008,161588,29283,57095,10500,146798];
%p = pie(x);
%pText = findobj(p,'Type','text');
%percentValues = get(pText,'String');
%txt = {'ENS1:';'ENS2:';'ENS3:';'ENS4:';'ENS5:';'ENS6:';'ENS7:';'ENS8:';'ENS9:'};
%combinedtxt = strcat(txt,percentValues);
```

```
%pText(1).String = combinedtxt(1);
%pText(2).String = combinedtxt(2);
%pText(3).String = combinedtxt(3);
%pText(4).String = combinedtxt(4);
%pText(5).String = combinedtxt(5);
%pText(6).String = combinedtxt(6);
%pText(7).String = combinedtxt(7);
%pText(8).String = combinedtxt(8);
%pText(9).String = combinedtxt(9);
%set (gca, 'FontSmoothing', 'off')
% X= 1:3;
%labels = {'Taxes','Expenses','Profit'};
%pie(X,labels)
```

# APPENDIX B: Publication

2020 IEEE PES/IAS Power Africa

# Non-Technical Power Loss Reduction and Transients Stability: Optimal Placement of Reclosers

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***Abstract*---Rarely do power distribution system, nowadays operates without a novel protection device to manage transients caused by electricity theft. Reliability requirements had been previously the subject, considered by researchers using reclosers to manage transients. However, Non-technical power loss and its cost reduction has not been sufficiently addressed to enhance high quality power supply. Consequently, consumers have always paid more on system losses. To safeguard on this menace, optimal reclosing, ENS.COST, firefly algorithm based has been discussed in this work. The results and analysis of proposed method had a forty three percent (43%) cost reduction on energy not served (ENS) during transient. Radial distribution system employed to analyze this can be replaced by a closed network for further work together with another novel optimization method other than Firefly algorithm for validation.**

***Index Terms*---Loss Reduction; Non-Technical; Optimal Placement; Recloser; Stability Transients**

## I. INTRODUCTION

### A. Research Background

Notably, power consumers and Industries struggle with frequent power failures [1]. Reviewed work showed that numerous power consumers suffer the loss, particularly developing countries such as Kenya. Similarly, republic of Congo had experienced massive losses on its distribution system and this had been due to lack of metering facilities, theft and fraud acts by non-genuine consumers among others [1]-[2]. Basically, power system stability has always proved to be very expensive, if not well managed and controlled. In power distribution system with limited information on transients, adaptive reclosing strategy was employed to restore system stability [3]. Basing on such experiences, a modern microprocessor-based relay and recloser controls was used to record oscillator performance of distribution line during faults [4]. This was meant to enable operators know the real cause of fault and then design fuse saving scheme and high-speed sensitivity at the expense of securing the system during inrush. Another development employed a multi-objective for the combination of "electricity levels" and "reliability in communication channels" and formulations to optimally place reclosers using genetic algorithm GA [5]. The former objective was on investment costs of recloser as latter was for reliability. Other works came up with a modelled MATLAB-SIMULINK simulation using the principle of adaptive reclosing technique (ART) [3]. A solid-state power controller (SSPC) to replace conventional electromechanical circuit breaker in power distribution was modeled to distribute power and protect it against various loads effects [6]. This technique had the following merits: Improved stabilized transients; the implementation of reclosing scheme was more advanced than the traditional; Web based implementation was possible due to less mathematical calculations. Ordinarily, a flow chart with Monte Carlo convergence was developed to randomly manage the faults [7]. Hitherto, the operation of recloser and settings depended on historical data of transients [7]-[8]. The model was capable of offering (kVA *t) energy held on the line caused by instantaneous faults. Drastic measures showed that, four ways of placement of reclosers for optimal operation can be developed [12]. This work categorized methods applied as follows: Ant colony algorithm, Enhanced network Genetic algorithm without dominated sorting, sectionalized schemes with network loop automation, and CENS-cost of anergy not served savings at the power point.

### B. Contributions

This research enhanced ability of recloser reaction time and provided optimal location. The study realized controlled power distribution system, accomplishing balance amid transient deficiencies. There was a realization of energy saving during recloser operation.

### C. Paper Organization

This paper is organized into a number of sub-topics including; research background, literature review, problem statement and formulation, research methodology, results, results analysis and conclusions/recommendation.

## II. LITERATURE REVIEW

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### A. *Review of Related Work*

Ahmed R Adly, et al. (2017) [3], significantly presented a transient stability enhancement by employing adaptive recloser technique. The modeled method eventually decreased oscillations of the system under study. This method could only work within some limited information and the authors predicted its practicability for real power system. The advantages of this method were: enhanced transient stability and adaptive controller that could automate reclosing strategy. This was meant to reduce fluctuations in generator load angle and zero down to the exact reclosing time.

Renaldo Strydom et al. (2019)[12], highlighted four ways of placement of reclosers for optimal operation. In his work he categorized methods applied as follows: Ant colony algorithm, Enhanced network Genetic algorithm without dominated sorting, sectionalized schemes with network loop automation, and CENS-cost of anergy not seved savingsat the power point. However the aurthors on recloser placement in relation to transients were missed out.

Wei Liu et al. (2006) [13] modeled solid-state power controller (SSPC) to replace conventional electromechanical circuit breaker in power distribution. The system was able to distribute power and protect it against various loads. The model was capable of offering current squared time protection ($I^2t$) caused by instantaneous faults. However, his work did not employ artificial intelligence to solve the problem.

not employ artificial intelligence to solve the problem.

### B. *Theoretical Background*

In this situation, to prevent the damage to three-phase loads, it was desirable to use a recloser with single- phase tripping and three phase lockouts. Whereas enhancing loops schemes would require replacing one feeder with two parallel ones to increase reliability. Adapting feeder design: altering feeder paths and cross-section would increase feeder impedance and lower voltage sag. Overcurrent protection would be adopted easily by adopting the first five actions. Faults that normally occur along the power lines were classified as temporary or permanent. The former type could self-clear and power interruption would be restored at least in one to four times and the latter would require line crew work.

## III. PROBLEM STATEMENT AND FORMULATION

No doubt, electrical power supply has become a necessity in every sector of economy together with domestic use. Eventually new connections are increasing progressively and will not be able to stop any time soon especially in developing countries. Meantime, more alarming state of power supply is the cause of frequent power failures that culminates to interruption of industrial processes and power supply to domestic use. Research on the causes have shed light on electricity theft which had become a menace because of short circuit transients it causes to the distribution lines. According to research conducted [1], as power consumers increased, new installation emerged and power theft also increased in a similar magnitude. In the recent time non-technical power loss reduction and related research work are stagnant only on improving the reliability concept of power supply and quality. More power producers may opt to close their supply to vulnerable areas with frequent power theft cases. Following this, Kenya Power and Lighting Company (KPLC) brought down their transformers in Kibera area due illegal connections, according to Kenya News Agency (KNA) 24th August, 2019. In this research work, specifically, the study conducted, looked at the non-technical loss reduction techniques and employed the reclosing cycle model (RCM) applicable to transient condition to formulate the problem. An Artificial intelligent technique (Firefly Algorithm) correspondingly, was employed to provide Optimal reclosing to minimize the power loss cost.

The problem formulation is based on [7]

$$W_{ENS} = \text{Min}\,[\sum_{\mathrm{r}=1}^{\mathrm{n}} \mathrm{P_r}\,\mathrm{T_r}\mathrm{C_r}] \tag{1}$$

Where $W_{ENS} = Energy\ not\ served$, $\mathrm{P_r}$, $\mathrm{T_r}$and $\mathrm{C_r}$ are utility power, power recovery time and energy cost for load in that order, r = recovery time during brief failure. The total electricity consumption for a given distribution system in a given power outage is given in (2). In the protection of power-system equipment, $kVA$ value is sometimes defined as let-through energy.

$$E_h = \sum_{i=1}^{9} kVA_i * t_r = P * t \tag{2}$$

Where $\mathrm{E_h}$ = Un-served Energy in kWA, P = power supplied by the system at time $t_r$ in seconds of the recloser operation and r = recovery time. Using reclosing philosophy of (3)

$$ENS = kVA * t_1 + 0.11kVA * t_2 + 0.06kVA * t_3 \tag{3}$$

where, I = Fault current, $t_{1,}t_2\ and\ t_3$= reclosing times at various intervals.

This study seeks to minimize the overall objective function for cost savings formulated in (4)

$$Min\ f(x) = d_i t_1 + 0.11 d_i t_2 + 0.06 d_i t_3 \tag{4}$$

$$\text{Where } d_i = D_j F_k L_m R(t) C C_r \tag{5}$$

The overall objective is subject to the following constraints:

$$0.5 \le t_r \le 45.9;$$
$$75 \le D_j \le 400;$$
$$0 \le F_k \le 1;$$
$$\mathrm{R(t)} \ge R_0;$$
$$\mathrm{ENSmin} \le \mathrm{ENS} \le \mathrm{ENSmax}$$

Where *CENS* = Cost of Energy not served due to reclosing to protect feeder line and electricity apparatus,
$\mathrm{D_i}$ = Demand upstream up to 9-zones, $F_k$=Failure rate per line length, Lm=line length downstream, $t_r$= Reclosing time for three shots to clear Fault, *C*=costs of a recloser (including

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maintenance and operation) over the whole review Period, $C_r$ = Energy outage cost per kW. R(t) =Failure rates
Therefore, Savings on Energy not supplied was based on the location of radial network considered the following equation. Setting vector parameters: time, distance, current and power and equate them as: $x_1$= Standard sensing time per km in seconds as given in recloser settings, $x_2$ = Line length downstream of i km, $x_3$ = Line length Upstream in kilometers.
Fault sensing time per km along the feeder =2seconds/km
Note 15 and 30 seconds are waiting time for faults to clear.

$$x_2 = \sum_{i=1}^{9} \boldsymbol{L_i} \tag{6}$$

$$x_3 = \sum_{i=1}^{9} \boldsymbol{L_j} \tag{7}$$

$$L_i = 5.6 ,7.4, 10.4, 13.2 ,16.7, 19.9, 22.5 ,24.5 ,26.1 \tag{8}$$

$$L_j = 26.1, 25.4.22.5 ,19.9 .16.7 ,13.2, 10.4, 7.4 ,5.6 \tag{9}$$

If $g_1$ = Fault location time and $x_1$=2 sec/km fault detection time per km along the feeder. Switching time for the feeder is given by:

$$g_1 = \frac{x_2}{x_2 + x_3} x_1 \tag{10}$$

Switching time for the feeder line after fault is given by

$$g_2 = g_1 + 15s \tag{11}$$

Fault clearing time of the feeder is given by:

$$g_3 = g_2 + 30s \tag{12}$$

Energy not supplied due to outage based on demand is given by:

$$g_4 = \sum_{i=1}^{9} 1.17 g_1 D_i \tag{13}$$

Energy outage cost per kW is given by:

$$C_r = \$ \frac{1}{kVA} \tag{1}$$

Failure rate of the Zonal line per kVA

$$g_5 = 0.008D \tag{11}$$

D = demand downstream
Operational and Maintenance expense of the protective device is given by:

$$g_6 = \$ \frac{0.008}{kWA} \tag{13}$$

Savings on the cost of Energy not used in given as

$$\text{CENS} = \min\left(C_r * \sum (g_1 g_2 g_3 g_4 g_5 g_6)\right) \tag{14}$$

Subject to Constraints:
$0.5 \le x_1 \le 45$: $80 \le D \le 1800$;$0 \le g_5 \le 1$ and $1 \le x_3 \le 26$

## IV. METHODOLOGY

Along with problem formulation, the planned Firefly algorithm is employed to minimize energy not supplied during reclosing operation as in (2). The objective of the methodology is to limit the blackout cost that comes about due to recloser mitigation process [9]. Ideal setting of a recloser includes parameters with arbitrary nature, such as, faulted area and fault type (transient or permanent). To reclose vulnerabilities, the firefly technique, a computational calculation depended on rehearsed irregular examination to acquire numerical outcomes that are utilized in the planned strategy [13].

### *A. Pseudo code for classical firefly (FA) algorithm*

```
The code for FA is as follows:
Step 1: Initiate algorithm
Step 2: Develop initial population using equation $X_{j,i} = X_{j,i}^{L} + rand\ (X_{j,i}^{U} + X_{j,i}^{L})$
(where j = 1,2...n, i=1,2...N and N is the number of decision variables)
Step 3: Calculate objective function $f(X), X = (x_1, \dots x_N)^T$
Step 4: Define parameters for the algorithm (γ - light absorption coefficient, α - randomization parameter and β - attractiveness)
While (Iter < max_Iteration)
for j=1: n all n firefly
for k=1: j all n firefly
Light intensity $I_a$ at $x_a$ is decided by f ($x_a$)
if (Ia < Ib)
Step 5: Shift firefly a towards the direction of firefly b (shift towards brighter one)
Attractiveness varies according to distance $d_{a,b}$ via exp [-$\gamma d_{a,b}^2$]
Step 6: Create and calculate new solutions and update light intensity
end for k loop
end for j loop
Step 7: Put limits for equality and inequality constraints violations
Step 8: Rate the fireflies, and find the best currently available
end while
Step 9: Post results
Step 10: Display the highest light intensity firefly among all the fireflies, which is the optimum solution
Step 11: Plot the light intensity versus time/iterations
Step 12: end of algorithm
```

### B. *Optimal reclosing Flow Chart [7]*

Apparently, optimal reclosing flow chart of Fig.1 was used to develop an algorithm to place reclosers along the feeder. The solution procedure: assigned the initial values for the firefly algorithm, followed by setting limits and uploading data for the system. Finally, tuning and running of the algorithm is done to generate output values. The output is responses to the feeder radial system during transient fault. The algorithm was meant to automate the whole system during fault condition. Energy not served was generated as the system iterates to mitigate the disturbance. The optimized algorithm had the ability to perform the simulation with the intention to reduce the expense of reclosing. The tuned algorithm at the end of the process will give the amount of the total cost or expense (fees) alongside the CENS values. The difference between the fees charged at the actual CENS was the actual savings required

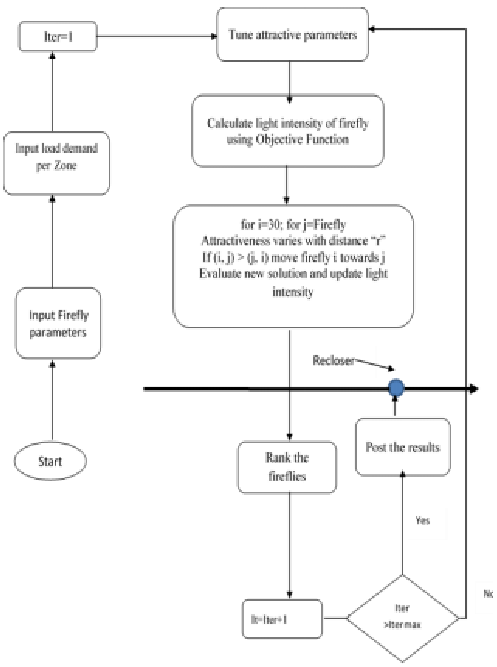

Fig. Optimal reclosing Flow Chart

## V. RESULTS

Following the results generated, as illustrated in Table I, input values are in every column. These inputs are found in the radial network of the power system. Zones were separated by different distances between them. Larger span of the a given zone is taken to have less reliability. Fault location time depended on the distance of the zone from the upstream reclosers and that also determines time at which the fault can be cleared. Slightly more time is taken to clear furthest zone such as zone9. In Table I , CENS in zone 8 is less than zone 9 because zone8 has kVA*t and maintenance and operation cost being lower in the network system making saving low.

Table I: Summary results

| Zone | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|
| **kVA** | 100 | 300 | 315 | 400 | 230 | 110 | 160 | 75 | 90 | |
| **Distance Downstream** | 5.6 | 7.4 | 10.4 | 13.2 | 16.7 | 19.9 | 22.5 | 24.5 | 26.1 | |
| **Failure Rate (Reliability Level)** | 0.7143 | 0.54 | 0.384 | 0.303 | 0.239 | 0.201 | 0.177 | 0.163 | 0.153 | |
| **Maintenance and Operation Cost ($)** | 25.0 | 75.0 | 78.75 | 100.0 | 57.0 | 27.0 | 40.0 | 18.7 | 22.5 | |
| **Fault Location Time** | 0.1767 | 0.2209 | 0.2849 | 0.3359 | 0.3902 | 0.4326 | 0.4630 | 0.4842 | 0.5000 | |
| **Fault Clearing Time** | 45.1767 | 45.2209 | 45.2849 | 45.2849 | 45.3902 | 45.4326 | 45.4630 | 45.4842 | 45.5000 | |
| **Min (CENS ($)** | **234137** | **189518** | **125643** | **104778** | **81795** | **71376** | **59786** | **52307** | **54746** | **822339** |
| | | | | | | | | | **Min (Cost) ($)** | **1451400** |
| | | | | | | | | | **Savings ($)** | **629061 =43.3%** |

### A. *Savings for cost of energy not served*

Table I illustrates CENS in the downstream**,** where an optimized re-closer upstream automatically acts on fault based (kVA *t) as a protection scheme expressed in equation (2) [12]. The transients are cleared within first or second shot while in permanent fault; line is closed during the third shot. Fig.3 depicts the demand of energy upstream and their cost during the transient. The simulation provides the downstream cost of energy not served (CENS). The downstream shows a lower cost compared to upstream during transient. This agrees with the fact that the upstream loads have higher values of power being transferred per zone. Non-technical power loss reduction is discussed here as adding up all losses which are not technical in nature. Formulating non-technical power loss could only be tackled using equations derived from the energy not served during power failures. Based on the past experiences and major causes of power failures, transients such as power line tapings by humans and interruptions by animals were considered. Savings of this energy loss was the major concern.

Substation recloser reaction time during faults upstream from this analysis provides a greater power loss savings during transients than reclosers downstream

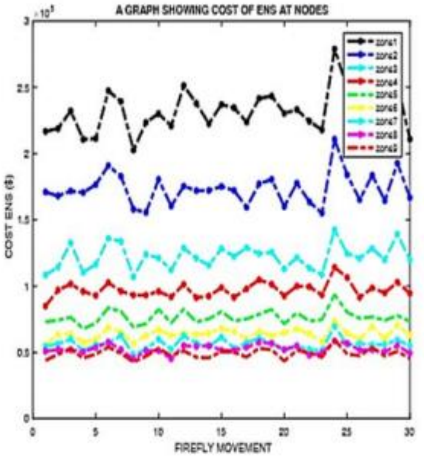

Fig 3: Cost of energy not served

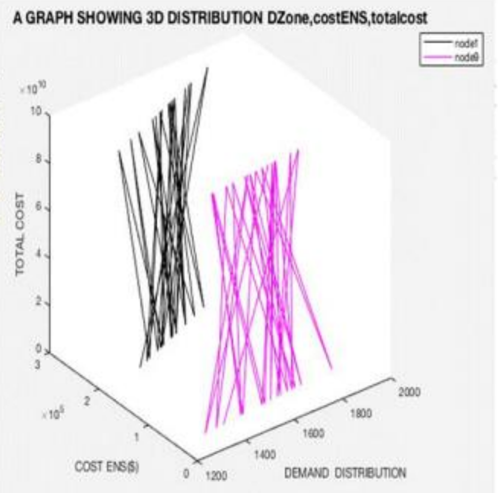

Fig. 4: Distribution of Recloser Optimisation

## VI. CONCLUSION

In the final analysis, recloser had similar effect on cost along the feeder and costs were reducing as you move away from the substation. CENS savings can be achieved when the number of zoning is minimized to avoid numerous interruptions. Reclosers would be useful in place of switches and fuses of which the latter leads to long time interruptions and increased CENS Recloser allocation and placement can be achieved satisfactorily through optimal reclosing technique with firefly algorithm simulation. CENS saving was achieved as it was projected. The difference between minimum total cost or fees charged and minimum CENS value was best measure for saving required.

Recloser optimization using FA with hard constraints such as non-radial network topology can be pursued in future. Applicability of FA in cost savings for ENS can be examined using a different meta-heuristic or parameter tuning approach to improve on FA in future

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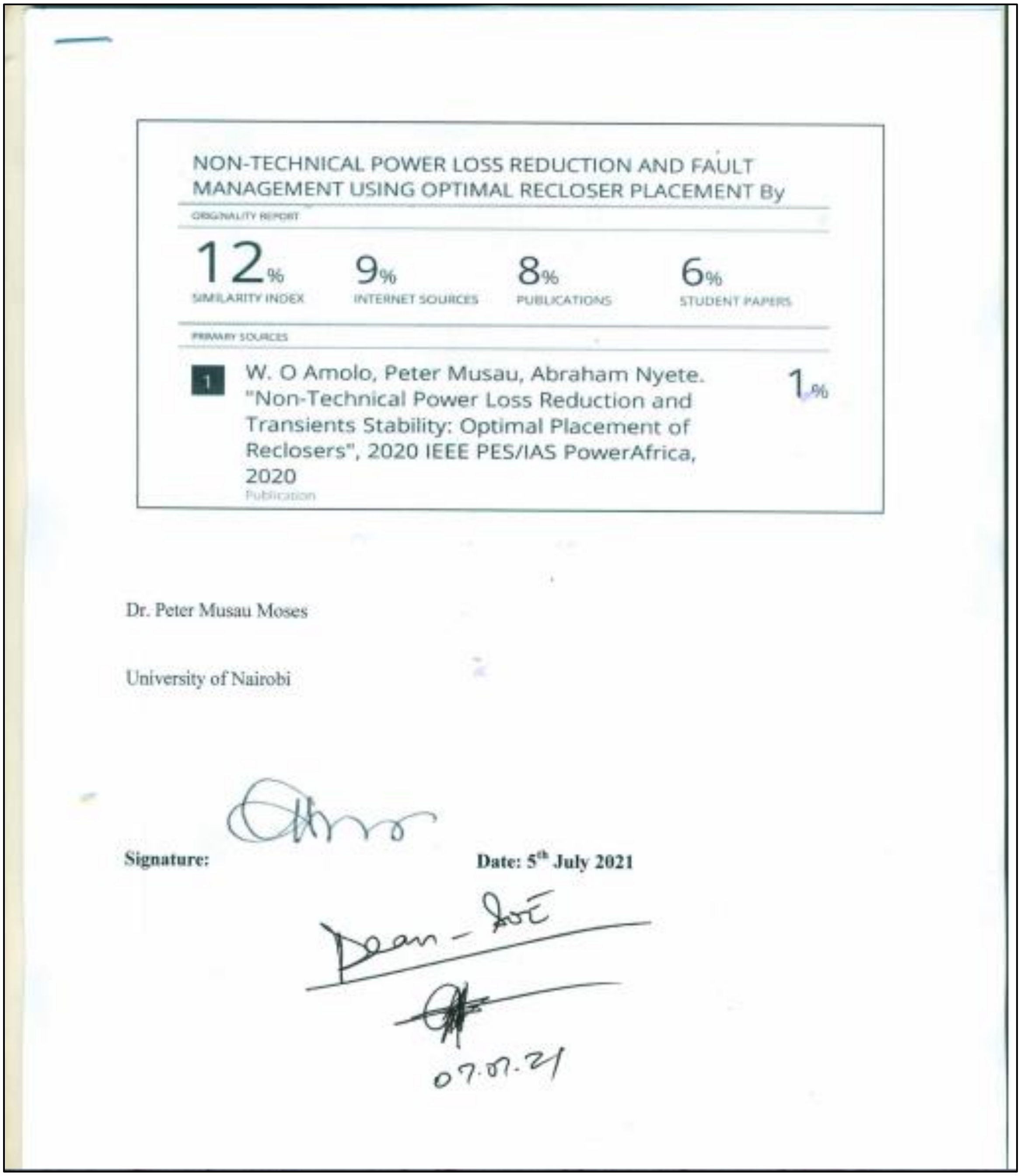

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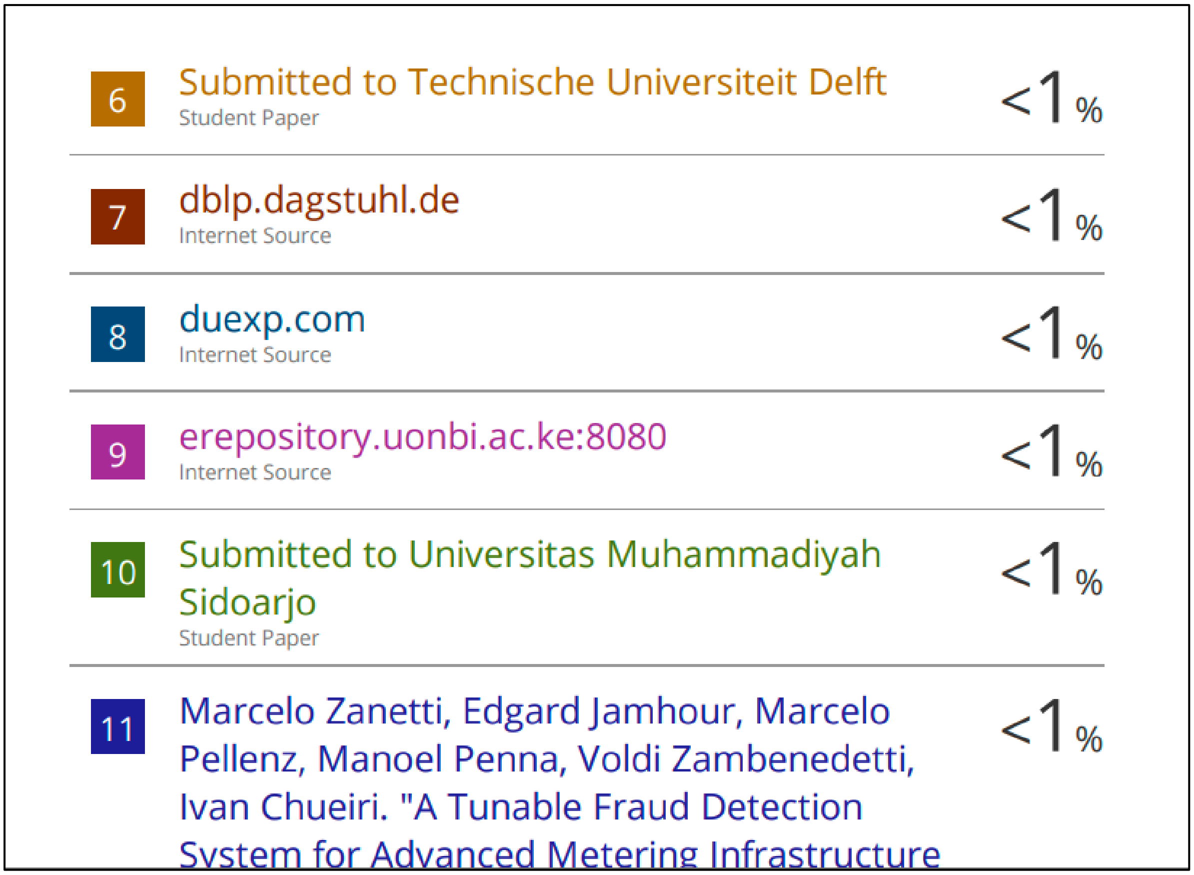

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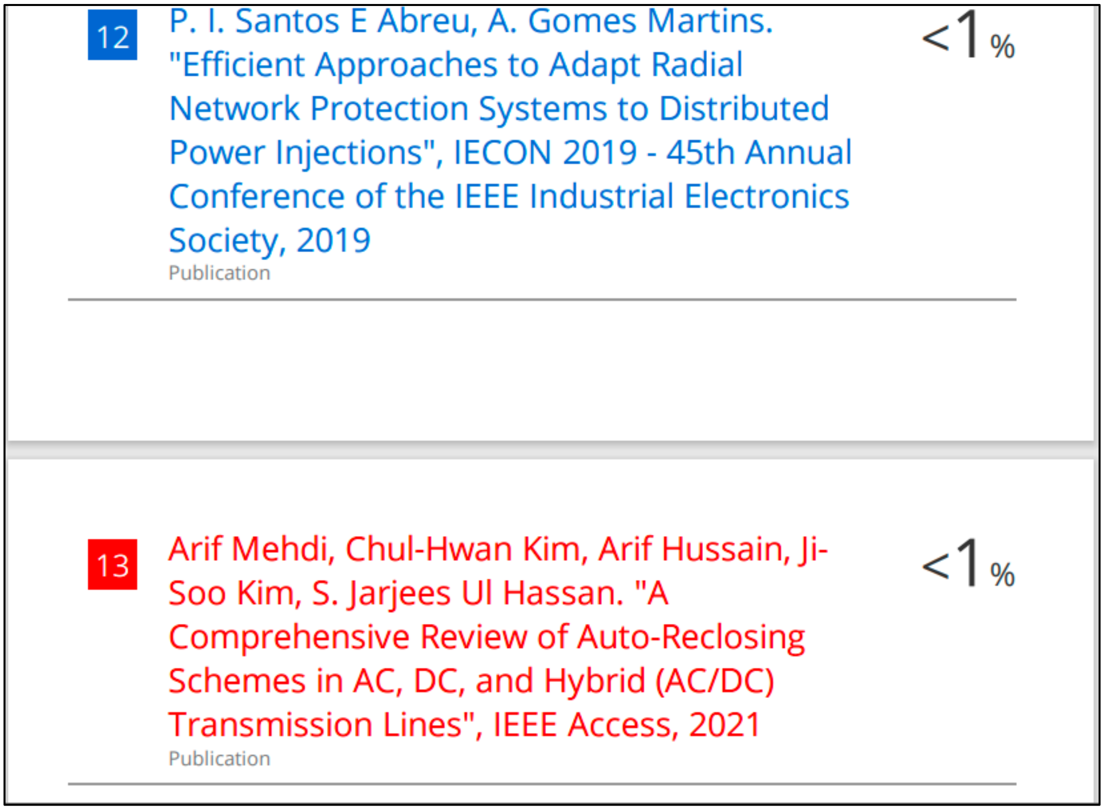

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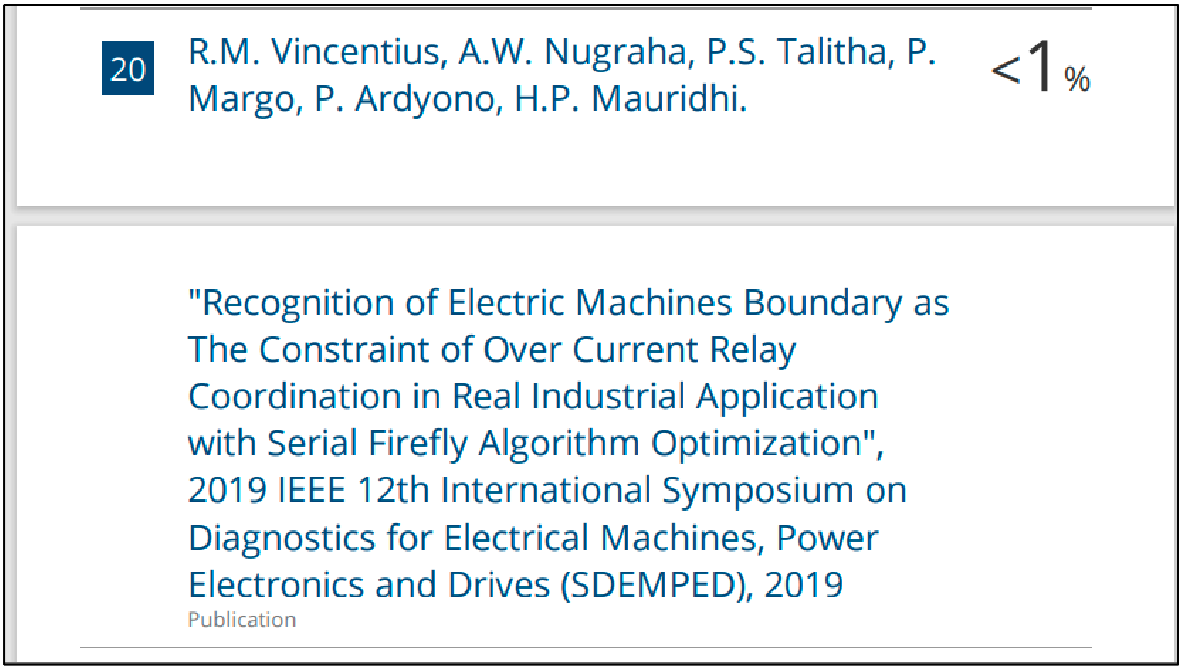

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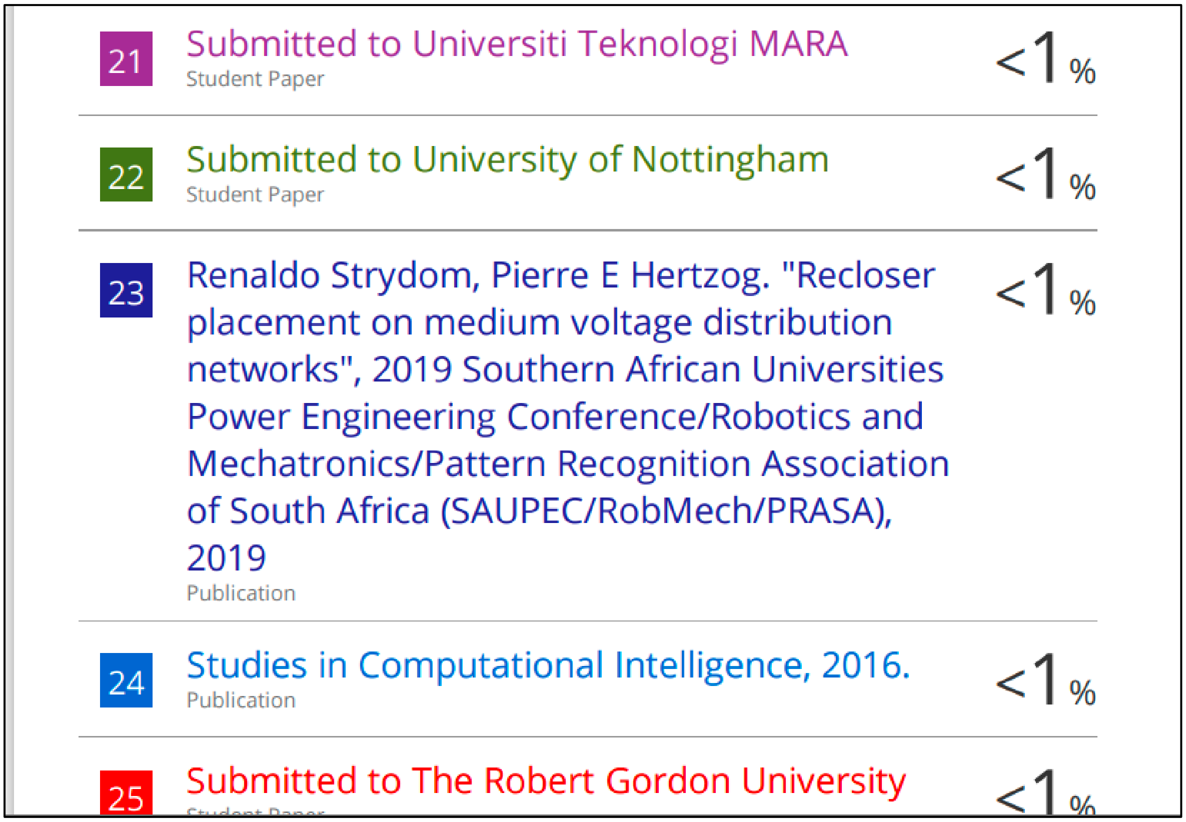

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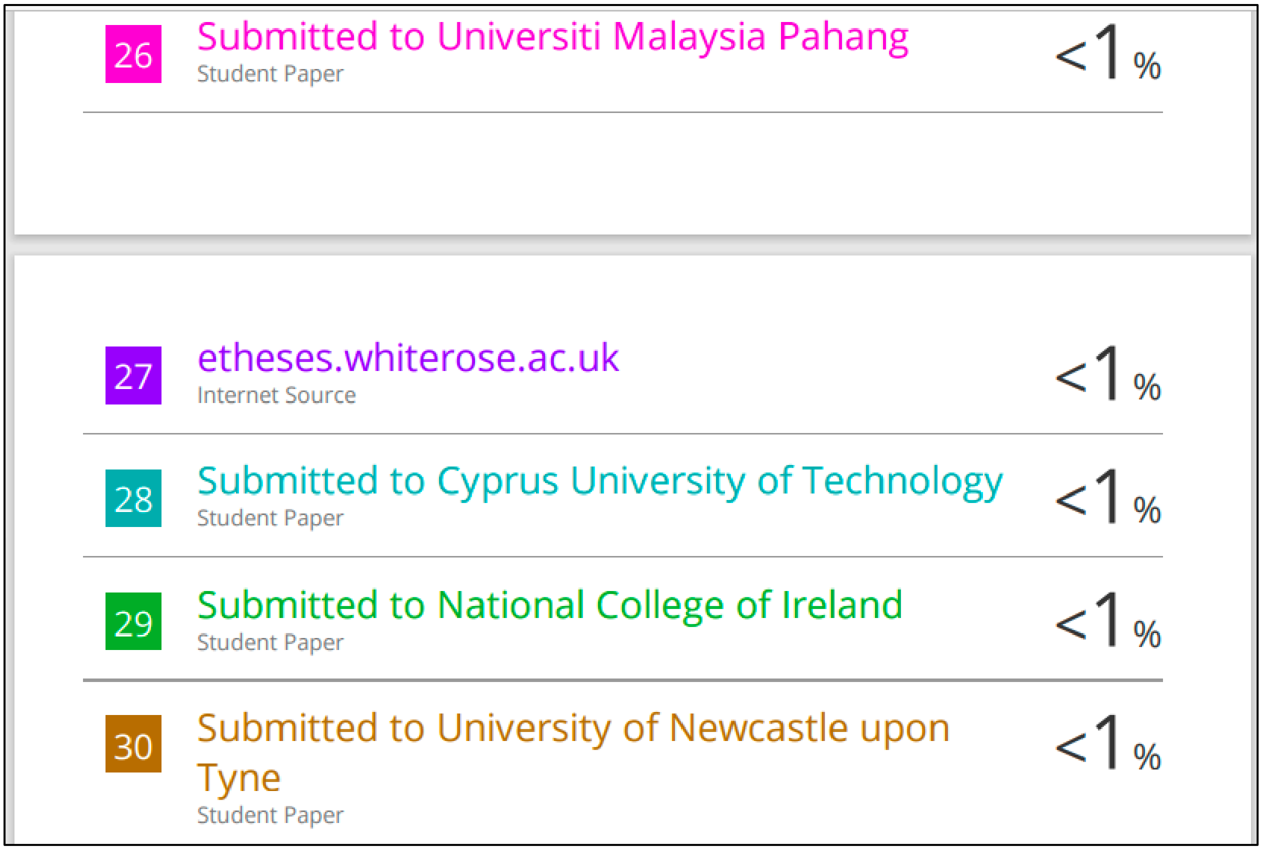

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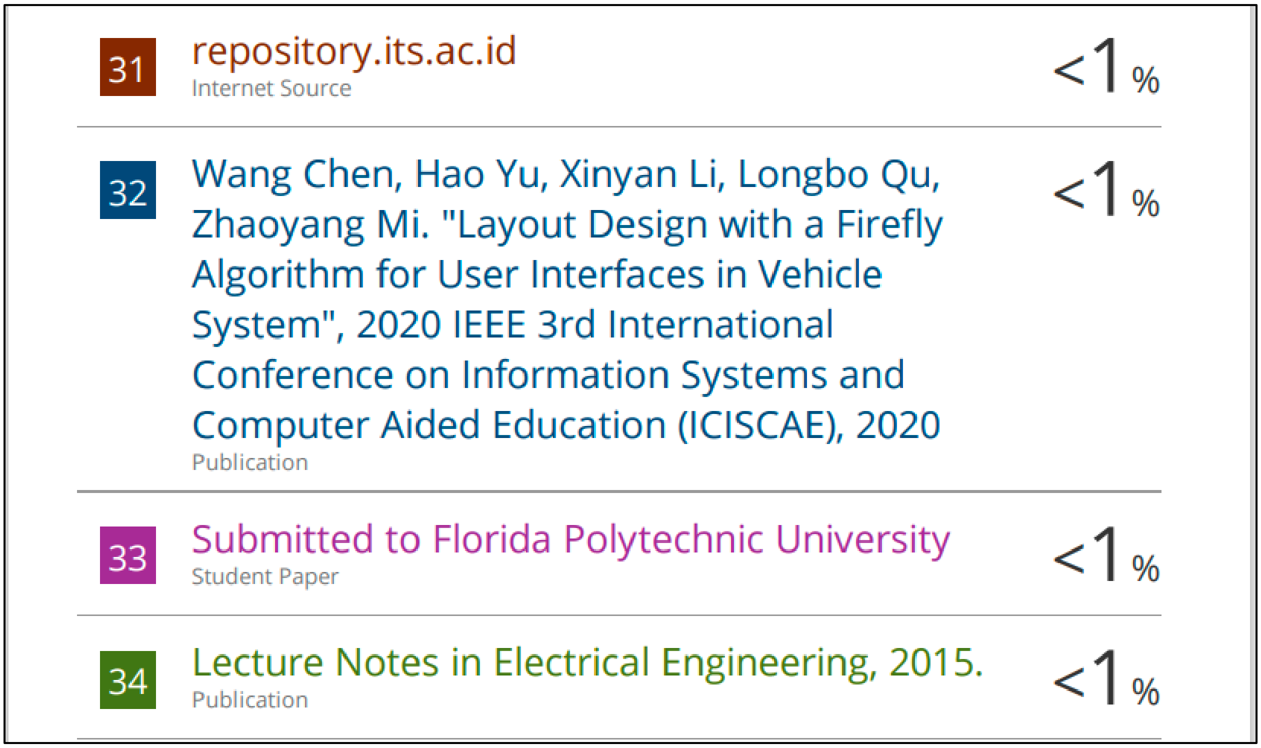

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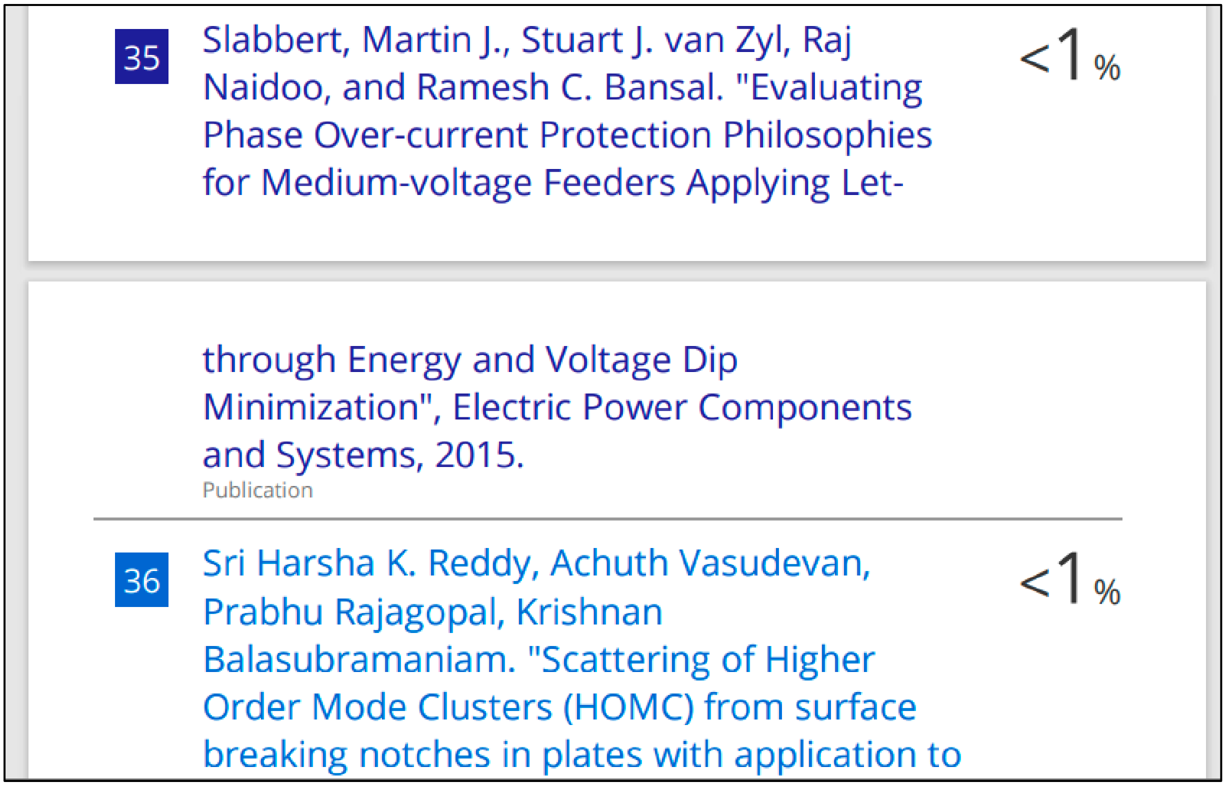

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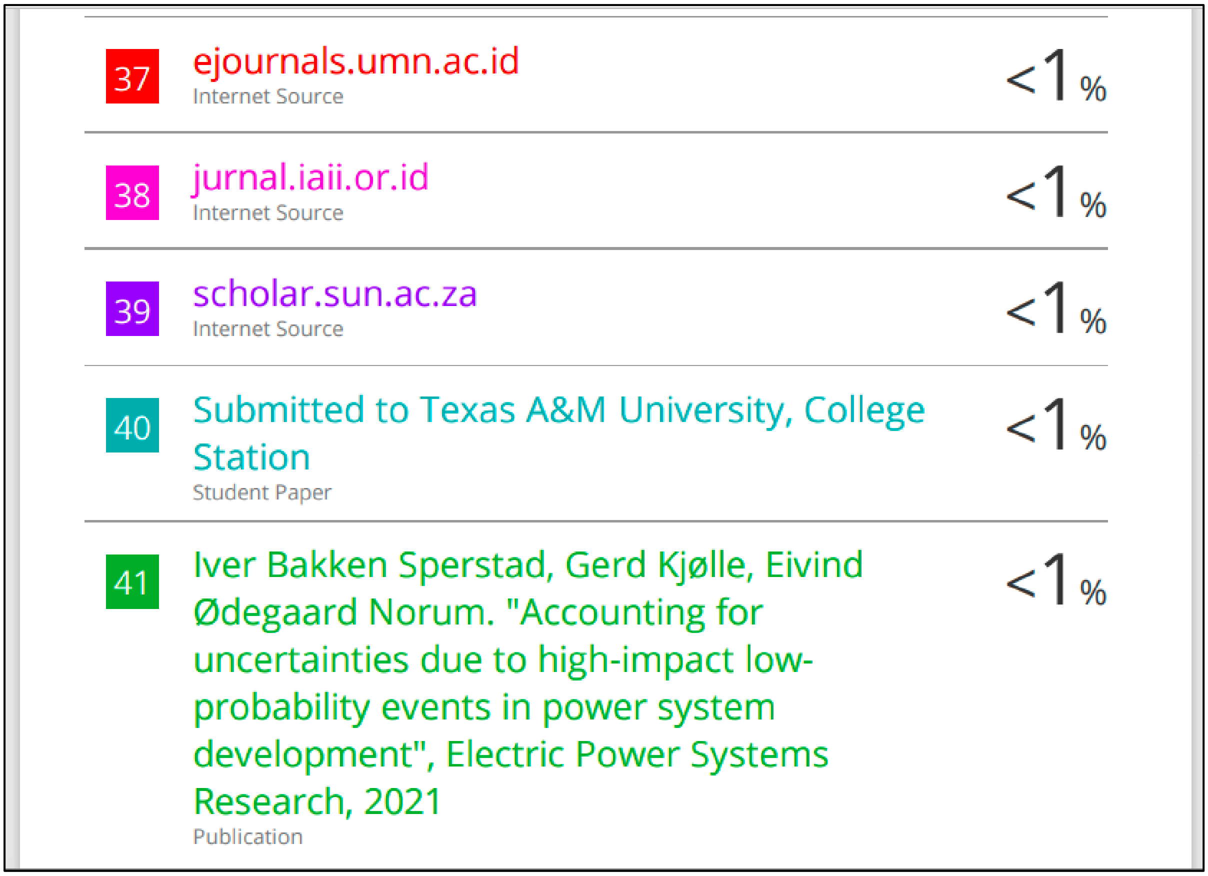

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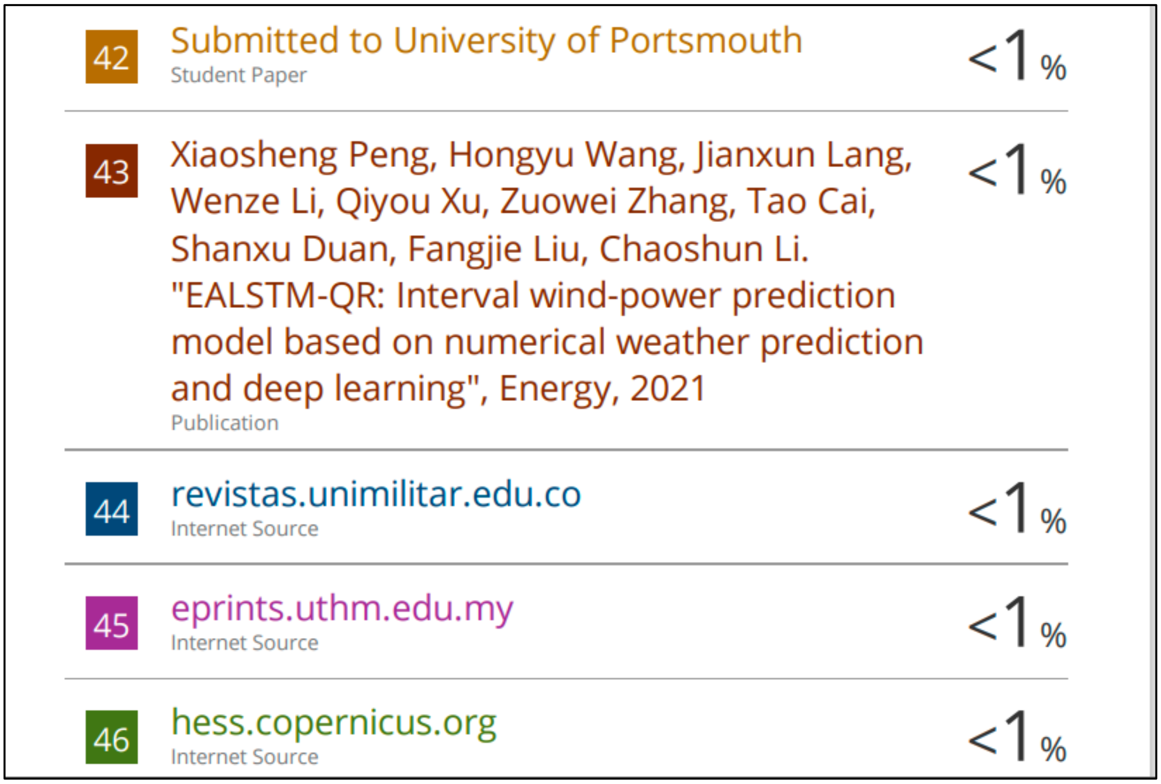

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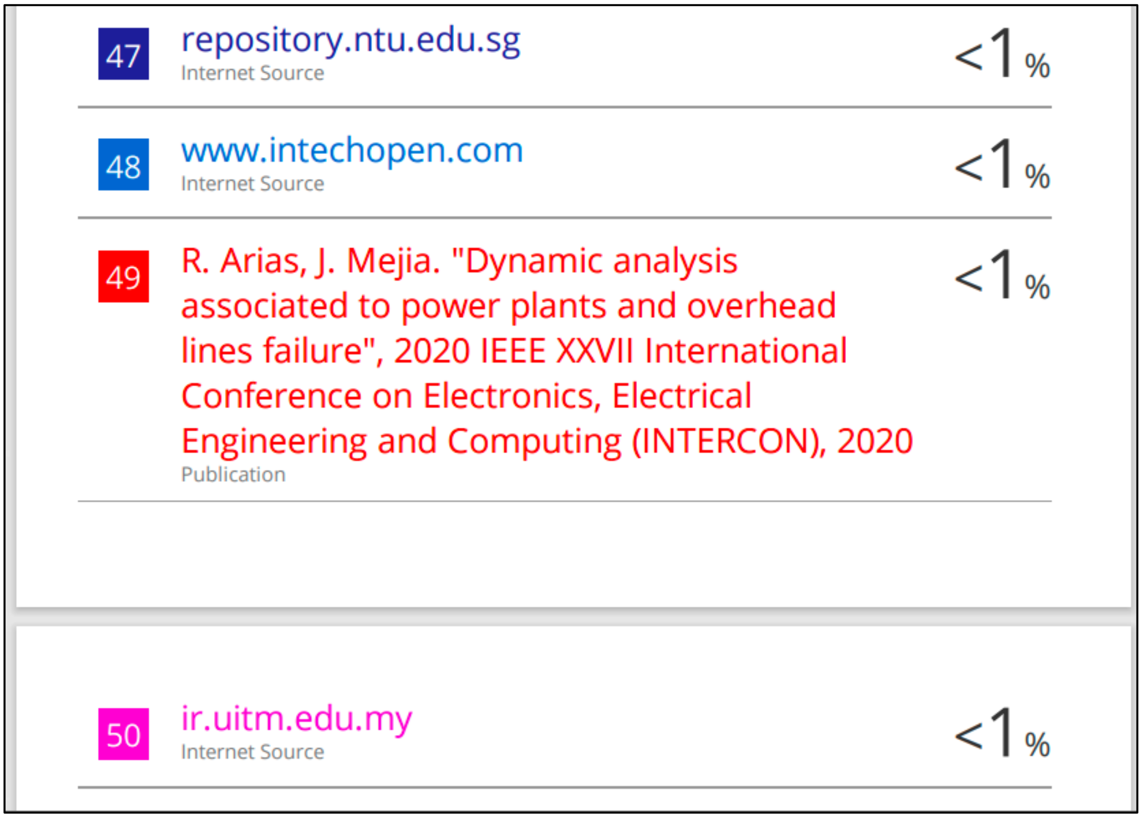

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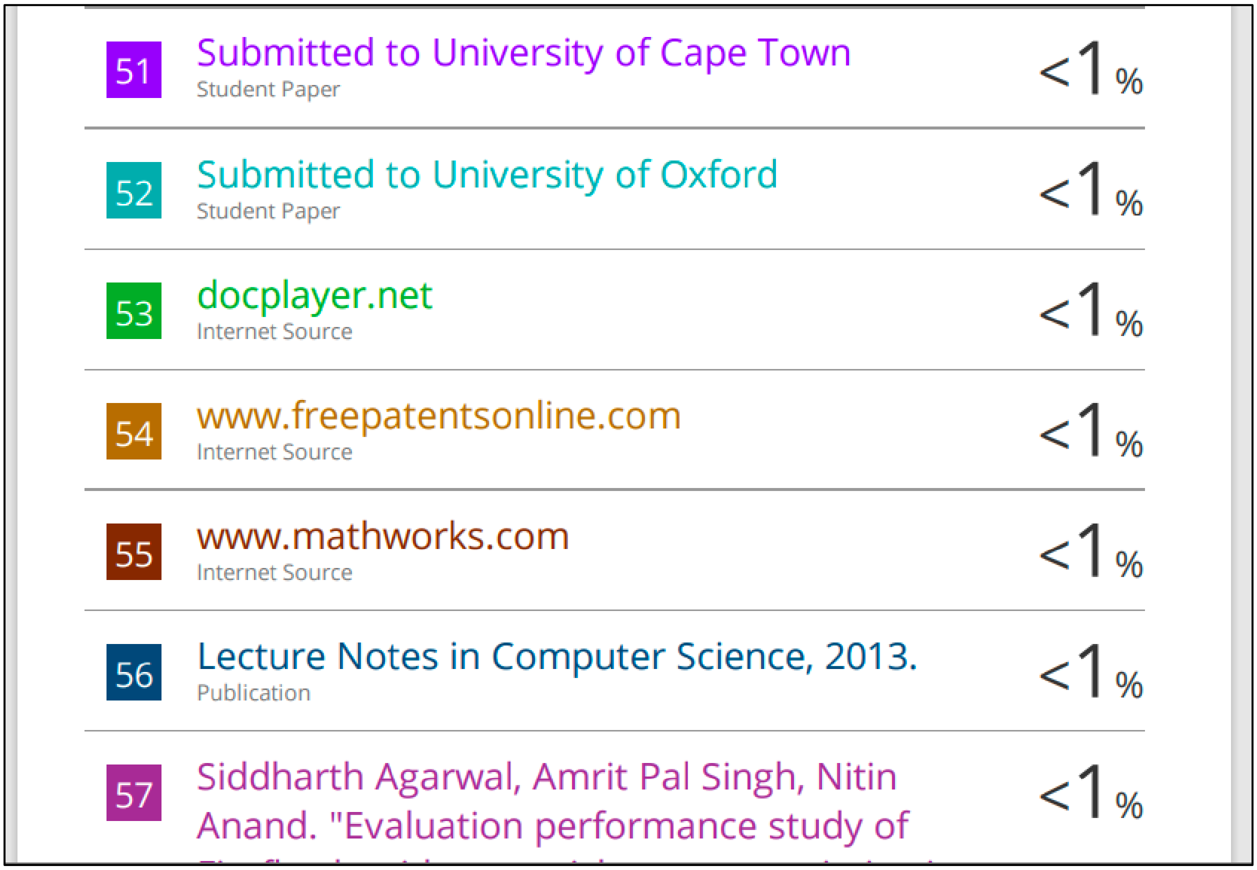

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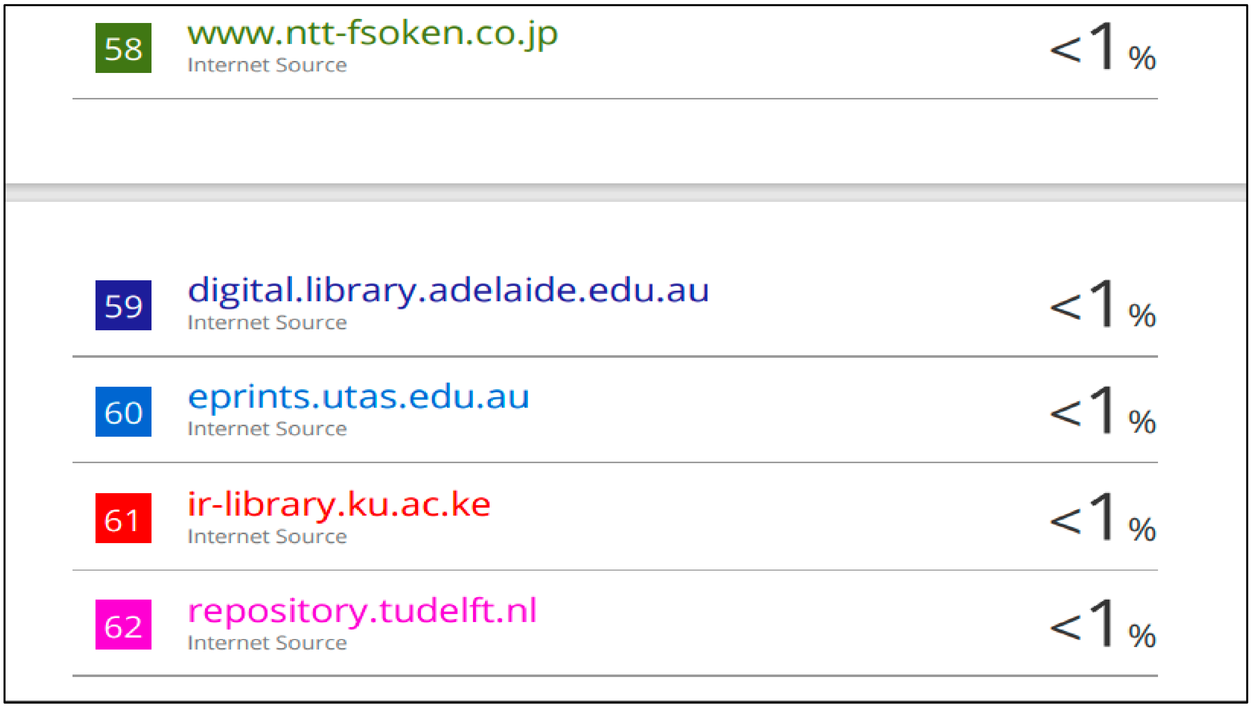

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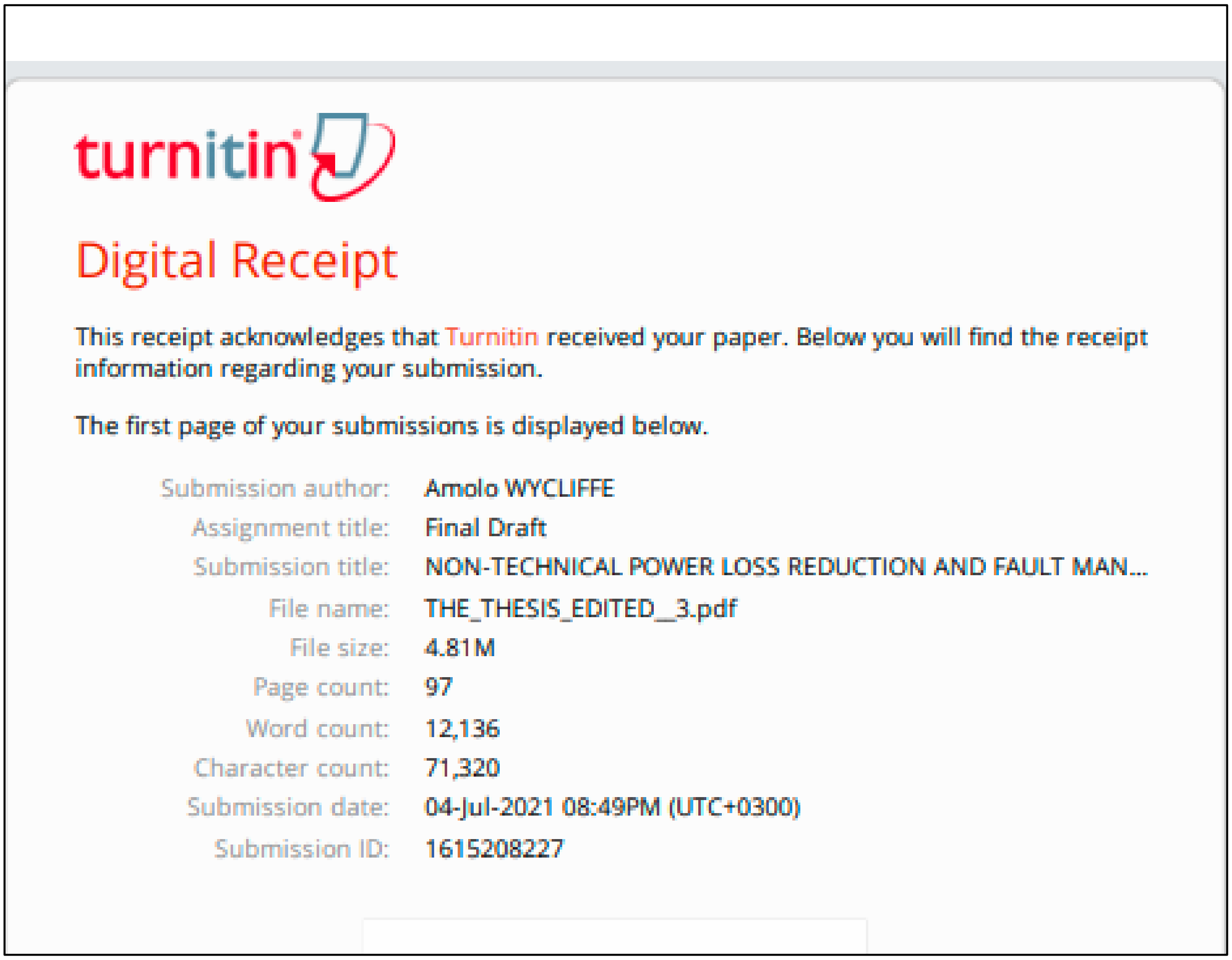

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