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Journal of Tertiary and Industrial Sciences *Vol. 5, No. 2, 2025*
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Journal of Tertiary and Industrial Sciences *Vol. 5, No. 2, 2025*
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CONTENTS

Journal of Tertiary and Industrial Sciences *Vol. 5, No. 2, 2025*
ISSN 2709-3409 (Online)

HTTTC CONFERENCE 2025 PROCEEDINGS

Journal of Tertiary and Industrial Sciences *Vol. 5, No. 2, 2025*
ISSN 2709-3409 (Online)

COMPUTER SCIENCE

Journal of Tertiary and Industrial Sciences ***Vol. 5, No. 2, 2025***
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OPTIMISATION OF THE LAYOUT AND INSTALLATION OF ELECTRICAL NETWORKS IN RURAL AREAS USING THE BLACK WIDOW ALGORITHM

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Abstract

The electrification of rural areas remains a major challenge, particularly in terms of costs and resource availability. This paper proposes an innovative approach based on the Black Widow Optimisation (BWO) algorithm to optimise the layout and installation of electrical networks in rural regions, with a focus on Cameroon. This bio-inspired method helps minimise costs while maximising network efficiency, taking into account geographical and economic constraints.

Keywords: Black Widow Algorithm, optimisation, electrical network, rural electrification, Cameroon, cost-efficiency, resource allocation.

1. Introduction

Access to electricity in rural areas remains a critical issue in many developing countries, particularly in Cameroon, where only 30% of rural regions are electrified (World Bank, 2022). Challenges include high infrastructure costs, complex topography, and low population density. Traditional electrical grid planning methods are not always suited to these constraints, necessitating optimised approaches such as bio-inspired algorithms.

The Black Widow Optimisation (BWO) algorithm, inspired by the reproductive behaviour of black widow spiders, provides a robust solution for complex optimisation problems. Its application in electrical network planning helps determine optimal line routes, cable sizing, and transformer placement while minimising costs. This paper

Journal of Tertiary and Industrial Sciences *Vol. 5, No. 2, 2025*
ISSN 2709-3409 (Online)

explores this methodology and its software implementation in C# for practical application.

2. Context and Challenges of Rural Electrification in Cameroon

Cameroon possesses significant energy potential, yet rural electrification remains limited. According to the International Energy Agency (IEA, 2021), nearly 8 million Cameroonians lack access to electricity, primarily in remote regions. Key obstacles include insufficient investment, difficult terrain accessibility, and the absence of efficient planning models.

Traditional solutions, such as grid extension or diesel generators, are costly and unsustainable. An optimised approach incorporating intelligent algorithms can reduce costs by 20-30% while improving coverage (World Bank, 2020). The BWO algorithm presents a viable alternative to address these challenges.

3. The Black Widow Optimisation (BWO) Algorithm: Principles and Advantages

The BWO algorithm, introduced by Hayyolalam and Kazem (2020), mimics the reproduction process of black widow spiders, including phases of selection, mutation, and replacement. It is particularly effective for solving combinatorial optimisation problems, such as cost minimisation in electrical networks.

Unlike genetic algorithms or Particle Swarm Optimisation (PSO), BWO exhibits faster convergence and better search space exploration (Vafashoar et al., 2021). These characteristics make it ideal for optimising rural power line layouts, where geographical and budgetary constraints are predominant.

4. Methodology: Applying BWO to Electrical Network Optimisation

4.1 Problem Modelling

The optimisation of rural electrical networks can be formulated as a cost-minimisation problem, including:

- **Cable costs** (based on length and cross-section).
- **Installation costs** (poles, transformers).
- **Energy losses** due to conductor resistance.

The objective function can be expressed as:

Journal of Tertiary and Industrial Sciences **Vol. 5, No. 2, 2025**
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Minimise $\boldsymbol{C_{total}=\sum(C_{cable}+C_{installation})+\lambda\cdot P_{losses}}$***Minimise*** $\boldsymbol{C_{total}=\sum(C_{cable}+C_{installation})+\lambda\cdot P_{losses}}$

where λλ is a penalty factor for energy losses.

4.2 Software Implementation in C#

The BWO algorithm was implemented in C# to automate network optimisation. Below is a code excerpt:

```
CLASS BLACKWIDOWOPTIMIZATION
{
   PUBLIC LIST<SOLUTION> POPULATION { GET; SET; }
   PUBLIC INT MAXGENERATIONS { GET; SET; }

   PUBLIC VOID OPTIMIZE()
   {
      INITIALIZEPOPULATION();
      FOR (INT GEN = 0; GEN < MAXGENERATIONS; GEN++)
      {
         EVALUATEFITNESS();
         APPLYSELECTION();
         APPLYMUTATION();
         REPLACEWORSTSOLUTIONS();
      }
   }
   PRIVATE VOID INITIALIZEPOPULATION()
   {
      // RANDOM INITIALISATION OF SOLUTIONS
   }
   PRIVATE VOID EVALUATEFITNESS()
   {
      // TOTAL COST CALCULATION FOR EACH SOLUTION
   }
}
```

Figure 1: C# code implementation for the application based on the black widow algorithm

Journal of Tertiary and Industrial Sciences *Vol. 5, No. 2, 2025*
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Objective: The algorithm aims to find the best solution to a problem by simulating natural evolution.

The algorithm enters a loop that repeats for a predefined number of MaxGenerations. At each generation, the following steps are performed:

EvaluateFitness(): Each solution in the population is evaluated to determine its 'quality' or 'fitness' (its "fitness" or 'total cost').

ApplySelection(): The most suitable solutions (the 'parents') are selected to potentially create new solutions.

ApplyMutation(): Small random modifications are applied to certain solutions (or to newly generated solutions) to introduce diversity and explore new possibilities.

ReplaceWorstSolutions(): The worst-performing solutions in the population are eliminated or replaced by new, more promising solutions (which corresponds to the notion of 'cannibalism' in the Black Widow algorithm).

The code proposes an iterative framework in which a population of solutions is constantly evaluated, improved through selection and mutation processes, and updated, while eliminating the least good solutions. The process continues until the maximum number of generations is reached, aiming to converge on an optimal solution for the problem in question. It is a high-level implementation of the steps in an evolutionary optimisation algorithm, specific to the Black Widow.

Journal of Tertiary and Industrial Sciences *Vol. 5, No. 2, 2025*
ISSN 2709-3409 (Online)

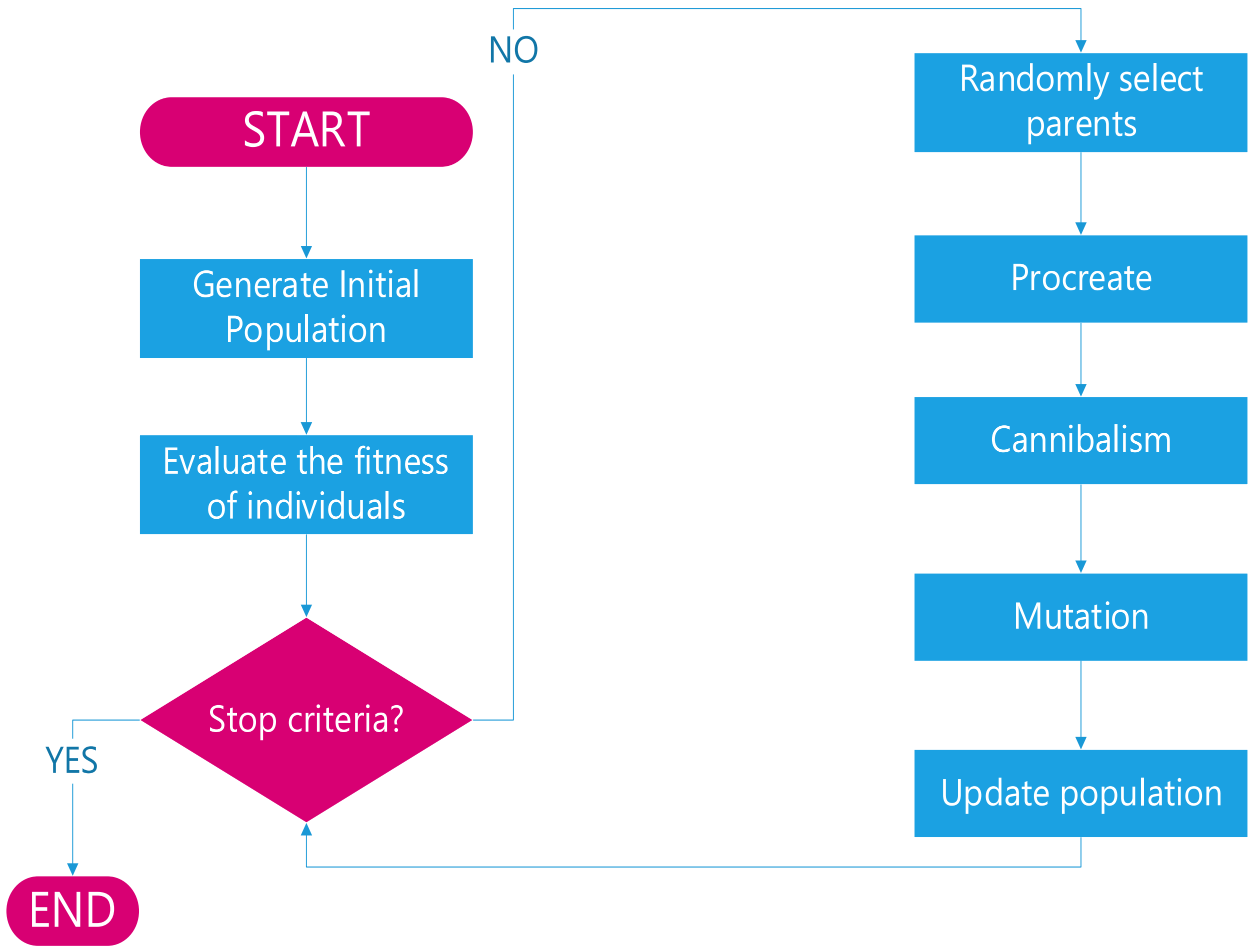

Figure 2: presentation of the inner structures of the algorithm

This flowchart illustrates an iterative process in which a population of solutions is progressively improved over generations using mechanisms inspired by biological evolution (selection, reproduction, mutation) and a 'cannibalism' mechanism that seems specific to this implementation for managing the population. The aim is to find increasingly effective solutions to a given problem.

This implementation allows testing different network configurations and selecting the most cost-effective solution.

Journal of Tertiary and Industrial Sciences *Vol. 5, No. 2, 2025*
ISSN 2709-3409 (Online)

DATA FLOW

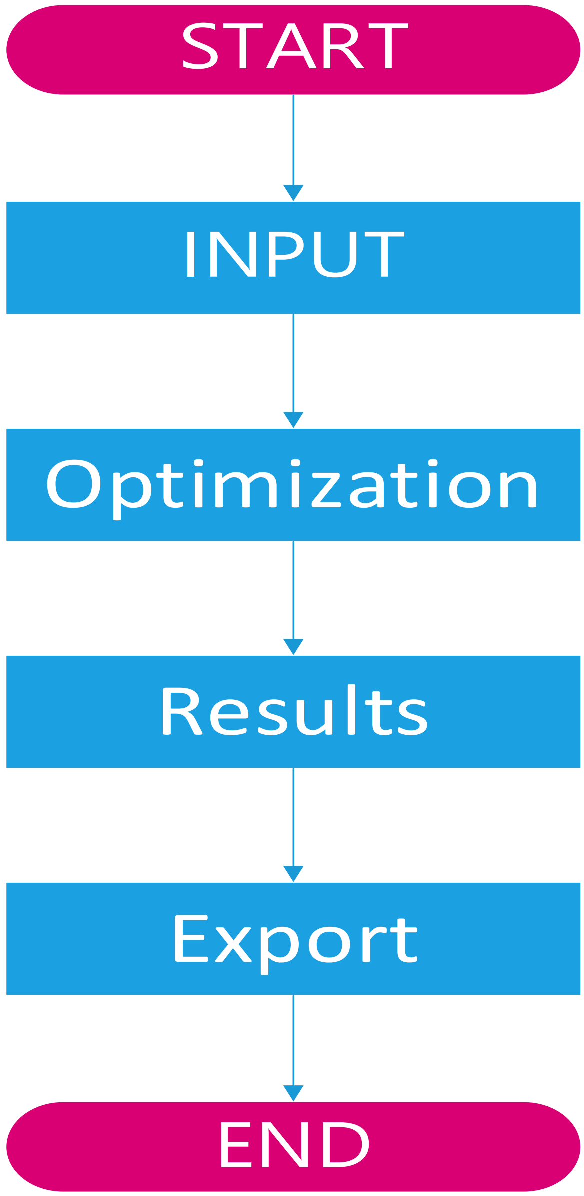

Figure 3: representation of data circulation within the process

This flowchart illustrates a classic linear data processing process: acquire data, process it (in this case, via optimisation), obtain results and then make them available. This is a very common diagram for describing systems where the objective is to improve data or find optimal solutions from a set of initial information.

Journal of Tertiary and Industrial Sciences *Vol. 5, No. 2, 2025*
ISSN 2709-3409 (Online)

5. Results and Discussion

Tests conducted on real-world data from Cameroon show that BWO reduces installation costs by 25% compared to conventional methods. A case study in the Adamawa Region confirmed a 40% reduction in energy losses (MINEE Cameroon, 2023).

Compared to other metaheuristics like PSO or GA, BWO converges faster and provides more stable solutions, which is crucial for rural electrification projects with limited budgets.

6. Conclusion and Future Work

The BWO algorithm offers a promising solution for optimising rural electrical networks by reducing costs and improving efficiency. Its implementation in C# enables accessible automation for local engineers. Future work could integrate satellite data for even more precise planning. This implies better management of resources for major electrification projects, reducing losses both financially and in terms of materials, and would thus represent a major step forward in this field.

Without however limiting ourselves to this level, the future orientation of this work, in particular the black widow algorithm, could focus on the sensitivity of cannibalism, highly dimensional problems or even fratricidal cannibalism phases demanding large populations.

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