# Swarm-based algorithms for the Minimization of the Magnetic Field of Underground Power Cables

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**Summary.** In this paper a Swarm-Based algorithm approach for detecting an optimal geometrical and electrical connection of underground cables is presented, in order to minimize the magnetic field strength on the ground surface. Since the problem is a Mixed-Integer and Constraint Programming, a Discrete version of Flock-of-Starlings Optimization has been developed. A death penalty method has been used in the optimization process for evaluate the constraints. A comparative analysis is presented for different configurations, with the aim to evaluate the performance.

## 1 Introduction

In the last years the electric companies has revisited the design method of the underground power cables in order to address the problem of an optimal displacement of them. On the other hand, it is widely acknowledged that the current (50-60 Hz) of transmission and distribution lines, including electrical substations, generates magnetic fields that are the basis of electromagnetic pollution. Indeed the underground power lines were identified as major sources of magnetic fields, since they can produce a significant magnetic field on the ground surface, especially in cases where there are more than four three phase circuits. From an economic point of view, shielding the entire path of a transmission line is impractical. For these reason there needs of optimization techniques at design concerning both the geometrical and circuit assignation of each bundle [1, 2]. From the computational prospective this kind of problems belongs to the Mixed-Integer and Constraint Programming (MICP), in which discrete variables appear. The algorithms usually employed for these problems operate as a string generator, where the string is the individual, which codifies a possible solution. Being the solution a string of numbers the first inconvenient is that some solutions are incompatible with the physical problem.

In this paper a new kind of binary algorithm derived from the Flock of Starlings Optimization algorithm is presented and its performance over MICP problems are analyzed. In the work particular attention is given to the optimization of a system of power lines that generates the magnetic field of lower intensity without sacrificing efficacy, stability and availability of power systems.

## 2 Discrete Flock-of-Starlings Optimization

FSO is a bio-inspired algorithm, swarm-based, which has been employed successfully in several others electromagnetic optimization problems, thanks to its high capability of exploration and to escape from local minima [4]. As FSO can be considered an extension of PSO, so Discrete FSO (DFSO) is an extension of the Discrete Particle Swarm Optimization. In these model the trajectories of particles/birds have a probabilistic mean. In particular the velocity of a single particle must be interpreted as the probability that the current position may change from current state to another. Being the algorithm binary, also each coordinate of the position of k-th bird $x_k(t)$ can be 0 or 1. In addition the various component of the personal best and the global best are integer in $\{0,1\}$. The velocity of k-th bird $v_k(t)$ is a probability and it must be constrained. A logistic transformation is introduced by using a sigmoid function in order to do this:

$$S(v_k) = \left(1 + e^{-v_k}\right)^{-1}$$

The resulting change in the j-th component of position then is defined by the following rule:

$$x_k^j(t) = \begin{cases} 1 & if \ S\left(v_k^j\right) > random(0,1) \\ 0 & otherwise \end{cases}$$

Starting from these equations we can obtain the DFSO model. Indeed, in the FSO each individual chooses the direction in accord to the velocity of other members arbitrary chosen in the swarm. But now the velocity is the probability that an individual will change its status. Therefore, the choice of an individual is influenced from the mean probability of changing of the other member followed by it. The updating velocity equation for the DFSO becomes:

$$v_k = M_k \cdot [\omega v_k + \lambda ( p_{best_k} - x_k ) + \gamma^j ( g_{best} - x_k )]$$

where $M_k$ is the average velocity among controlled birds, expressing the probability of changing a digit from 0 to 1 of the members followed by the generic individuals in the swarm. The value of the $M_k$ is constrained in [0.0, 1.0], in order to underestimate the influence of other members on the generic individual: this choice is extremely important since linking in a strong way the individuals can produce a stagnation and saturation in 1 or 0 direction. In figure 1 the pseudo code of DFSO is presented.

```
Initialization;
Building of the Interconnection Matrix;
For i = 1 : Nstep
      For each bird
            Fitness evaluation;
            Personal and Global best evaluation;
            Mccb computation;
            Update the Velocity;
            Update Position;
      End
End
```

**Fig. 1.** Pseudo code of DFSO

## 3 Codification of the problem and results

The simulation performed in this section takes as reference the analysis done in [1]. In [1] the design of cables displacement in a tunnel is trefoil configuration with the aim to minimize the effects of capacitive and inductive currents and support by racks. In the example hereafter presented, we use a simplified version of the circuit used in [1], by changing the number of circuits employed. The data are reported in Table 1, whereas in the fig. 2 are depicted the displacement of cables in the rack with relative position of the bundles. The combination of the cables are 6 and they can be explicitly expressed, 123;132; 213; 231; 312; 321, for instance if there is a string such as 6345, it means that the first circuit is arranged as 321, second as 213 and etc. Set $N_C$ as the number of circuit and with $N_B$ the number of bundles, then any element is codified as an array of 0 and 1 of assigned length.

We have implemented the algorithm in the MATLAB© environment and all the tests has been performed starting from a random initialization. In order to take into account the constraints we divided the array in 2 parts: the first part of the array represents an individual and must consist of integer value in the range 1-6; whilst the second portion of array represents the connections. Then we use a death penalty, which consists of assigning a huge value to the "bad" solution that doesn't meet the constraints. The fitness function, that is the magnetic field intensity, is computed by using Biot-Savart formula and the result of a statistical analysis performed on 50 BFSO launches is reported in Table 2, showing the good performance reached.

**Table 1**. Data of the power circuit employed in the test

| N.circuit | P(Mw) | Q(MVAr) | Im (A) | θ (deg) |
|---|---|---|---|---|
| A | 180 | 60 | 680 | 18 |
| *B* | 155 | 43 | 577 | 16 |
| *C* | -100 | -25 | 370 | 194 |
| *D* | -125 | -30 | 461 | 193 |

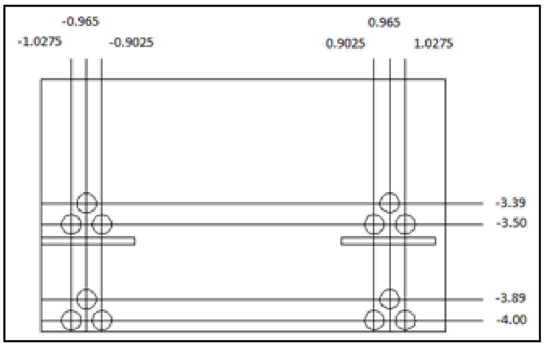


**Fig. 2.** Displacement of bundles in the underground rack, all values is expressed in meter.

**Table 2**. Results of BFSO

| Mean | Variance | Best Configuration | Best Fitness Value |
|---|---|---|---|
| 6.4005e-007 | 3.262e-016 | 56533124 | 6.2566e-007 |

## References


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