A novel algorithm for isolated electrification projects

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Abstract. In this report it is proposed a metaheuristic procedure to support the design of stand-alone community electrification projects. In particular, the solution returned by the procedure specifies the generator locations and distribution through micrograds. This report provides the description of the proposed procedure, which would require low computational resources.

Keywords: electrification projects, micrograds, metaheuristic

1. Introduction

The design of off-grid electrification projects considering hybrid systems and distribution micrograds is a complex task that requires the use of decision support tools. Most of existing tools focus on the design of hybrid systems without defining generator locations and distribution through micrograds. Recently a deterministic heuristic was developed to solve the complete problem (Ranaboldo et al., 2014).

In this report we propose a meta-heuristic procedure for designing community off-grid electrification projects based on renewable energies considering micro-scale resource variations and a combination of independent generation points and micrograds. The proposed procedure is a complete design tool that can efficiently support the design of stand-alone community electrification projects requiring of low computational resources.

First, we present an enhanced version of the heuristic proposed by Ranboldo et al. (2014). Then, we describe the proposed meta-heuristic procedure based of the enhanced heuristic.

2. Enhanced deterministic heuristic

The deterministic heuristic proposed in Ranaboldo et al. (2014) is considered as the starting point for the development of the proposed metaheuristic procedure. The heuristic is composed by 2 phases: first construction, and then a local optimization. In the construction phase, the solution considering all independent generation points is firstly calculated, and then the algorithm iteratively extends micrograds as much as possible, according to the cost criterion. The local optimization phase is composed by 2 steps that are repeated if they improve previously obtained solution: firstly the micrograds are divided (if this reduces solution cost) into smaller ones and then the resulting micrograds are tried to be interconnected between them.

The original deterministic heuristic creates micrograds minimizing cables length (i.e, solving the minimum spanning tree procedure (Prim, 1957)). However, the distribution system cost depends on both the cable length and the cable type (i.e. unitary cost) used in order to fulfil distribution system constraints, such as maximum permitted voltage drop. In order to take into account this issue, we propose to enhance the deterministic heuristic by including an additional third phase that aims to reduce distribution system cost (Distribution system optimization phase)..

The main steps of the construction phase are shown in Fig. 1. Starting from the solution considering all independent generation points, the algorithm constructs the microgrids extending them as much as possible if solution cost decreases. The microgrids are subsequently constructed in two iterative cycles:

1) Cycle 1: New microgrid construction iteration starts. The grid generation point of the (current) microgrid is firstly selected (STEP1) and then it stars cycle 2 in which the microgrid is extended.
2) Cycle 2: In each cycle one microgrid (composed by one or more users) is tried to be connected to the current microgrid depending on certain criterion (STEP2). If the new microgrid has a lower cost than the two previous ones then the connection is accepted and Cycle 2 restarts. If the connection is not accepted then a new Cycle 1 starts.

The algorithm ends when all the demand points of the community are part of an extended (created) microgrid.

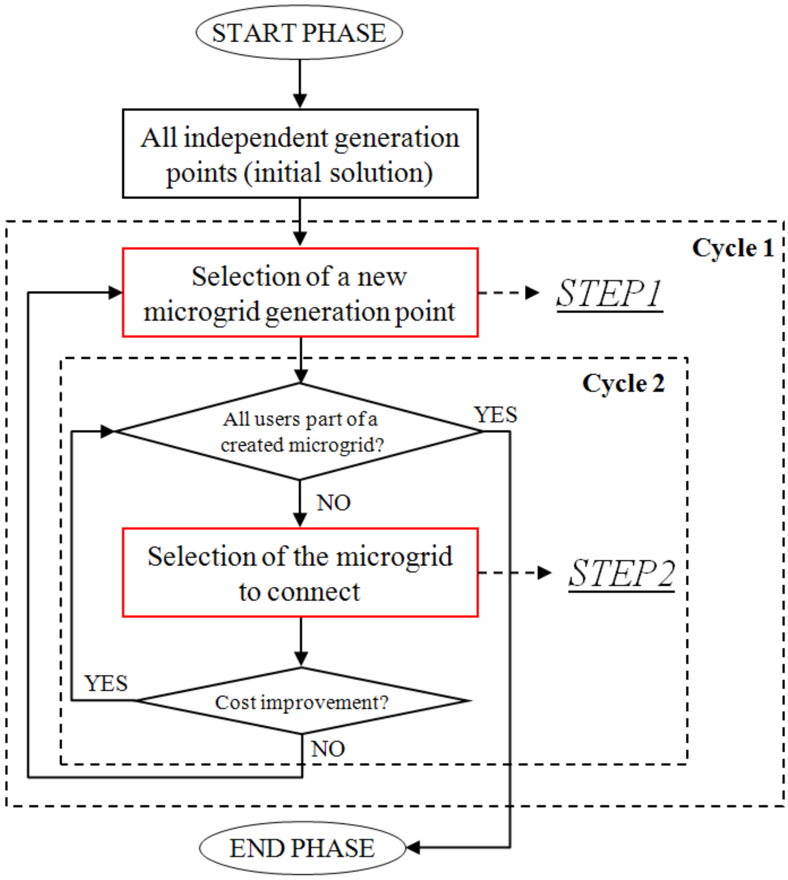

Fig. 1 – Main structure of the construction phase. STEP1 and STEP2 indicate the selection steps.

The selection steps (STEP1 and STEP2 of Fig. 1) are the most critical ones and are defined by two characteristics: the pool of possible candidates (PE_1, PE_2, respectively) and the indicator or heuristic function used to rank the *PE* and select the best one.

Regarding STEP1, PE_1, from which the microgrid generation point could be selected, is the union of the sets of demand and no-demand points not selected as a grid generation point in a previous iteration of cycle 1. The heuristic function to rank the elements of the PE_1 is the Grid Generation Score (*GGS*): an indicator that, based on demand and resource distributions, evaluates how much a certain point has the adequate characteristics for being the generation point of microgrid composed by multiple users (Ranaboldo et al., 2013).

Regarding STEP2, i.e. the selection of the microgrid to connect, being *m* the current microgrid in expansion, PE_2 is composed by all microgrids of the current solution *s* (excluding *m*) located at a distance lower than their Break Even Distance (*BED*) from *m*. The microgrid *y* to be connected to microgrid *m* could be selected in the following three different ways, adapted from Ranaboldo et al. (2014): HF_{2a}, HF_{2b} and HF_{2c} (equations 2.1, 2.2 and 2.3).

1) By distance (the element with the lowest HF_{2a} value is selected):

$$HF_{2a}(y) = L(y,m) \qquad \forall y \in PE_2 \tag{2.1}$$

2) By *NGS*, *IGS* and distance (the element with the highest HF_{2b} value is selected):

$$HF_{2b}(y) = \frac{\max\limits_{py \in DP(y)} \left(1 + NGS(py) - IGS(py); 0.1\right)}{L(y,m)} \qquad \forall y \in PE_2 \tag{2.2}$$

The *NGS* (No-generation Score) and the *IGS* (Independent Generation Score) are indicators that evaluate how much some a-priori characteristics of a point indicate that should be a no-generation point (*NGS*) or an independent generation point (*IGS*) (Ranaboldo et al., 2013).

3) By savings (the element with the highest $HF_{2}c$ value is selected):

$$HF_{2c}(y) = \left(\left(C(m) + C(y)\right) - C\left(MU\left(m, y, \text{false}\right)\right)\right) \qquad \forall y \in PE_2 \tag{2.3}$$

The Distribution system optimization phase is summarized in Fig. 2: firstly the branches of the microgrids of a previously obtained solution are tried to be subdivided and then microgrids are iteratively tried to be interconnected, subdividing the branches of every new microgrid.

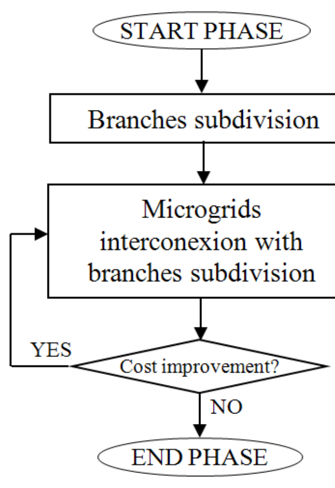

Fig. 2 – Main structure of the distribution system optimization phase

The branches subdivision step aims to improve the distribution system cost of the microgrids of the current solution by means of trying to subdivide the branches. The microgrids interconnection step is applied as follows. For each microgrid *m* the following steps are carried out:

- The microgrids located at distance to the microgrid (*m*) lower than their Break-Even Distance are tried to be connected (separately) to *m*. Next, the cost of the distribution system is improved in each newly obtained microgrid. The microgrid *mc* that leads to the highest savings is selected.
- If the connection between microgrids *m* and *mc* decreases the cost of the solution then the two microgrids are connected and the algorithm tries to connect another microgrid to the latter obtained microgrid.
- This process stops when the connection is rejected (no cost improvement is obtained).

3. Metaheuristic procedure

The proposed metaheuristic procedure is a multi-start process, in which iteratively a solution is constructed and then improved with a local search. The solution construction is done with a randomized greedy algorithm based on the enhanced deterministic heuristic explained in Section 2. As stopping criterion, a maximum calculation time is defined.

To randomize the deterministic heuristic, two restricted candidate lists (RCL1 and RCL2) are used in STEP1 and STEP2, respectively (recall Fig. 1). Instead of selecting the best element ranked by a heuristic function, the element is selected at random within the elements in the respective RCL with a probability proportional to the goodness of their heuristic function value. The characteristics of RCL1 and RCL2 are reported in Table 1:

Table 1 – Characteristics of RCL1 and RCL2

Characteristic	RCL1 (STEP1)	RCL2 (STEP2)
Elements of the RCL	(Microgrid) generation points	Microgrids (to be connected)
a) Pool of possible candidates[a]	$PE_{1:}$ Set of demand and no-demand points not previously selected as a grid generation point	$PE_{2:}$ Set of microgrids (excluding the current microgrid in expansion) located at a distance lower than their BED
b) Size of the RCL	$\max\left(\left\lceil \alpha_1 \cdot \lvert PE_1 \rvert \right\rceil, 1\right)$	$\max\left(\left\lceil \alpha_2 \cdot \lvert PE_2 \rvert \right\rceil, 1\right)$
c) Heuristic function	*GGS*	3 alternatives: - HF_{2a} (distance) - HF_{2b} (*NGS*, *IGS*, distance) - HF_{2c} (savings)

α_1 and α_2 and parameters to fine-tune

As shown in Table 1, there are three heuristic functions for STEP2 (HF_{2a}, HF_{2b}, and HF_{2c}). The heuristic function that obtains the best results cannot be defined a-priori. Therefore, we propose the following 5 procedure versions:

- PROC1: HF_{2a} (distance) is always applied in each STEP2
- PROC2: HF_{2b} (*NGS*, *IGS* and distance) is always applied in each STEP2

- PROC3: HF_{2c} (savings) is always applied in each STEP2
- PROC4: HF_{2a}, HF_{2b} or HF_{2c} are randomly selected (with the same probability) in each STEP2 of the construction phase.
- PROC5: HF_{2a}, HF_{2b} or HF_{2c} are alternatively applied in each procedure iteration.

References

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