Restoration Method for Active Distribution Networks Considering Black Start

Yan Matheus de Toledo
Universidade de São Paulo
Av. Trab. São Carlense, 400 - São Carlos
yan.toledo@usp.br

Wandry Rodrigues Faria
Universidade de São Paulo
Av. Trab. São Carlense, 400 - São Carlos
wandry@usp.br

Benvindo Rodrigues Pereira Junior
Universidade de São Paulo
Av. Trab. São Carlense, 400 - São Carlos
brpjunior@usp.br

ABSTRACT

Avoiding outage events is impossible, as they may be caused by planned or random situations. In this sense, great effort has been put into developing techniques for designing and operating more reliable power systems capable of efficiently resupplying the loads in the face of power interruption situations. This paper is inserted in the restoration process context in modern distribution networks, aiming to minimize out-of-service loads due to permanent faults. The proposed method employs two metaheuristics to provide the user with feasible restoration plans. Considering a practical perspective, the proposed methodology presents an optimized sequence of maneuvers guaranteeing the feasibility of intermediate solutions. We test the proposed method for a 405-bus system. Analysis of the algorithm's behavior shows its convergence capacity, while a time-domain simulation demonstrates the method's efficiency in providing good quality feasible restoration plans.

KEYWORDS. Black Start, Power Distribution Restoration, Variable Neighborhood Search

Topics: EN&PG – PO in Energy, Oil and Gas Fields, MH – Metaheuristics

1. Introduction

Electricity is essential for society since it is associated with comfort and quality of life. Industry, transportation, telecommunications systems, and other sectors are highly dependent on the power supply. Therefore, outage situations cause social and, mainly, economic disorders. However, interruptions in power supply are inevitable [Elmitwally et al., 2015], due to fault scenarios and maintenance interventions. Distribution Systems (DSs) are usually designed as weakly-meshed systems, but operate in a radial topology. Hence, whenever the DS operates under a contingency scenario (due to maintenance or a short-circuit event) the energy supply is interrupted to every consumer downstream of the faulty sector [1] [Zidan et al., 2017]. Note that the loads connected out of the faulty sector are healthy; nonetheless, they may be included

[1]In this approach, the sector is defined as the group of buses and branches between two maneuvering devices (*e.g.* secctionalizing swithces and reclosers).

in the out-of-service region, if connected downstream of the fault. Restoring such consumers increases the network's reliability, maximizes the utility's proftability and improve customer satisfaction [Li et al., 2020]. In this sense, it is crucial to determine a restoration plan to resupply healthy out-of-service loads, once the location and isolation of the faulty sector has been conclued. The Service Restoration Plan (SRP) is a sequence of switching maneuvers to be executed in the DS to supply power to the maximum number of healthy consumers adopting an alternative topology [Marques, 2018].

Several authors have investigated the Service Restoration (SR) problem due to the issue's relevance. Given the large amount of possible solutions, the set of non-linear constraints and the need for real-time solving, the SR is a complex optimization problem. There is a broad range of methods proposed for solving the optimization problem, including mathematical models [Romero et al., 2016; Souza et al., 2020], metaheuristic [Pereira et al., 2012; Camilo, 2013] and artificial intelligence [Shi e Dong, 2009]. It is fundamental to point out that the insertion of Distributed Generators (DGs) demands, at least, the revision of established proposals. In this context, one can notice an increasing number of methodologies that incorporate this aspect of modern DSs, such as [Hafez et al., 2018; Dietmannsberger et al., 2018; Khederzadeh e Zandi, 2019]. A proclivity observed in papers that considers the presence of DGs is the island operation of these units [Xu et al., 2016; Shen et al., 2020]. In such an environment, the DGs may supply a portion of the network's loads after a fault occurrence [Abbey et al., 2014; Peralta et al., 2019a].

The island operation is not widely applyed yet, especially due to concerns regarding the quality of the power supplyed by the DGs without the substation's support. The operational limits of a DG determine whether or not the generator is able to supply the loads, guaranteeing power quality, in steady-state. However, the DG's transient behavior is a critical issue for the island's maintenance and power quality during the first seconds of island operation [Faria et al., 2019]. Nevertheless, this characteristic is commonly overlooked most methodologies addressing the island operation as a means to provide SR. Among the few exceptions, one can mention the proposals presented in [Xu et al., 2016] and [Faria et al., 2021]. In [Xu et al., 2016] the authors investigated the possibility of supplying critical loads using three DGs after an extreme situation has disabled their power supply throught the substation. The authors use GridLAB-D to verify each swithing maneuver and then determine whether or not the action is feasible based on voltage and frequency transient thresholds. As a result, they present a single SRP to supply specific consumers. The authors of [Faria et al., 2021] studied the behavior of synchronous machines upon swithing maneuvers and established limits for the power variation on each maneuver. As a result, the method is able to produce feasible restoration plans for generic faults.

It is fundamental to highlight that, although the method proposed in [Faria et al., 2021] provides feasible SRPs considering the dynamic behavior of DGs, the authors have investigated only the automatic islanding process. Thus, the island is created through the operation of a protective device and the conditions for maintaining the island are met. In real operation, it is not rare for the DG to export much mor power than the island region's demand. In this context, should a fault happen, the automatic islanding would not be effective and the DG would shut down due to frequency deviations caused by active power mismatches between the machine's setpoint and the island's demand [Faria et al., 2019]. Considering this possibility, this paper provides, in addition to the restoration plan, a black start sequence for DGs moved by syncrhonous machines. We employ a Variable Neighborhood Search (VNS) to search for feasible SRPs, a Genetic Algorithm (GA) to determine the maneuvering sequency and an heuristic tool to suggest the black start sequence. We tested the tool for a 405-bus distribution system considering an extreme scenario wherein the DG must black start and energyze the loads, as the substation is unable to do so.

2. Service Restoration Optimization Model

The optimization model adopted in this paper is represented in (1).

$$\min \left\{ \text{PNS(G)} \right.$$

$$s.t. \left\{ \begin{array}{c} \text{G must be a graph forest (radial topology)} \\ \text{Maximum and minimum bus-voltage} \\ \text{Conductors' maximum current} \\ \text{DG's steady constraints (active power, reactive} \\ \text{power and power factor within its operation limits)} \\ \text{Maximum frequency deviation (transient} \\ \text{and steady-state values)} \end{array} \right. \quad (1)$$

wherein $PNS(G)$ is the power not supplyed associated with topology G. It is important to highlight that the constraints concerning frequency deviation were incorporated from [Faria et al., 2021], where further details regarding the constraints and justification for the thresholds can be found. According to the mentioned paper, adopting these constraints eliminates the need for time-domain simulations to verify the frequency deviations.

One of the peculiarities of the SR problem is the search for good quality solutions that do not require many switching maneuvers, *i.e.*, the SRP is not supposed to modify the original topology in its totality, only the healthy affected portion. This can be seen as a neighborhood search. In this sense, many authors have successfully employed neighborhood search-based algorithms, such as Tabu Search, to solve this problem [Pereira et al., 2012], [Peralta et al., 2019b], [Toune et al., 2002]. In this paper, we investigate the use of VNS, which is another metaheuristic that explores the search space based on the concept of neighborhood examination.

Moreover, note that by solving the optimization problem (1) one obtains only the new topology, but not the intermediate solutions between the original and the final topologies. In a practical context, it is crucial to provide the sequence of operations to obtain the final topology. Furthermore, each intermediate solution (obtained whenever a maneuver is executed) must also comply with the optimization model's constraints. In this approach we employ a GA to determine feasible maneuvering sequences with minimum Energy Not Supplied (ENS). A maneuvering sequence is considered feasible if every intermediate solution complies with the constraints of (1).

The presented optimization model associated with the maneuvering sequence provided by the GA are sufficient to define practical restoration plans under both steady-state and transient perspectives. In the next section, further details regarding the VNS and GA codifications and their interaction are provided.

3. Optimization Algorithms

3.1. Variable Neighborhood Search Algorithm

VNS is a metaheuristic based on local search, in this sense the method is similar to tabu search. However, while tabu search accepts the degradation of the current solution as a means to escape of local minima, VNS does not. When the algorithm's search in the neighborhood does not find a solution better than the current one, it expandes the search space by modifying the concept of neighborhood [Mladenovic e Hansen, 1995]. In this approach, we adopt an encoding based on the one presented in [Pereira et al., 2012]: each solution is represented by two integer vectors P_1 and P_2. P_1 represents the energized nodes (source), while P_2 stores the healthy out-of-service buses (load). The indexes of P_1 and P_2 imply the connection between the nodes stored in each slot, as can be observed in Fig 1. Noteworthy mentioning that once a out-of-service node is connected to an energized node, it may also be used as a source node, as illustrated in Fig 1 by node 4.Observe in Fig. 1 that nodes 3 and 6 are not codified in P_2 in the second scenario since these buses have direct connections only to other out-of-service consumers. Therefore, the size of vectors P_1 and P_2 is dynamically managed since they may increase or decrease along the search space exploration. We adopt the Node-Depth encoding, presented in [Delbem et al., 2004], to portray the DS aiming to enhance the computational performance.

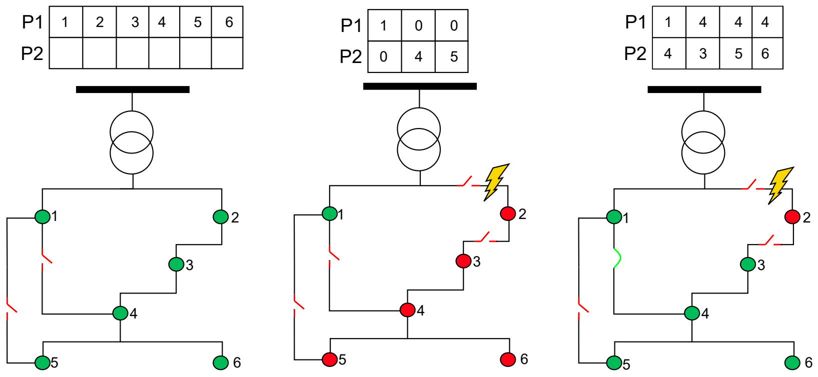

Figure 1: Illustration of the encoding adopted for VNS.

It is important to stress that the algorithm is not able to indefinitely expand the search space or it would become an exhaustive search. Hence, defining neighborhoods is the central point of this method. We have adopted four concepts of neighborhood all of which are exmplained bellow:

1. The first neighborhood is defined as the set of solutions obtained after a single index of vectors P_1 and P_2 is altered. In this sense, the practical effect is: one of the healty out-of-service loads changes its supplier node. Observe in Fig 1 that the right-most topology is found as a result of changing bus 4 source node (from 0 to 1), *i.e.*, bus 4 was disconnected and now is supplyed through bus 1. It is important to highlight that the opposit is also possible; bus 6, for instance, could be disconnected from bus 4.

2. The second neighborhood comprises the solutions obtained after two values of vectors P_1 and P_2 are altered. In this sense, two new loads may be resupplyed or disconnected. It is also possible to disconnect one and resupply another consumer.

3. The third neighborhood was defined following the same principle as the two previous neighborhoods: adding one more maneuver. In this sense, this neighborhood considers changes in three nodes of the current solution.

4. The final neighborhood addresses the transference of healthy unaffected loads between source nodes. It is important to highlight that we do not consider the possibility of disconnecting unaffected loads, we merely change the path through which they are supplied.

One of the premisses for applying VNS is the existence of a current solution, as the neighborhoods are defined based on a valid topology. In this approach, we set the initial solution as the topology obtained right after the fault has been isolated. The proposed algorithm does not consider load prioritization nor the disconnection of loads that were not affected by the fault. In this approach we have considered only automatic secctionalizing switches; however, the consideration of manual switches can may integrated in the tool in future investigation. The adopted stop criterion is reaching the iteration limit. It is important to highlight that one VNS iteration is accounted for when the search tries to expand the neighborhood and there is no larger neighborhood defined, *i.e.*, the current neighborhood is 4 and the algorithm does not find a better solution and tries to use the fifth neighborhood.

3.2. Genetic Algorithm

The SRP's final topology is a result of applying VNS. Nonetheless, one of the constraints presented in (1) is the transient frequency deviation, which occurs whenever a switching maneuver is performed. This particular constraint is not verified by VNS, since the algorithm analyzes only two solutions: the initial and the final. In this sense, an analysis of each intermediate solution must be performed by a second routine. Noteworthy, voltage and current limits must also be verified for the intermediate topologies. The determination of a sequence of switching maneuvers is mandatory for practical applications and has been investigated by several researchers [Hafez et al., 2018], [Khederzadeh e Zandi, 2019], [Xu et al., 2018]. In this approach, we employ a GA, based in [Chu e Beasley, 1997], for determining there is a feasible switching sequence to modify the faulted DS and attain the solution found by VNS.

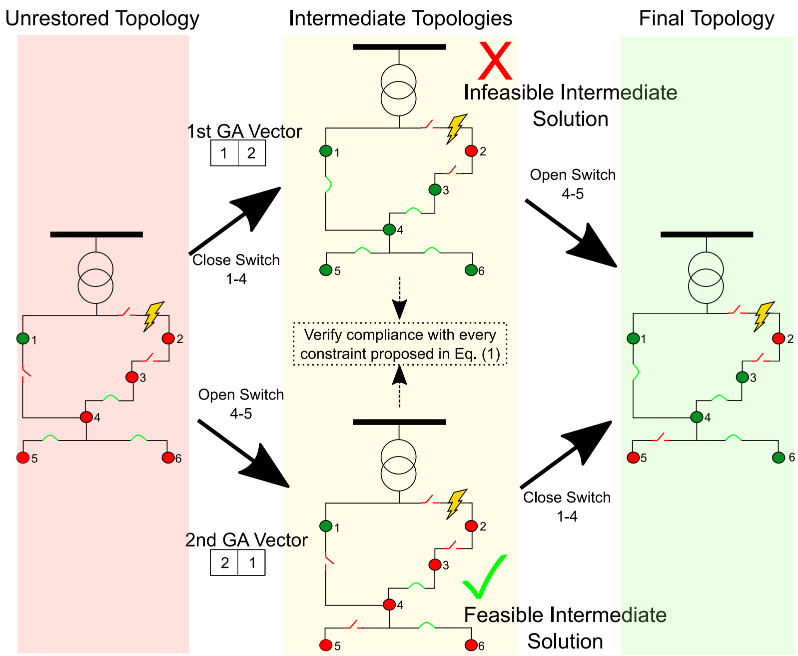

Figure 2: Illustration of the encoding adopted for GA.

In this paper, the GA solutions are encoded as integer vectors; each value represents one switch and the vector's index represents when each maneuver is performed. Therefore, the vector codifies the complete switching sequence. The vector size is easily determined by comparing the initial (unrestored) and final solutions, more specifically the number of switches with opposite status (open or closed) in each topology. Observe that the intermediate solutions are obtained by performing the changes in topology codified in each index of the vector, as illustrated in Fig. 2. Each chromosome is subjected to every constraint presented in (1). Hence, a given GA solution is evaluated as feasible only if all of intermediate solution encoded by the chromosome are feasible. The feasibility of a solution is attested if every constraint in (1) is satisfied, *i.e.*, **(i)** the topology is radial; **(ii)** voltage magnitude at every node and **(iii)** current magnitude on every line are kept within established limits; **(iv)** active and reactive power injections do not violate the DG's limits; and **(v)** the frequency is kept within a pre-defined range (both during transient and steady-state). The GA is executed in processing time, *i.e.*, the construction of the switching plan occurs within the VNS as a part of its evaluation routine. Therefore, the VNS final topology is considered feasible only if there is a feasible switching sequence to attain such state. Since there is an appropriate order for the maneuvers, it is possible to compare the ENS associated with each solution. Hence, the GA's fitness function is the ENS. Observe that the Power Not Supplied (PNS) (objective function of (1)) computes the sum of the installed capacities of every client out-of-service, while the ENS is given by the product of the out-of-service load and the outage duration. In this sense, the algorithm will favor solutions that energize first the customers with higher power demand, as long as such maneuvers are not infeasible.

Finally, it is important to highlight a secondary feature carried out by the GA. We consider the possibility that the automatic islanding may fail and the DG may need to perform black start. Additionally, we contemplate extreme scenarios wherein the substation is unable to provide the loads due to the occurrence of permanent faults and the generator must supply as many costumers as possible. In both cases, considering a fixed set-point for the DG's active power, as done in [Faria et al., 2021], can either limit the SRP's capacity (the restoration plan does not recover as many loads as possible due to frequency deviations caused by a fixed set-point) or be unfeasible (the automatic islanding may fail and this is not addressed by the SRP). In this approach, the GA also generates a black start sequence for the DGs, providing the user with the maneuvers to restore loads and alterations to the generator's set-point. If the automatic islanding does not fail, the user may disregard some of the steps proposed in the black start sequence. In Fig. 3 we provide the flowchart of the proposed optimization method, illustrating the interaction between the two metaheuristics.

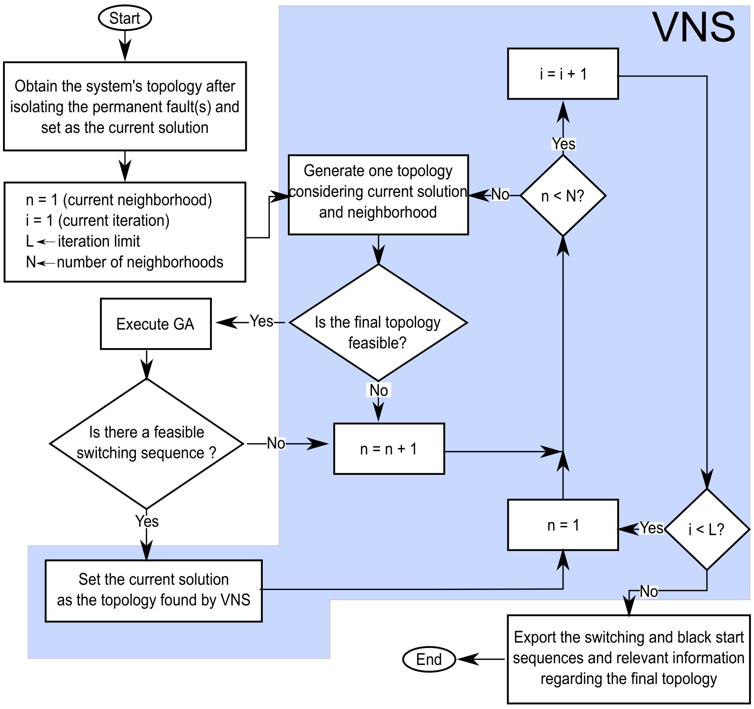

Figure 3: Flowchart of the proposed optimization method.

4. Results

4.1. Test System Data

We adopt a modified version of the test system presented in [Faria et al., 2021]. The system's topology, the DG's location and the faulty sections are illustrated in Fig. 4. Observe that the contingency scenario considered in this paper renders the substation unable to supply none of the three feeders. Hence, the DG alone must provide energy to as many loads as possible. We investigate only the feasibility of the DG's black start sequence, since the optimization model's capacity of producing feasible maneuvering sequences has already been investigated in [Faria et al., 2021]. The DG showed in Fig. 4 is a 1.5 MVA synchronous machine and its speed governor and exciter control systems are the same presented in [Faria et al., 2021]. The sequence of maneuvers and power set-points provided by the proposed optimization tool were performed in a time-domain simulation using ATP-EMTP to graphically show their feasibility. The following limits were adopted for voltage magnitude and frequency: the voltage magnitude must be kept within the range 0.95∼1.05 p.u.; during the steady-state the frequency must be kept between 58.5 Hz and 61.2 Hz; and between 56.5 Hz and 62 Hz during transients. The frequency may extrapolate the transient's threshold as long as the event does not last longer than 160 ms.

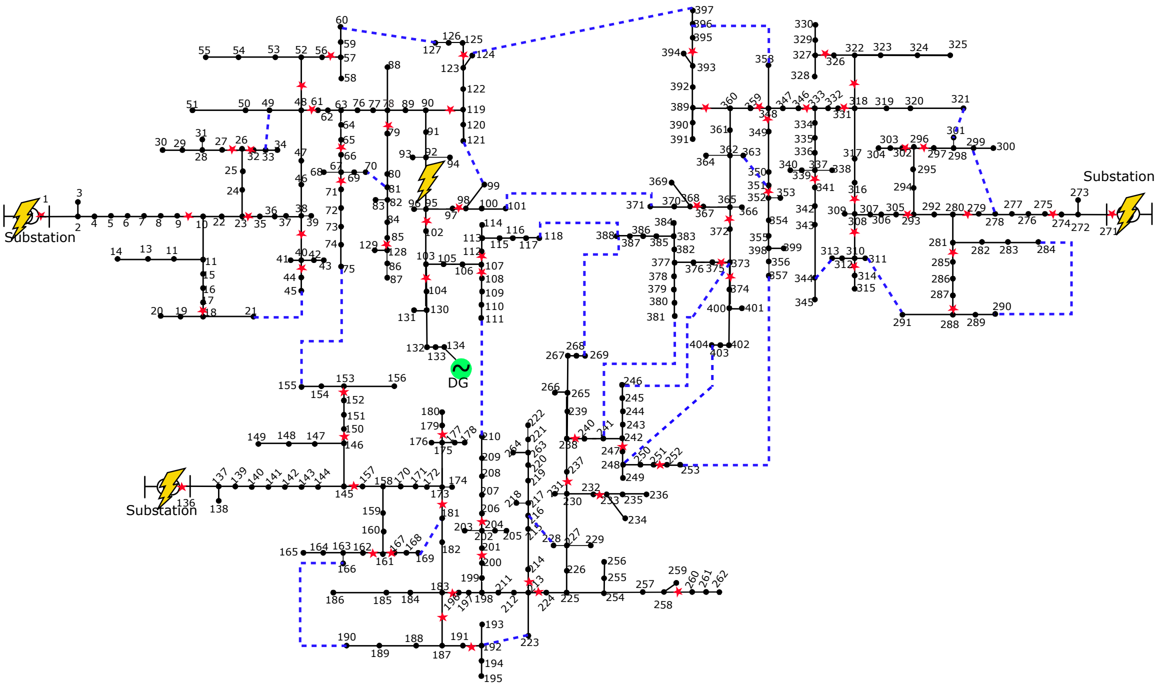

Figure 4: Test system diagram (yellow lightnings illustrate the locations of simultaneous faults, stars represent normally closed switches, blue dashed lines denote tie lines with normally open switches, black circles represent nodes and the black lines are conductors).

4.2. VNS Convergence Analysis

The optimization tool was implemented in C++ and executed on a personal computer with an Intel(R) Core(TM) i7-7700, 3.60 GHz and 8 GB of RAM. The stop criterion of the employed VNS was 55 iterations. We ran the optimization 30 times for the extreme scenario presented in Fig. 4 and obtained the same result every time. The best solution found by the method has a total of 6632.67 kW not supplied. On average, the problem was solved in 0.125 seconds. In Fig. 5 the evolution of the objective function in one of the executions is shown. The first solution (iteration 1) is penalized as it violates some of the constraints presented in (1); thus, it has an exaggerated objective function. The objective functions of feasible solutions can be better observed in the highlighted portion of Fig 5. Note that the method quickly finds the best solution (the DG injects its maximum capacity) and the search stagnates.

4.3. Black Start Sequence

The literature presents some investigations wherein the authors consider the presence of protective devices capable of islanding the DGs and some loads whenever an upstream fault situation occurs [Pereira et al., 2018; Faria et al., 2019]. However, such strategy may fail depending on balance between each DG's instantaneous power injection and their respective islands' demand [Faria et al., 2019, 2021].

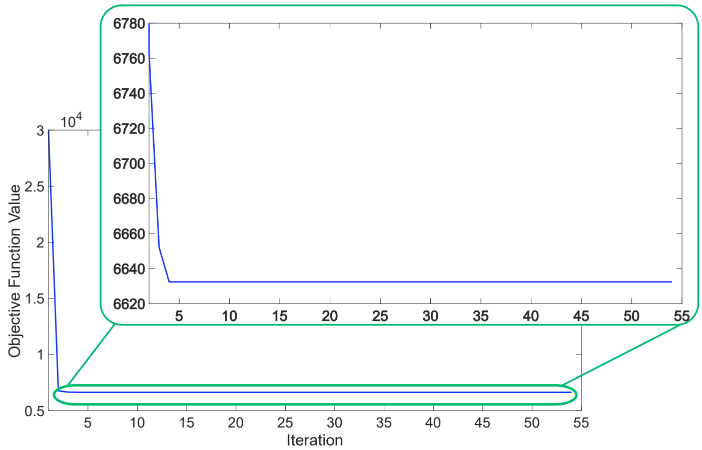

Figure 5: Objective function evolution throughout the search space exploration.

Note that, in real operation, information regarding the islands' maintenance may not be available. Hence, providing a sequence of maneuvers that assumes that every island is kept operational may be unrealistic. In this sense, the proposed algorithm presumes that every DG must black start to supply the loads, *i.e.*, the automatic islanding strategy has failed. If that is not the case, the user can disregard the first actions of the sequence.

Considering that the automatic island was not maintained is equivalent to assume that the DG has shut down [Faria et al., 2021]. Hence, the first action on the black start sequence will always be energizing the local load, *i.e.*, supply the loads connected in the same node as the DG. It is important mentioning that it is not unusual to install generators with capacity far greater than the local load demand; in this paper, the DG's load represents approximately 10% of its capacity. Therefore, the DG's active set-point must be defined accordingly to avoid over/underfrequency scenarios that may cause the DG's shut down. Observe in Fig. 6 that the DG's maximum active set-point during this phase that does not violate the frequency limits suggested in [IEEE, 2018][2] is 0.4 p.u. Note that, although the transient frequency does not surpass 62 Hz when the set-point is 0.5 p.u., the steady-state value is 61.3 Hz, which is higher than the 61.2 Hz operational limit recommended in [IEEE, 2018].

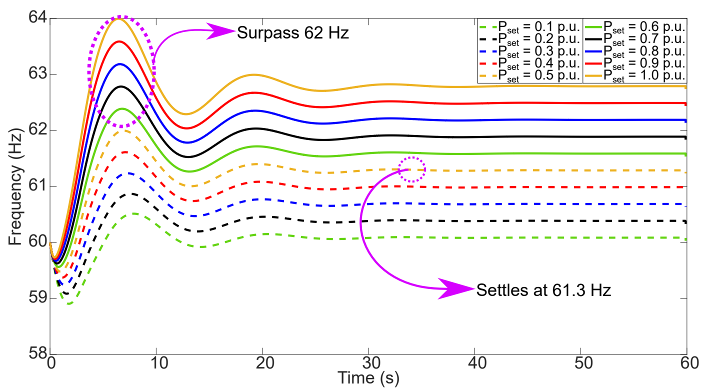

Figure 6: DG frequency behavior supplying only the local load.

[2]Lower than 62 Hz during transient and lower than 61.2 Hz during steady-state.

Next, the islanding region may be expanded by maneuvering secctionalizing switches. It is crucial to highlight that the thresholds presented in [Faria et al., 2021] for adding/removing loads into/from the island must be complied with. In this sense, the island's new demand after adding a load cannot surpass the DG's power injection in more than 0.3 p.u. (considering the DG's capacity as power base). Similarly, the island's demand after removing a load block cannot be less than 0.2 p.u. compared to the DG's instantaneous power.

4.4. Black Start Sequence with Static Active Power Set-point

One of the conclusions presented in [Faria et al., 2021] is that the DG's active power set-point determines the island's maximum and minimum demand. The critical demand must be kept within a $[-0.4, +0.5]$ p.u. range compared to the DG's set-point. In this sense, adopting the highest set-point guarantees the maximization of loads restored. As observed in Fig. 6, the maximum feasible set-point is 0.4 p.u. Hence, considering the set-point as an unchangeable parameter, the obtained optimized sequence of maneuvers is presented in Table 1, while the DG's frequency behavior is shown in Fig.7.

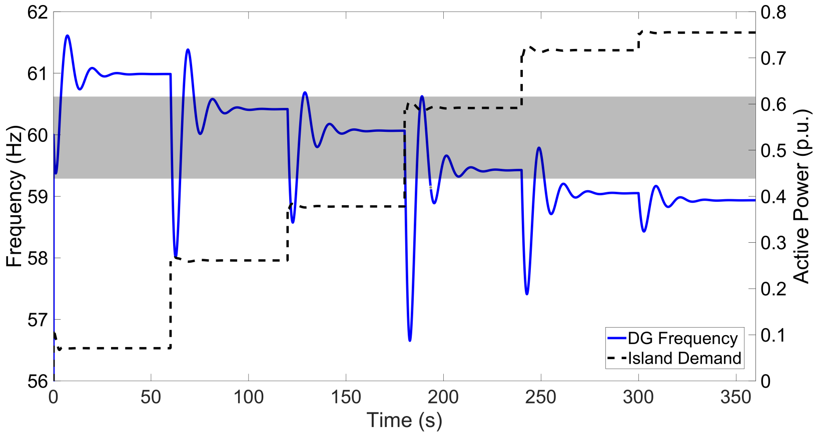

Figure 7: DG frequency behavior for case 1 - Static Set-point.

Table 1: Black Start Sequence for Case 1

Open	Close	$P_{setpoint}$	ΔP_m*	ΔP_s**	P_{island}***
95-102	-	0	-	0	0
103-104	-	0	-	0	0
107-108	-	0	-	0	0
107-112	-	0	-	0	0
133-134	-	0	-	0	0
386-387	-	0	-	0	0
Energize local load		0.4	-0.071	0.329	106.43
-	133-134	0.4	-0.191	0.138	393.06
-	103-104	0.4	-0.117	-0.021	569.03
-	107-108	0.4	-0.211	-0.190	885.11
-	107-112	0.4	-0.123	-0.313	1069.10
-	118-388	0.4	-0.038	-0.351	1126.62

* Instantaneous power mismatch, measured in p.u., caused by the switching maneuver (must be kept between -0.3 and 0.2 [Faria et al., 2021]).
** Deviation, measured in p.u., between the island demand and the machine's set-point (must be kept between -0.5 and 0.4 [Faria et al., 2021]).
*** Current island demand measured in kW.

One can notice that ΔP_m relates to the island's transient frequency, while ΔP_s affects the steady-state value. Also, observe that the DG's transient frequency does not violates the thresholds that implicates in the instantaneous action of the protection system suggested in [IEEE, 2018]. Additionally, the stead-state frequency is kept within the range 58.5$\sim$61.2 Hz, guaranteeing that the DG will not shut down due to the delayed action of protective devices [IEEE, 2018]. In this sense, this solution may be considered feasible as the DG will not be disconnected by the protection system. Nonetheless, it is important to highlight that customer satisfaction should also be taken into account when evaluating a solution. One important aspect of power quality is the frequency, which must be kept as close as possible to its nominal value. The hatched area in Fig. 7 indicates a 0.5 Hz interval around the nominal frequency.

4.5. Black Start Sequence with Dynamic Active Power Set-point

In contrast to the critical transient frequency, the island's steady-state frequency can easily be estimated as presented in [IEEE, 2018] and in (2). Using this formulation, one can calculate dynamic set-points for the DG to guarantee that the insertion/removal of each load block does not result in steady-state frequency deviations considering an acceptable interval.

$$\Delta f = R \cdot (P_{setpoint} - P_{island}) \tag{2}$$

wherein Δf represents the acceptable frequency interval, R is the machine's droop, $P_{setpoint}$ and P_{island} are, respectively, the DG's active set-point and the island's current demand. Adopting $R = 0.05$ and a 0.5 Hz frequency interval, the absolute value of the difference between the set-point and the demand must not surpass 0.16 p.u. [Faria et al., 2021]

Considering any change in the DG's set-point as a maneuver, the proposed GA must include actions of increasing or decreasing the generator's set-point in the black start sequence, guaranteeing that Δf does not violate the acceptable interval in steady-state. In this context, the new sequence is presented in Table 2 and the island's dynamic performance is illustrated in Fig. 8.

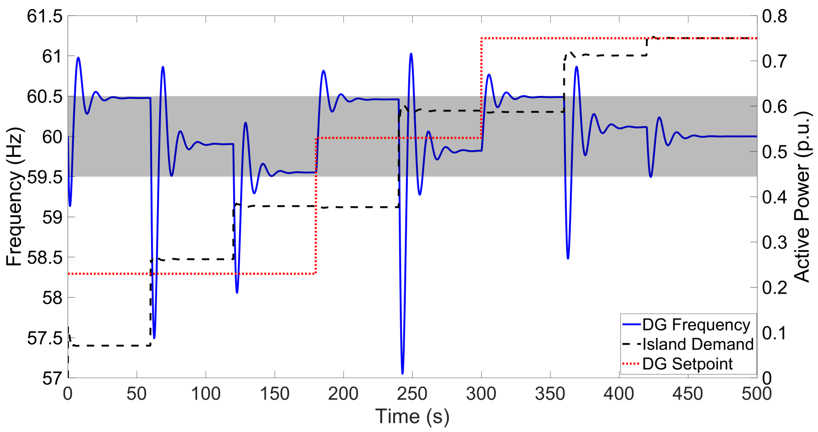

Figure 8: DG frequency behavior for case 2 - Dynamic Set-point.

Observe in Table 2 that the final value of ΔP_s is 0, which means that the frequency of the island's last stage is 60 Hz, as can be confirmed in Fig. 8. Each adjustment in the DG's set-point is accounted for as a maneuver. Hence, it is expected that the GA will try to minimize the number of corrections in this variable to minimize the system's ENS. This behavior can be noticed in the black start plan since the set-point value increases only when it is extremely necessary, *i.e.*, any other maneuver would cause the frequency to violate

Table 2: Black Start Sequence for Case 2

Open	Close	$P_{setpoint}$	ΔP_m*	ΔP_s**	P_{island}***
95-102	-	0	-	0	0
103-104	-	0	-	0	0
107-108	-	0	-	0	0
107-112	-	0	-	0	0
133-134	-	0	-	0	0
386-387	-	0	-	0	0
Energize local load		0.23	-0.071	0.160	106.43
-	133-134	0.23	-0.191	0.030	393.06
-	103-104	0.23	-0.117	-0.140	569.03
Change DG's set-point		0.53	-	0.160	569.03
-	107-108	0.53	-0.211	-0.060	885.11
Change DG's set-point		0.75	-	0.160	885.11
-	107-112	0.75	-0.123	0.040	1069.10
-	118-388	0.75	-0.038	0.000	1126.62

* Instantaneous power mismatch, measured in p.u., caused by the switching maneuver (must be kept between -0.3 and 0.2 [Faria et al., 2021]).
** Deviation, measured in p.u., between the island demand and the machine's set-point (must be kept between -0.5 and 0.4 [Faria et al., 2021]).
*** Current island demand measured in kW.

the acceptable interval in steady-state. It is important to highlight that, even though the new sequence has two more maneuvers than its previous version, the additional time is negligible when compared to the typical duration of permanent faults. Moreover, the black start sequence considering multiple set-points not only addresses the island's feasibility protection-wise but also contemplates a power quality aspect.

5. Conclusion

In this paper we investigated the use of a hybrid VNS-GA optimization tool to solve the SR problem considering the presence of decentralized generation. The proposed method is capable of generating feasible SRPs, guaranteeing the feasibility of the intermediate solutions throughout the application of the augmented optimization model presented in [Faria et al., 2021]. We focused on restoration process under extreme situations to test the proposed algorithm since the augmented optimization problem had already been applied to restore a DS considering the automatic island formation. In this sense we evaluated the hybrid optimization tool's performance in providing black start sequences. Nonetheless, the tool is also able to provide SRPs for conventional fault scenarios.

Besides the proposal of a novel tool for solving the SR problem, this paper contributes to the field as it considers an important and practical aspect of service restoration considering island operation. The proposal of maneuvering sequences does not rely on the automatic islanding success, *i.e.*, the method suggests sequence of actions starting from the energization of the DG's node. In a scenario wherein the automatic islanding is successful, the user may disregard the first steps of the sequence. Furthermore, we consider the possibility of dynamically changing the DGs' active power set-point throughout the restoring process. As a result, the user may create an acceptable steady-state frequency interval, which will be guaranteed by the switching maneuver. A 405-bus test system was employed for testing the tool and time-domain simulations were carried out in ATP-EMTP to attest the feasibility of the proposed black start sequences.

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