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Source Resizing and Improved Power Distribution for High Available Island Microgrid: *A Case Study on a Tunisian Petroleum Platform*

MOHAMED GHAIETH ABIDI[1,2], MONCEF BEN SMIDA[2,3], MOHAMED KHALGUI[1,2], ZHIWU LI[4,5], AND TING QU[6]

[1]School of Intelligent Systems Science and Engineering, Jinan University (Zhuhai Campus), Zhuhai 519070, China
[2]National Institute of Applied Sciences and Technology, University of Carthage, Amilcar 1054, Tunisia
[3]LSA Lab, Tunisia Polytechnic School, University of Carthage, Amilcar 1054, Tunisia
[4]Institute of Systems Engineering, Macau University of Science and Technology, Macau 999078, China
[5]School of Electro-Mechanical Engineering, Xidian University, Xi'an 710071, China
[6]School of Electrical and Information Engineering, Jinan University (Zhuhai Campus), Zhuhai 519070, China

Corresponding authors: Mohamed Khalgui (khalgui.mohamed@gmail.com) and Zhiwu Li (zhwli@xidian.edu.cn)

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ABSTRACT A microgrid is a small-scale smart network that contains distributed resources and loads and serves several technical, economic, and environmental aims. In this kind of power system, the energy generated by different sources is often collected in an adequate bus system (ac or dc busses) and transported to loads across a distribution system. In case of islanding operation of a microgrid, each production insufficiency or distribution system fault can cause a partial or total interruption of power supply required by loads of the microgrid. This unavailability can last longer because of the randomness and intermittent behavior of renewable sources and the importance of the maintenance actions of the distribution system. To guarantee high availability of power supply, microgrid must be able to produce and to transfer the power energy requested by loads. The sizing of distributed sources and the design of the distribution system present an important challenge to achieve this goal. This paper offers a new global methodology carried out in two steps: in the first, it aims to optimize the source sizing by adding some microsources for ensuring the balance between sources production and loads requirement, then, in a second step, it aims to enhance the distribution system design by the creation of new paths of power transmission for transferring the produced energy from sources to loads. The proposed optimization methodology aims to achieve the requested availability rate requested by each load (considering their priorities) by taking into account some technical and economic factors. In this methodology based on genetic algorithms, objective functions are defined, and several electrical and economic constraints are formulated. The graph theory is used to represent the architecture of the microgrid distribution system, and Matpower tool of MATLAB is used to model it. An application and implementation of the proposed optimization methodology in a Tunisian petroleum platform indicate that the proposed solution is efficient in optimizing of power supply availability in its microgrid.

INDEX TERMS Distribution system, genetic algorithm, microgrid, power supply availability, sources sizing.

NOMENCLATURE

$A(N_i^j)$	Availability rate of N_i^j
$C(L_{kl}^{ij})$	Cost of E_{kl}^{ij}
ξ	Electrical distribution system
E_{kl}^{ij}	Edge between N_i^j (the starting node) and N_k^l (the end node)
L_{kl}^{ij}	Electrical line between Sw_i^j (the starting switchgear) and Sw_k^l (the end switchgear)
$L(L_{kl}^{ij})$	Connection length of E_{kl}^{ij}
MD	Matrix of distances between the nodes
$Max(L_{kl}^{ij})$	Maximum allowable transmitted power of E_{kl}^{ij}
N_i^j	$j^t h$ node in the $i^t h$ level
$P(L_{kl}^{ij})$	Transmitted power by E_{kl}^{ij}

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$P_L(N_i^j)$ Power demanded by the loads directly connected to N_i^j
$P(N_i^j)$ Nominal power of N_i^j
Sw Switchgear
Sw_i^j j^th switchgear in the i^th level
$\lambda(L_{k^l}^{i^j})$ Failure rate of $E_{k^l}^{i^j}$
ρ Recoverability index

I. INTRODUCTION

Since its appearance, electrical energy has gained significance in several fields of human activity [1]. Its availability has become increasingly important for many applications (factory, hospital, military base, etc.) [33]. For this type of applications, even temporary dysfunction of some loads due to unavailability of electrical energy may cause important economic losses or be dangerous for human safety. These loads must have a permanent supply in order to be able to operate without any interruption [32]. In these sectors, the electrical energy availability is considered as a major factor.

In order to improve the electrical energy availability, minimizing the negative effect of the intermittent, uncontrollable and stochastic behavior of power sources [50] is unavoidable. For this reason, recent researches focus on the optimization of the choice, allocation, and sizing of sources [18], [31], [43]. An adequate choice of energy sources and an optimized sizing of sources present crucial factors to reach a high level of power availability and to prevent frequent blackouts caused by production insufficiency in microgrids. In order to resolve this complicated task, various optimization methods have been proposed ranging from single objective optimization to multiobjective optimization approaches. Most studies of optimal sizes of sources that use multiobjective optimization approaches combine the economic, technical and environmental criteria into a single objective function. In this context, different methods have been used. Queuing multi-objective optimization (QMO) [53], intelligent Pareto-search genetic algorithms (IPSGA) [23], and evolutionary algorithms (EA) [47] present the most recent and the popular multi-objective methods used to optimize the source sizing in the microgrid. In the case of single objective optimization approaches, researchers usually choose the cost as an objective function and take the reliability of electrical energy as the only constraint. In some works, linear programming techniques are used to resolve the sizing problem [52]. However, the use of these techniques is limited, especially for complicated microgrids. The main optimization approaches used for this kind of microgrids are the probabilistic approaches, graphical construction methods [48] and enumerative/iterative methods (used by HOMER software [55]). By using the probabilistic approach, the proposed sizing is not generally the most optimized solution. Graphical construction methods are limited by the degree of the problem complexity. It can be used only in microgrids that use two types of sources. Over the past decades, the literature on complex problems (especially combinatorial problems) solving shows a variety of approaches called metaheuristic and heuristic. Genetic algorithms (GA), hybrid gray wolf optimizer (HGWO) [34], particle swarm optimization (PSO) [9], tabu search (TS) [56], and artificial bee colony (ABC) [6] are metaheuristic and heuristic algorithms that have also been frequently used for solving source sizing problem. In both optimization approaches, the choosing methodology has to define the objective function. Levelized cost of energy (LCOE) and net present value (NPV) are suggested to highlight the economic profitability of the proposed solution. In this field of research, some technical factors are considered. These factors are mainly the power availability (PA), the loss of power supply probability (LPSP), the deficiency of power supply probability (DPSP), the total energy deficit (TED) [3] and the loss of load probability (LOLP) [12], [41]. To evaluate the reliability of the customer load points in a microgrid, the customer average interruption duration index (CAIDI), the system average interruption frequency index (SAIFI), the system average interruption duration index (SAIDI), the energy not supplied (ENS) and the average energy not supplied (AENS) indices are frequently used by Cheng *et al.* [57].

The self-sufficiency of power production is not the only constraint to meet the energy demands of loads. An electrical distribution system should be used to transfer the produced energy to these loads. Each breakdown in this system can cause a partial or a full unavailability of electrical energy and the level of loads. Generally, these problems are caused by the failures of the network components (essentially the connection lines [39]). Although the high reliability of distribution system components, the system availability is negatively influenced by the long duration of the maintenance actions.

The reduced scale of microgrids compared with traditional power systems presents a technical and economic advantages that make the architecture design of the distributed systems more flexible. Several works are focussed on the influence of microgrid architecture on the power supply availability [4], [22]. In this context, some researchers are interested in improving the distribution system reliability by using reconfiguration and fault recovery strategies [37], [38]. The reconfigurable systems offer the necessary flexibilities that they exploit in order to maintain an adequate quality of service despite the presence of disturbances [14], [25], especially in the case of a real-time reconfiguration [15], [51]. In order to ensure the continuity of service, even in case of fault occurrence, several studies show that the distribution system must be reconfigurable to enhance its reliability and flexibility. Until now, the reconfiguration task presents a very complex combinatorial, non-differentiable and non-linear mixed integer optimization problem [40]. To solve this problem, different solutions, that deal with heuristic methods, are based on the expert system (ExS) [11], artificial intelligence (AI), genetic algorithm (GA) [54], artificial neural network (ANN) [21], gray wolf optimization (GWO) [7], tabu search (TS) and particle swarm optimization (PSO) [8]. In order to evolve the performance of a solution, researchers must use indices that can highlight the impact of the used optimization strategy. The expected outage cost (ECOST), the expected energy not supplied (EENS), the expected demand not supplied (EDNS), and the energy index of reliability (EIR) present some examples of the reliability index used by Elsaiah *et al.* [42]. Even some proposed methods are simple to use, they take a long time to verify constraints. In addition, the majority of the proposed solutions does not take into account the impact of the control strategy and load priorities in the optimization solution.

These different researches show that the availability of energy depends mainly on the capacity of the sources to produce the required energy and the capacity of the distribution system to transfer it to the loads. For this reason, this study aims to optimize the source sizing and distribution system availability in order to improve the availability of power supply requested by each load. This paper suggests a design assistance methodology based on Genetic Algorithms that can be used to enhance the availability rate of power supply in an existing microgrid efficiently and economically. Contrary to other solutions, this methodology can be used in any microgrid, by taking into account its current state and propose the least expensive modifications. This proposed solution presents a global optimization methodology that is done in two steps:

- In the first step, this methodology aims to enhance electrical power production by optimizing the number of distributed generation sources. In the first step, this methodology aims to enhance the electrical power production by optimizing the number of distributed generation sources. The objective of this step is to ensure a self-sufficiency of power generation in a microgrid by acting on source sizing. According to the power supply requirement for loads, we defined various levels of production to which sources have to reach. Source sizing methodology must ensure that the probability to reach each production level is at least equal to the availability rate requested by the loads supplied at this level. This methodology takes into account the demand side flexibility (by load shedding) to reduce the energy requirements during the sources sizing. To evaluate this solution, LCOE is chosen as an economic index.
- In the second step, the optimization methodology aims to ensure the transfer of the produced energy to loads. This methodology is based on the creation of new paths of power transmission [19] by adding some electrical lines between switchgears. New paths become in passive redundancy with the initial path in the network and can replace them in the event of a defect in order to avoid any power supply interruption. To choose the lines to be added, a binary genetic algorithm is proposed. This type of algorithms is characterized by its fast convergence. Each line that can be added is presented by a bit, i.e., this bit is equal to '1' if this line is added, and 0 in the opposite case. These bits will be used to activate or deactivate connections in modeling the system of distribution on Matpower tool in order to determine the influence of these connections on the energy flow. A recoverability factor that reflects the distribution system ability to meet the availability requirements of loads is defined. This factor takes into account the priority level of the various loads connected to the microgrid and reflects the ability of the distribution system to meet the needs of loads on power supply availability. The cost of distribution system optimization depends on the sections of cables to be added that can be determined according to the electric currents passing through these new lines. Matpower tool for Matlab is used to determine these currents in order to facilitate the calculation of the optimization cost.

Compared with others solutions based on heuristic methods (PSO [17], and ABC [16]), GA requires fewer adjustable parameters. Binary coding for distribution system optimization improves the speed of the algorithm convergence by comparing with studies that use other types of coding. Sizing sources by changing the number of microsources also has the same impact on the algorithm convergence. ii. The proposed method of sizing takes into account the difference of the loads classes to minimize the cost. LCOE is used to determine this cost for projected life cycle costs. For distribution system optimization, we defined a new performance factor called a recoverability index. Generally, the factors used in the other works are based on the average values of reliability and availability [30]. The proposed factors can determine the ability of the distributed system to meet load requirements by calculating the difference between the availability value achieved and that requested at the level of each load. By using this factor, the algorithm can be oriented to increase the recoverability of loads that have an insufficient availability rate.

In this study, the microgrid distribution system is modeled by a directed graph that takes into account the probability aspect of the faults. Matpower tool for Matlab is used for modeling the distribution system to facilitate the calculation of the optimization cost [58]. This tool reduces the calculations complexity, minimizes resolution time, and facilitates the evaluation of each potential solution on the technical (availability) and economic (cost) scale [35].

To verify its efficiency, this optimization strategy was used to optimize the power supply availability in a Tunisian petroleum platform. The test results confirm the efficiency and promptness of the proposed solution. This solution enhances the power supply availability at the level of loads, the energy unavailability is reduced to half of its initial value. Accordingly, the productivity of the platform increases and the Tunisian government earns more than 20 thousand dollars as an additional profit.

This paper is structured as follows: In the Section II explains the formalization and introduces the problem. The third Section proposes the methodology used by the proposed solution to guarantee an optimal availability. In Section IV,

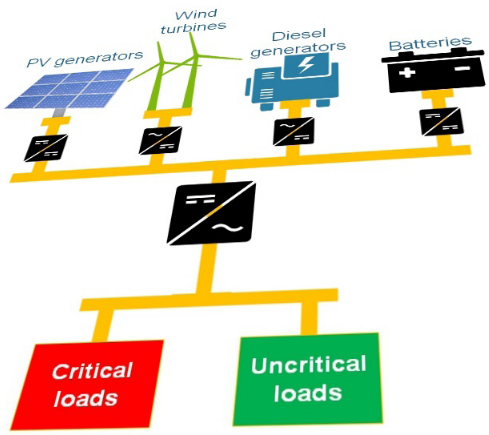

FIGURE 1. Schematic diagram of microgrid.

the case study and evaluate the performance of the proposed solution is discussed. Finally, Section V concludes the paper.

II. FORMALIZATION AND PROBLEM

In this section, the proposed formalization of the microgrid energy sources and distribution system is described and the problem is introduced.

A. FORMALIZATION OF ENERGY SOURCES

The considered microgrid in this paper is composed of four kinds of sources α_S, (e.g., wind turbines {WT}, photovoltaic generators {PV}, diesel generators {GE} and batteries {B}), that supply two sets of loads β_L (e.g., critical loads {C} and uncritical loads {NC}) as described in Fig.1.

For each kind of source S_i $(i \in (\alpha_S = (PV, WT, B, GE)))$, there are n^i microsources defining subset $S_{S_i} = \{S_i^1, \ldots, S_i^{n^i}\}$. Each kind of source S_i is characterized by (i) nominal power $P(S_i)$, (ii) availability rate $A(S_i)$ (capable of being used), (iii) penetration state $S(S_i)(t)$ (connected to provide electrical power to the network or not), and (iv) cost $C(S_i)$. For each of sources, all microsources are identical. So, all microsources of type S_i denoted by S_i^j are characterized by the same (i) nominal power $P(S_i^{ms})$, and (ii) cost $C(S_i^{ms})$.

$$\begin{cases} P(S_i) = n^i \times (P(S_i^{ms}) \times S(S_i)(t)) \\ C(S_i) = n^i \times C(S_i^{ms}) \end{cases} \tag{1}$$

The loads β_L can be classified according to their priority. There are two classes of loads defining subsets β_{L_C} for critical loads and $\beta_{L_{NC}}$ for uncritical loads. Each class of load is composed by m^p loads defining subset $L_{p\in(C,NC)} = \{L_p^1, \ldots, L_p^{m^p}\}$. Each subset of loads L_p is characterized by (i) nominal power $P(L_p)$, (ii) requested power availability $A(L_p)$, and (iii) connection state $S(L_p)(t)$.

The considered microgrid consists of two renewable sources (PV, WT) and two backup energy sources (B and GE) that feed two different categories of loads (critical and uncritical loads). Modeling these components is a fundamental step to optimize the sources sizing.

1) PHOTOVOLTAIC GENERATORS

In this paper, a simplified model of photovoltaic generator (PV) is used as follows [49]:

$$P_{PV}(t) = \eta \times Ap \times N_{PV} \times E(t) \tag{2}$$

where $P_{PV}(t)$, η, Ap, N_{PV} and $E(t)$ are respectively the PV output power, the energy conversion efficiency (%), the area of a single PV module, the number of PV modules, and the solar radiation value.

2) WIND TURBINES

A wind turbine transforms the kinetic energy of the wind in electrical energy. This generated power depends on wind velocity. The equation that describes the output power P_{WT} of a wind turbine is as follows [45]:

$$P_{WT} = \begin{cases} 0 & V \leq V_{cut-in} \\ P_{rated} \times (\dfrac{V - V_{cut-in}}{V - V_{rated}})^3 & V_{cut-in} \leq V \leq V_{rated} \\ P_{rated} & V_{rated} \leq V \leq V_{cut-off} \\ 0 & V > V_{cut-off} \end{cases} \tag{3}$$

where V, V_{cut-in}, V_{rated} and $V_{cut-off}$ are the actual, cut-in, rated and cut-off wind speeds respectively. P_{rated} is the power rated of the wind turbine.

3) BATTERIES

At any time t, the energy stocked in the battery ($E_B(t)$) can be calculated according to its previous state in $t-1$ and the energy balance established between sources production and loads consumption. The battery can be (i) connected in charge mode if there is an excess of energy produced by the renewable sources, (ii) connected in discharge mode if there is deficit of energy produced by other sources, or (iii) disconnected if the energy produced by other sources equals to the loads demand. $E_B(t)$ is given by [12]

$$E_B(t) = \begin{cases} \textit{In charge mode}: \\ \quad E_B(t-1)(1-\sigma) + (E_S - \frac{[E_L]}{\eta_{inv}})\eta_B \\ \textit{In discharge mode}: \\ \quad E_B(t-1)(\sigma - 1) + (E_S - \frac{[E_L]}{\eta_{inv}}) \\ \textit{In disconnected mode}: \\ \quad E_B(t-1) \end{cases} \tag{4}$$

where $E_{B-1}(t)$ and $E_B(t)$ are the energy stocked in battery (Wh) at particular time $t-1$ and t, respectively; σ is the hourly self-discharge rate, $E_L(t)$ and $E_S(t)$ are respectively the energy consumed by the loads and the energy produced by the sources at particular time t; η_{inv} and η_B are respectively the efficiency of the inverter and the charge efficiency of the battery.

To avoid the overcharging and undercharging of battery, E_B must respect the following constraint at each time t:

$$E_B^{min} \leq E_B(t) \leq E_B^{max} \tag{5}$$

where E_B^{max} is the maximum energy stored in the battery, it equals to the value of nominal capacity of the battery bank, and E_B^{min} is the minimum energy stored to avoid the phenomenon of sulfation.

4) DIESEL GENERATORS

The diesel generators are used if PV generators, wind turbines and batteries production are insufficient. In this study, they are used to supply critical loads only. The energy produced by the diesel generator can be described as follows:

$$E_{GE}(t) = P_{GE} \times H_o \tag{6}$$

where P_{GE} is the rated power and H_o is the number of operation hours.

$P_{GE}(t)$ is bounded as follows [29]:

$$P_{GE}^{min} \leq P_{GE}(t) \leq P_{GE}^{max} \tag{7}$$

where P_{GE}^{max} is the maximum power of the diesel generator, and P_{GE}^{min} is the minimum power that can be produced by it.

B. FORMALIZATION OF DISTRIBUTION SYSTEM

An electrical distribution system (EDS) transfers the energy produced by the available sources to the connected loads. The available energy in the AC bus should be distributed to the connected loads. A distribution system is mainly composed of Sl levels of the switchgears Sw that are usually in tree topology as shown in Fig.2. These switchgears are linked between them by using some electrical lines L to power-supply the loads. Each level i ($i \in (1, .., Sl)$) is composed of sg_i switchgears defining the set $\{Sw_i^1, \ldots, Sw_i^{sg_i}\}$. A switchgear is subdivided into incoming CB_i and outgoing CB_o circuit breakers.

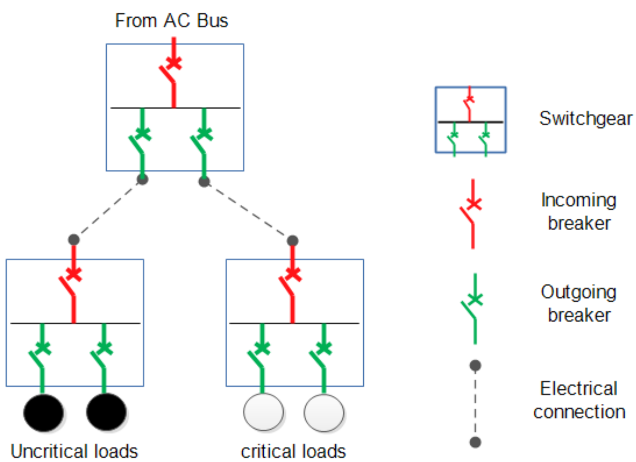

FIGURE 2. **An example of a distribution system.**

Sw_i^j is the j^{th} switchgear in the i^{th} level. L_{kl}^{ij} is the electrical line that links Sw_i^j and Sw_k^l. In this study, the electrical distribution system is modeled by an acyclic graph as described in Fig.3. In this figure, each switchgear Sw_i^j is modeled as a node N_i^j. Each electrical line L_{kl}^{ij} that ensures the power

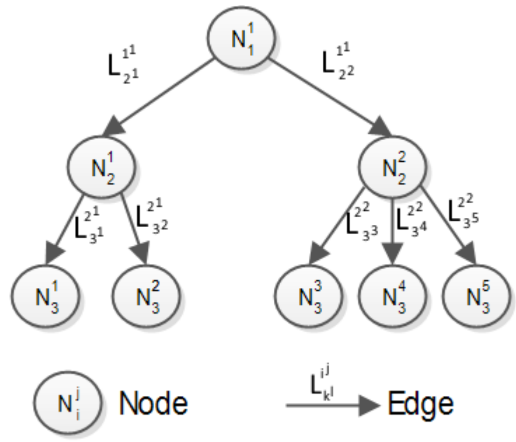

FIGURE 3. **A directed graph of the distribution system.**

transmission between Sw_k^l and Sw_i^j is presented by an edge E_{kl}^{ij}. In fact, this electrical distribution system (ξ) can be written as:

$$\xi = (\upsilon, \epsilon) \tag{8}$$

where υ is a set of nodes and ϵ is a set of edges.

Each node (switchgear) N_i^j is characterized by (i) the rate of power availability $A(N_i^j)$, and (ii) the nominal power $P(N_i^j)$. If N_i^j feed directly q loads $\{L_1 N_i^j, \ldots, L_q N_i^j\}$, then N_i^j called loaded node and it will be characterized by a requested power supply availability $A_r(N_i^j)$. In this case, each load $L_g N_i^j$ ($g \in (1, \ldots, q)$) is characterized by (i) the demanded power $P(L_g N_i^j)$, (ii) the power supply availability $A(L_g N_i^j)$, (iii) the requested power supply availability $A_r(L_g N_i^j)$, (iv) the length of the connection $L_n(L_g N_i^j)$ that linked the node N_i^j to the load $L_g N_i^j$, and (v) the failure rate of this connection $\lambda(L_g N_i^j)$.

Each edge (electrical line) E_{kl}^{ij} is characterized by (i) the connection length $L_n(E_{kl}^{ij})$, (ii) the failure rate $\lambda(E_{kl}^{ij})$, (iii) the cost $C(E_{kl}^{ij})$, (iv) the maximum allowable transmitted power $P_{max}(E_{kl}^{ij})$ that depends on the cable cross section $S(E_{kl}^{ij})$,(v) the resistance $R(E_{kl}^{ij})$, (vi) the current passing through the connection $I(E_{kl}^{ij})$, and (vii) the transmitted power by the connection $P(E_{kl}^{ij})$.

Each node receives electrical energy from its predecessor and injects this power to its successors. In an ordinary distribution system, each node has only one predecessor and have two circuit breakers levels: (i) a circuit breaker to control the power supply reception, and (ii) the other circuit breakers control the power transmission by this node to its successors. For an EDS composed of z switchears, its graph represents z nodes and $z - 1$ edges. This graph can be modeled by ($z \times z$) matrix (MD). The (i^j,k^l) cell of this matrix represents the distance between the nodes N_i^j and N_k^l. If there is a connection between these nodes, then (i^j,k^l) cell will be colored in gray.

C. PROBLEMS

In a microgrid, the production insufficiency and the distribution system breakdown can cause a power supply unavailability for the loads.

1) SOURCE SIZING PROBLEMS

The improvement capacity of the power supply availability is one of the fundamental benefits of the microgrid concept. Accordingly, the microgrid can ensure a high availability of the electrical power even if it operates in the isolated mode (it cannot have recourse to an external power source). In this microgrid function mode, only local sources are used and the microgrid should guarantee its energy self-sufficiency. The renewable energy sources (photovoltaic generators and wind turbines) are characterized by their intermittent behavior. The backup sources (batteries and diesel generators) have a limited autonomy. Despite these problems, the sources should be able to produce the totality of the electrical power requested by the connected loads, i.e.,

$$\sum_{i=1}^{\alpha_S}\sum_{j=1}^{n^i} S(S_i^j) \times P(S_i^j) \geq P(L_C)) + P(L_{NC})) \tag{9}$$

Each defect in the sources or resources can decrease the energy production level and might upset the balance between loads demand and local sources production. The sources should be sized in an efficient and economic way.

2) DISTRIBUTION SYSTEM PROBLEMS

The electrical distribution system (EDS) plays an important role to insure the transfer of the requested electrical energy from the sources to the loads. Every defect at this system level causes an incapacity to feed certain loads. In this study, it is assumed that the sources are always capable of producing the energy required by the loads. The aim of this paper is to guarantee that there is at least an available electrical path (as shown in Fig.4) that connects the integrated sources and the loads at each time t.

The power quantity requested by each load has to follow some specific paths via various nodes interconnected by electrical lines to provide the electrical energy demands of loads (Fig.4). The electrical cables represent the basic element of the distribution system. Each fault occurrence in some cables can cause a partial or a full unavailability of power supply at the level of loads. The power supply availability in each node is influenced by the power availability in their predecessors' nodes and the reliability of the connections that liked them, as well as the capability of the electrical distribution system to transfer the power to the loads. The first node N_1^1 is called root node. At this level, the availability rate of electrical is assumed equal (100%).

$\lambda(E_{k^l}^{ij})$ is the failure rate of the connection between nodes N_i^j and N_k^l. It is approximately proportional to its length $L(E_{k^l}^{ij})$ as shown in Equation (10), i.e.,

$$\lambda(E_{k^l}^{ij}) = \alpha \times L(E_{k^l}^{ij}) \tag{10}$$

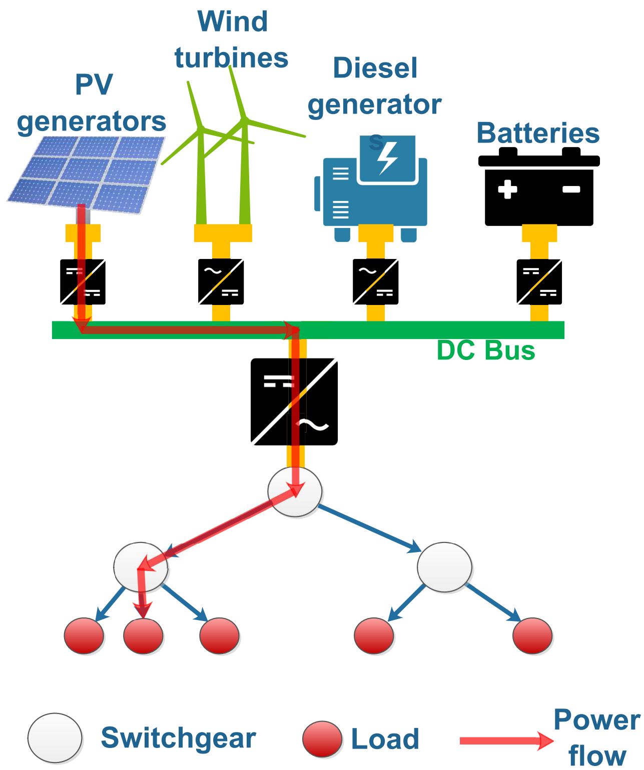

FIGURE 4. An example of an electrical power flow.

where α presents the failure rate of the electrical line $L(E_{k^l}^{ij})$ per unit of length.

If node of N_k^l has one only predecessor N_i^j, then its power supply availability can be computed by Equation (11), i.e.,

$$A(N_k^l) = A(N_i^j) \times (1 - \lambda(E_{k^l}^{ij})) \tag{11}$$

In this case (only one predecessor for each node), the electrical energy will become unavailable for some loads in each connection failure, which requires an action of maintenance to eliminate the defect. Typically, this type of defect is followed by a corrective maintenance action that can take a lot of time. This time affects negatively the availability rate of energy (Equation (12)).

$$Availability = \frac{MTBF}{MTBF + MTTR} \tag{12}$$

where MTTR (Mean Time To Repair) is the average time required to repair a failed system or component, and MTBF (Mean Time between Failure) is the average time between two failures in case of repairable system or component.

Generally, the duration of the corrective maintenance action cannot be decreased, but can our need for it can be reduced. So, some recovery connections that will be used in case of default should be added. Even a total redundancy of connections can ensure high availability, this solution is very expensive. For this reason, the cost of connections to add should be minimized while respecting the objective to have an optimized availability. The added connections must have a cross sections that allow to transfer energy between the nodes.

In this case, the connection cost $C(E^{ij}_{kl})$ is proportional to its length $L(E^{ij}_{kl})$ and its cable cross section $S(E^{ij}_{kl})$. It is given by Equation (13).

$$C(E^{ij}_{kl}) = \beta \times S(E^{ij}_{kl}) \times L(E^{ij}_{kl}) \tag{13}$$

where β is the connection cost per unit of length and power.

III. METHODOLOGY FOR HIGH AVAILABLE ISLAND MICROGRID

The main goal of the paper is to propose a new design support methodology for the island microgrids. This methodology can help us to optimize the electrical power availability in an island site by acting on the sources sizing and the distribution system flexibility.

A. MOTIVATION

This paper presents a novel methodology that can minimize as much as possible the risks of a power supply unavailability at the level of loads by acting on two main elements of the microgrid (sources and distribution system). This methodology can be used in conception or optimization (in case of insufficient availability of energy production) phase of microgrids. It can help us to avoid a power production insufficiency in an island site by acting on sizing of its local sources. The connection failure presents the second source of power unavailability for the loads. The failure of the distribution system can prevent the transfer of the energy collected towards loads. To insure the transmission of the energy produced by sources to loads, this methodology has to modify the distribution system architecture. To ensure a high availability rate of loads power supply, the distribution system should be flexible, reconfigurable, and fault-tolerant. In case of fault occurrence, this reconfigurable system can modify the path of power flow in order to supply loads. To achieve this object, some inexistent connections should be added to create new path of power flow and some existent connections should be resized to take into consideration the increase in the power transmission.

B. SOURCE SIZING OPTIMIZATION

This section describes the proposed optimization solution of source sizing based on the genetic algorithm methodology.

1) PROPOSED OPTIMIZATION SOLUTION

To solve the sizing/resizing problem, this article introduces a new genetic algorithm methodology (Fig.5). This methodology optimizes the number of microsources for each type of source, each number of them presents a gene. These genes constitute the chromosome $[n^{pv} \mid n^{WT} \mid n^{B} \mid n^{GE}]$, where n^{pv}, n^{WT}, n^{B}, and n^{GE} are respectively the numbers of photovoltaic, wind turbine, battery, and diesel generator microsources. Each chromosome presents a generation. Based on its fitness value, some genes are selected then evolve by application of two types of genetic operations (mutation or/and recombination) to generate new chromosomes in the upcoming generation.

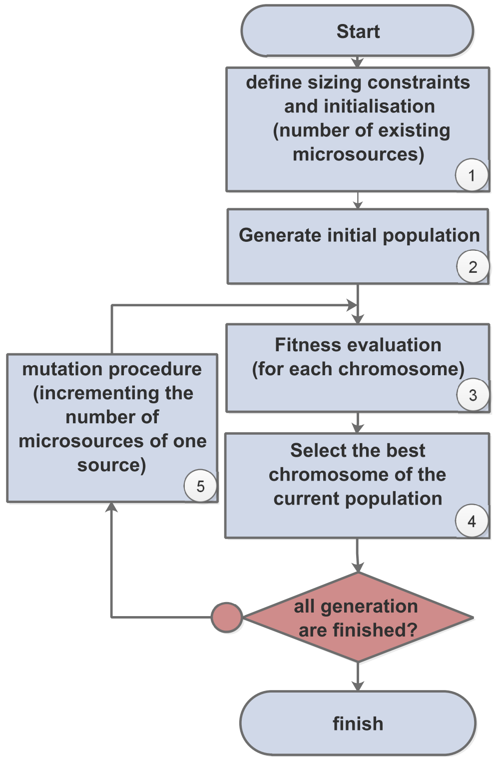

FIGURE 5. Flowchart of resizing algorithm.

As shown in Fig.5, the proposed optimization methodology is described as follows:

1) Define (i) genes that constitute the chromosome (numbers of the existing sources) (ii) the intervals in which these numbers vary, and (iii) the quantity and availability rate of energy requested by loads.
2) Generate initial population. The numbers of the existing microsources present the initial generation.
3) Measure the performance of new generated solutions by using the fitness function (Equation (16)).
4) Select the best solution (Equation (17)) of all the proven solutions (that verify Equation (18)) of the new population.
5) Generate a new generation by adding one microsource of one type of source in the selected solution.

To determine the performance of each solution from an economic viewpoint, the levelized cost of energy (LCOE) is used. The cost factor presents a constraint to be taken into consideration during the microgrid optimization [27]. LCOE presents the net present value of the electricity produced by sources during their lifetimes [2], [20] by taking into account several internal cost factors [5]. Traditionally, to set a minimum price of electricity for the consumer, the levelized cost of electricity is calculated by dividing the total net present cost over the lifecycle of the project by the total energy produced. LCOE allows the comparison of different technologies (e.g., PV, wind turbine) of unequal life spans, project size, different capital cost, risk, return, and capacities. LCOE is given by

$$LCOE(S_i) = \frac{\sum_{y=1}^{Ts} costs\ of\ (S_i)}{\sum_{y=1}^{Ts} electrical\ energy\ produced\ by\ (S_i)} \tag{14}$$

where:

$$\begin{cases} \sum_{y=1}^{Ts} costs\ of\ (S_i) = \sum_{y=1}^{Ts} \frac{I_y + M_y + F_y}{(1+r)^y} \\ \sum_{y=1}^{Ts} electrical\ energy\ produced\ by\ (S_i) \\ \qquad = \sum_{y=1}^{Ts} \frac{E_y}{(1+r)^y} \end{cases} \tag{15}$$

where (a) I_y is the investment expenditures in year y, (b) M_y is the operations and maintenance expenditures in y, (c) F_y is fuel expenditures in y (in case of non-renewable energy source), (d) E_y is the electrical energy generated in y, (e) r is the discount rate, and (f) Ts is the expected power station or system lifetime.

Calculating and comparing LCOE can:

- Measure value across the longer term, showing projected life-cycle costs.
- Highlight opportunities for Tribes to develop different scales of projects (facility, community, or commercial).
- Inform decisions to pursue projects on an economic basis, compared with utility rates.

By using the LCOE of each type of source, we can calculate the cost LCOE$[n^{PV}, n^{WT}, n^B, n^{GE}]$ of each combination of sources (each chromosome) [44]. The objective of determining the LCOE of each combination is to find the cost among all combinations of sources in order to choose the economic solution.

The fitness of chromosome is given by

$$Fitness = \frac{1}{LCOE[n^{PV},\ n^{WT},\ n^B,\ n^{GE}]} \tag{16}$$

2) MINIMIZATION OF THE COST

The objective function of the proposed methodology is to minimize the cost (Min_{cost}) of sizing/resizing of sources. The solution with the lowest value if LCOE must be chosen:

$$Min_{cost} = Minimize\ LCOE[n^{PV},\ n^{WT},\ n^B,\ n^{GE}]. \tag{17}$$

3) AVAILABILITY CONSTRAINT

In the proposed solution, different levels of production are defined according to the need of each class of loads. The lowest production level is the one that allows to power supply critical loads only. The sources must be able to reach this level of production with a rate that corresponds to the availability rate demanded by loads of this class. By adding another class of loads, the production level increases and the required rate of reaching this level decreases.

From the availability viewpoint, we have to ensure the power requirement of loads in (i) quantity and (ii) availability rate. To evaluate the proposed solution, a probability index is used. This index (noted by $Prob(P)$) presents the probability that the power produced by the different sources will be at least equal to a given production level (P). It is defined by

$$Prob(P) = Probability[(P_{PV}(t) + P_{WT}(t) + P_B(t) + P_{GE}(t)) \geq P] \tag{18}$$

According to this definition, $Prob(P(L_C) + P(L_{NC}))$ presents the probability that the produced power is sufficient to power supply all the loads (critical and uncritical loads). $Prob(P(L_C))$ presents the probability that the produced power is sufficient to power supply critical loads only. To ensure that the source sizing/resizing meets the requirement of (critical and uncritical) loads consumption, the following two conditions should be verified:

$$\begin{cases} Prob(P(L_C)) \geq A(L_C) \\ Prob(P(L_C) + P(L_{NC})) \geq A(L_{NC}) \end{cases} \tag{19}$$

By using this equation we can highlight the influence of the load shedding strategy on the reduction of the energy requested by the loads in order to decrease the size of the necessary sources and the cost of the installation.

4) SIZING CONSTRAINT

In this subsection, each microsource number is limited by an inferior and an upper bound based on a variety of realistic constraints. These bounds are used for sizing a microgrid in its construction phase. In case of resizing an existing microgrid, the inferior bounds will be replaced by the existing number of microsources. These intervals limit the possible number of sources combinations, minimize the number of generation and improve the convergence speed of the methodology towards an optimal solution.

In this paper, the function $ceiling(x)$ is represented by $\lceil x \rceil$.

a: PV SIZING

The number of PV microsources can range from 0 to the highest amount of PV microsources needed when PV generators can cover the entire load demand. Thus, PV output power is bounded as follows [10]:

$$0 \leq P(S_{PV}) \leq \frac{P_{Load}}{\eta \times H_D^S} \tag{20}$$

where η is the efficiency conversion loss and H_D^S is the average number of daily sunshine duration.

The number of PV microsources n^{PV} is bounded as follows:

$$0 \leq n^{PV} \leq \lceil \frac{P_{Load}}{\eta \times H_D^S \times P(S_{PV}^{ms}})\rceil \tag{21}$$

b: BATTERIES SIZING

The capacity of battery (kWh) is calculated by the following Equation [46]:

$$C_{batteries} = \frac{P_{Load} \times N_{AD}}{DOD \times \eta_B} \quad (22)$$

where: (i) N_{AD} is the number of days of battery autonomy, (ii) DOD is the depth of discharge, and (iii) η_B is the efficiency conversion loss of battery. The capacity of batteries C_B is limited from 0 (no batteries) to a value that can ensure N_{AD} days of autonomy. This capacity is bounded as follows:

$$0 \leq C_B \leq \frac{N_{AD} \times P_{Load}}{DOD \times \eta_B} \quad (23)$$

The number of batteries denoted by n^B is bounded as follows:

$$0 \leq n^B \leq \lceil \frac{N_{AD} \times P_{Load}}{DOD \times \eta_B \times P(S_B^{ms})} \rceil \quad (24)$$

c: DIESEL GENERATORS SIZING

The capacity of diesel generator C_{GE} is limited from 0 (no diesel generator) to the size requested to produce the entire power load demand for N_{GE} day in W:

$$0 \leq C_{GE} \leq P_{Load} \times N_{GE} \quad (25)$$

n^{GE} is bounded as follows:

$$0 \leq n^{GE} \leq \lceil \frac{P_{Load} \times N_{GE}}{C(S_{GE}^{ms})} \rceil \quad (26)$$

d: WIND TURBINES SIZING

Since it is expensive to achieve the total requested power with only wind turbines, we fix the maximum power to 100% of demanded power.

$$0 \leq P_{WT} \leq P_{Load} \quad (27)$$

The number of wind turbine generators n^{WT} is bounded as follows:

$$0 \leq n^{WT} \leq \lceil \frac{P_{Load}}{P(S_{WT}^{ms})} \rceil \quad (28)$$

The optimization problem (OP) can be summarized as follows:

$$OP = \begin{cases} Minimize\ LCOE[n^{PV},\ n^{WT},\ n^B,\ n^{GE}]. \\ Prob(P(L_C)) \geq A(L_C). \\ Prob(P(L_C) + P(L_{NC})) \geq A(L_{NC}). \\ 0 \leq n^{PV} \leq \lceil \frac{P_{Load}}{\eta \times H_D^S \times P(S_{PV}^{ms})} \rceil. \\ 0 \leq n^{WT} \leq \lceil \frac{P_{Load}}{P(S_{WT}^{ms})} \rceil. \\ 0 \leq n^B \leq \lceil \frac{N_{AD} \times P_{Load}}{DOD \times \eta_B \times P(S_B^{ms})} \rceil. \\ 0 \leq n^{GE} \leq \lceil \frac{P_{Load}}{P(S_{GE}^{ms})} \rceil. \end{cases} \quad (29)$$

C. DISTRIBUTION SYSTEM OPTIMIZATION

The capacity of the microgrid to produce the energy required by loads does not mean inevitably its capacity to power supply the loads efficiency in terms of quantity and availability. A distribution system must be available to ensure the produced energy transfer to these loads. An electrical distribution system should distribute the collected energy towards loads in order to avoid the degradation of the energy availability at the level of loads. It has to ensure a high availability rate of power supply in the ended nodes in order to minimize the impact of their interconnection components (electrical lines) defects.

For a given load ($L_i N_r^s$), its power supply availability is mainly influenced by the availability of the electrical power at the level of the ended node (N_r^s) that supply it and the reliability of the connection between them.

$$A(L_i N_r^s) = A(N_r^s) \times (1 - \lambda(L_g N_r^s)) \quad (30)$$

So, for an ended node (N_r^s) that supply a load ($A(L_i N_r^s)$), the availability rate $A(N_r^s)$ should be at least equal to $A_r(N_r^s)$.

$$A(N_r^s) \geq A_r(N_r^s) = \frac{A_r(L_i N_r^s)}{1 - \lambda(L_i N_r^s)} \quad (31)$$

But, an ended node can supply more than one load. For this reason, if (N_r^s) supply y loads $\{L_1 N_r^s, \ldots, L_y N_r^s\}$, then it has to ensure the power availability requested by all these loads. In this case, $A(N_r^s)$ has to reach a power availability rate that respects the following equation.

$$A(N_r^s) \geq A_r(N_r^s) = \max_{i \in (1,\ldots,y)} \frac{A_r(L_i N_r^s)}{1 - \lambda(L_g N_r^s)} \quad (32)$$

Similarly to $\lambda(E_{kl}^{ij})$, $\lambda(L_g N_r^s)$ can be calculated as shown in Equation (30), i.e.,

$$\lambda(L_g N_r^s) = \alpha \times L_n(L_g N_r^s) \quad (33)$$

If the inequality presented in Equation (32) is not justified in an ended node, then some new connections should be added. In this condition, some power supply paths are created, and the electrical energy that can pass through some nodes increases; these new connections have to ensure the existence of an electrical connection that able to power supply these nodes by the requested quantity of power, as mentioned by Equation (34). If this is not the case, then these connections must be replaced.

$$P_{max}(E_{kl}^{ij}) \geq P(N_k^l) \quad (34)$$

In all cases, the nominal power $P(N_i^j)$ of any node N_i^j must be equal or higher than the total power requested by their loads and successors, as described in Equation (35) given by

$$P(N_i^j) \geq \sum_{g=1}^{q} P(L_g N_i^j) + \sum P(successors\ of\ (N_i^j)) \quad (35)$$

We have to ensure that, at each instant t, there is an electrical path that can connect the source to the different loads.

Let ρ be the recoverability index of the entire electrical distribution system, and $Nf = \{N_{i_1}^{j_1}, \ldots, N_{i_e}^{j_e}\}$ be the set of the ended nodes with (e) is the number of this kind of nodes. During recoverability index ρ calculation, only the ended nodes need to be taken into account. The proposed factors can determine the ability of the distributed system to meet load requirements by using the required and achieved at the level of each load. Compared to other factors that used in several studies, the proposed recoverability index can orient the algorithm to increase the recoverability of loads that have an insufficient availability rate.

$$\rho = \frac{100}{e}\sum_{x=1}^{x=e}\frac{\min[A_r(N_{i_x}^{j_x}), A(N_{i_x}^{j_x})]}{A_r(N_{i_x}^{j_x})}(\%) \tag{36}$$

ρ must be equal to 100%. In this case, the new distribution system architecture become able to meet all the availability requirements of the ended nodes (as well as loads).

The recoverability index ρ can be raise if the number of power supply paths increases. A passive redundancy of these feeding paths can be adopted. In the case of a connection failure, the (EDS) uses another power transfer path in order to ensure the connection between sources and loads.

1) OPTIMIZATION ALGORITHM

In order to solve the problem of power supply availability, a genetic algorithm (GA) is chosen. In this proposed GA, each non-existent connection that can be added between two nodes is encoded by a gene using a binary representation (equals to "0" if it is not added and "1" in the contrary case). The distribution system is modeled on Matlab by using Matpower tool [26]. This modeling facilitates the calculation of power flows (power supply transferred between the different node), as well as the value of current intensity in each connection. This value is used to determine: (i) the cable cross section that must be added or modified and (ii) the cost of these modifications. The flowchart of the proposed (GA) is presented in figure 6:

a: POPULATION INITIALIZATION

Several mechanisms for generating the initial population are used in [28]. The choice of the initialization can be made according to the knowledge about the current state and the estimated evolution of microgrid (recoverability index of nodes and priority of loads). If it has no particular information, then a random initialization can be used. In this study, this population corresponds to the initial state of the distribution system (without adding any new connection). This state is modelized by using Matpower tool.

b: FITNESS EVALUATION

Fitness should be able to reflect the objective and to find the optimal solution. Fitness function can be written as

$$F = 1/\sum_{x=1}^{x=e}(A(N_{i_x}^{j_x})) \tag{37}$$

By using Matpower, Matlab can calculate the fitness (Equation (37)) of the proposed solution (gene) to evaluate its

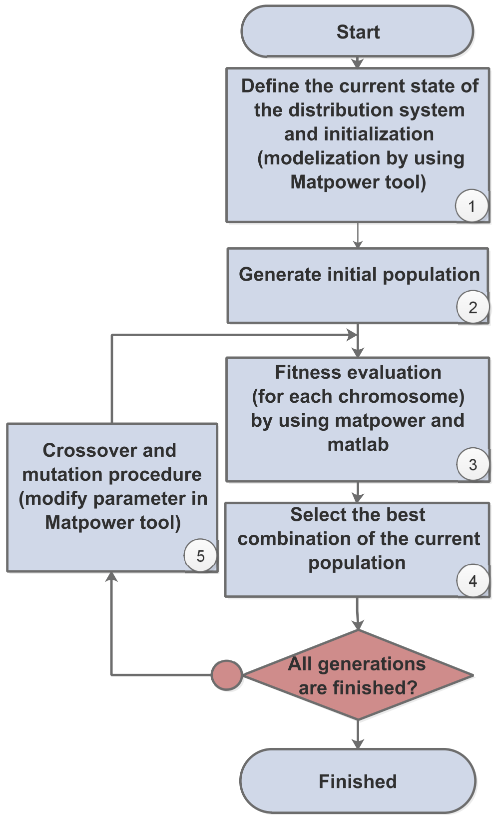

FIGURE 6. Flowchart of distribution system optimzation.

performance. Matpower is also used to determine the power transmitted by the new connections in order to estimate the cost of these connections.

c: SELECTION MODULE

Selection operator is the mechanism that ensures the replication for the best chromosomes in a population. Based on the fitness value, the chromosomes that survive for the next generation must be selected. The selection method for this problem is a ranking selection. Tournament selection can be used in the case of complicated distribution system.

d: CROSSOVER MODULE

After selection phase, an operator of crossover produces a better child based on the exchange of genes between parents. During crossover, the good properties of the parent chromosomes are recombined and retained to produce the next generation. In this study, the new connections that have a positive impact on the energy availability are retained.

e: MUTATION MODULE

A mutation operator is a genetic mechanism that aims to protect the chromosomes from the destruction. It is applied to add some new genetic materials in the new generation. The probability of mutation must be tiny to ensure the intergenerational interdependence, it equals to 1/50.

IV. CASE STUDY: MAAMOURA PLATFORM

The case study is an abstraction of an offshore petroleum platform located on the Tunisian coast. This platform represents an isolated microgrid which has no access to any macrogrid (like the Tunisian national distribution company of electrical energy) and it has to ensure its energy self-sufficiency. In case of defect of sources, the level of production decreases. The energy balance between the production and the consumption will not be guaranteed. The reliability of the components which transfer the energy produced towards the related loads represents another limit of the platform service continuity. Moving maintenance crews to fix some failures can take a long time. Sometimes the weather prevents the ability to navigate to the platform. Between July 2014 and June 2015, four total shutdowns and some partial blackouts are registered. These shutdowns caused approximately six hundred thousand dollars of losses for the Tunisian Government.[1] These significant losses motivate us to develop a strategy that increases the power supply availability and minimizes the blackouts. Generally, the total shutdowns are caused by the unavailability of the production sources or their converters, the partial stops are caused by problems at the level of the nodes interconnection of the distribution system.

A. PRESENTATION

Maamoura Platform is an island petroleum platform located on the Tunisian coast. This island microgrid is supplied by four types of sources as noted in the Table.I. On the other hand, there are two classes of loads: critical and uncritical loads. Table.I represents the initial number of microsources and the initial availability rate of the different sources.

TABLE 1. Initial characteristics of sources.

Sources (i)	Power rate by microsources (kW)	n^i	Availability rate (%)
PV	5	17	0.3421
WT	20	4	0.2254
B	4	21	0.3091
GE	17	2	0.1069

This microgrid is unmanned site. Each maintenance action requires a technical intervention from the outside of the platform. This intervention is not always possible, and can be postponed in certain cases for climatic reasons. All of these factors extend the repair period and increase the cost. For this study case the influence of the cables that connects ended node with loads have a negligible effect on the availability because of the reduced size of our microgrid (platform). To respect Equation (19), our goal is to achieve an availability rate greater than or equal to 0.9999 (99.99%) in each node that supply at least one critical loads and rate greater than or equal to 0.999 (99.9%) in each node that supply at only uncritical loads. As described in Table 2, there are sixteen loads partitioned on three floors of the platform.

[1] The information about shutdowns and losses was obtained through our partner http://cipem.com.tnCIPEM Company for the industrial assistance.

TABLE 2. Characteristics of Existing Loads in the Platform.

N	Load	Power rate (kw)	Critical load	Floor
1	HCU pump	1.5	☒	2
2	Corrosion inhibitor injection pump	0.5	☒	2
3	SSIV duty pump	0.5	☒	2
4	Process control system	1.5	☒	1
5	Emergency shutdown system	1.2	☒	1
6	Fuel & gas system	1.5	☒	1
7	Emergency lighting	2	☒	1
8	Radio system	1.2	☒	1
9	Navaids system	2.5	☒	1
10(a)	Main injection pump	18	☒	3
10(b)	Second injection pump	7	☒	3
11	Expedition pump	22	☒	3
12	Multiphase meter	1	☒	3
13	Lighting	3	☐	1
14	Air condition system	7	☐	1
14(b)	Server air condition system	2	☐	1
15	Air extraction system	2	☐	1
16	Restoration service	4	☐	1

Fig.7 shows the electrical distribution system of the platform: (a) the nodes and their power rate, and (b) the electrical lines and their lengths.

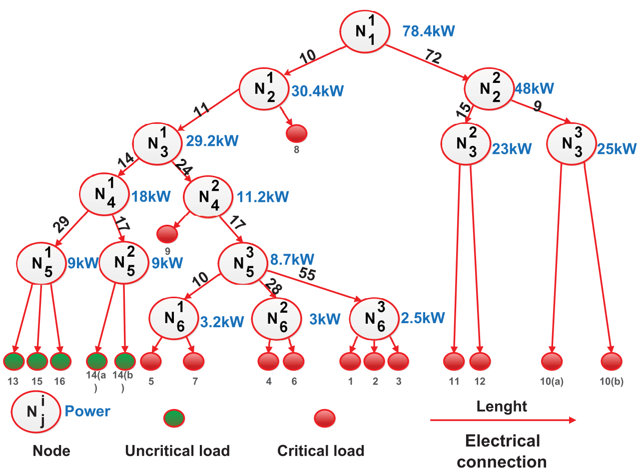

FIGURE 7. The electrical distribution system of the platform.

This EDS can be represented in the matrix *MD* form as shown in Table 3. In this matrix, cells present the distances between the various nodes of the distribution system. Cells in grey show the existence of a connection between two nodes.

Table 4 represents the initial power rate and the power availability in the different nodes. The availability in the nodes N_3^2,N_3^3 and N_6^3 does not reach the requested availability rate (0.9999). These three nodes are ended nodes that power supply some critical loads. Their availability must be

TABLE 3. Distance between nodes (existing connections are in gray).

	N_1^1	N_2^1	N_2^2	N_3^1	N_3^2	N_3^3	N_4^1	N_4^2	N_5^1	N_5^2	N_5^3	N_6^1	N_6^2	N_6^3
N_1^1	0	10	72	20	86	80	23	8	30	26	31	19	21	55
N_2^1	10	0	75	11	84	79	17	15	34	33	35	27	24	58
N_2^2	72	75	0	78	15	9	92	77	95	91	95	88	93	56
N_3^1	20	11	78	0	80	79	14	24	38	40	38	30	28	61
N_3^2	86	84	15	80	0	13	80	91	110	101	141	133	137	127
N_3^3	80	79	9	79	13	0	92	103	120	108	130	121	124	119
N_4^1	23	17	92	14	80	92	0	11	29	17	53	40	42	76
N_4^2	8	15	77	24	91	103	11	0	37	32	17	24	13	60
N_5^1	30	34	95	38	110	120	29	37	0	22	39	47	57	82
N_5^2	26	33	91	40	101	108	17	32	22	0	41	47	31	76
N_5^3	31	35	95	38	141	130	53	17	39	41	0	10	28	55
N_6^1	19	27	88	30	133	121	40	24	47	47	10	0	27	60
N_6^2	21	24	93	28	137	124	42	13	57	31	28	27	0	48
N_6^3	55	58	56	61	127	119	76	60	82	76	55	60	48	0

TABLE 4. Power rate and power availability of nodes.

Node	Power rate	Power availability
N_1^1	80	100
N_2^1	50	0.9999
N_2^2	50	0.9999
N_3^1	32	0.9999
N_3^2	32	0.9998
N_3^3	32	0.9998
N_4^1	20	0.9999
N_4^2	20	0.9999
N_5^1	10	0.9999
N_5^2	10	0.9999
N_5^3	10	0.9999
N_6^1	6	0.9999
N_6^2	6	0.9999
N_6^3	6	0.9998

optimized to improve the availability of electrical power at the level of loads supplied by each one of them.

B. NUMERICAL RESULTS AND DISCUSSION

For the genetic algorithm of the source sizing optimization, the algorithm must add a single microsource in each generation. According to the specification of the proposed solution, crossover rate must be equal to 0. After several simulations with different values, mutation rate is fixed to 0.7.

For the genetic algorithm of the distribution system optimization, crossover rate is equal to 0.8 and mutation rates is equal to 0.02. Several executions of genetic algorithms with different probabilities ('MutationFcn' and 'CrossoverFcn') show that the generic algorithm converges quickly using this pair of values.

1) RESULT OF SOURCE SIZING OPTIMIZATION

In this section, we apply the proposed solution to improve the availability of electrical power. We test the platform in similar situations that cause its shutdowns. The methodology results are compared with those of the Homer software. $A(L_C)$ must achieve at least 4-nines, and $A(L_{NC})$ must achieve at least 3-nines:

$$\begin{cases} A(L_C) = 0.9999 \\ \Rightarrow Prob(P(L_C)) \geq 0.9999 \\ A(L_{NC}) = 0.999 \Rightarrow Prob(P(L_C) + P(L_{NC})) \geq 0.999 \end{cases} \tag{38}$$

By realizing this objective, the source production can cover: (i)the energy needs for the critical loads in 99,99 % of times, and (i)the energy needs for the all the loads in 99,9 % of times. In this condition, the time of unavailability in the platform can dip below three hours by year.

We begin with the optimization of $A(L_C)$. The proposed methodology increases the numbers of microsources, by choosing at each step the most profitable source. Fig.8 represents the microsources number evolution by source type from one generation to another.

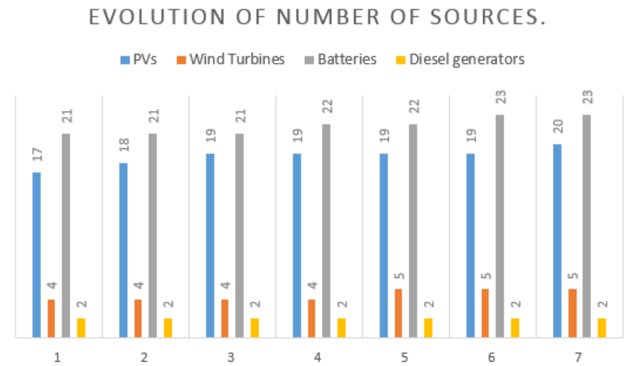

FIGURE 8. Evolution of microsources numbers by source type.

The increase of microsources number extends the availability of the associate source and the global availability of the power production. Fig.9 represents availability evolution by source type after each optimization step.

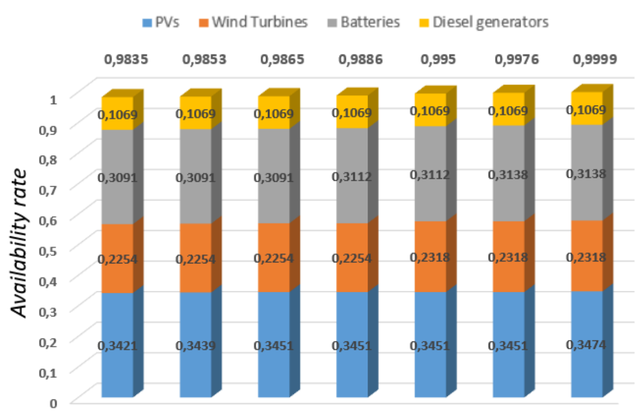

FIGURE 9. Availability evolution by source type.

Fig.10 represents the evolution of $A(L_C)$ after each augmentation of microsource.

The genetic algorithm converges quickly to an optimized solution after 7 generations. The proposed number of microsource is: 20 PV, 5 WT, 23 B, and 2 GE.

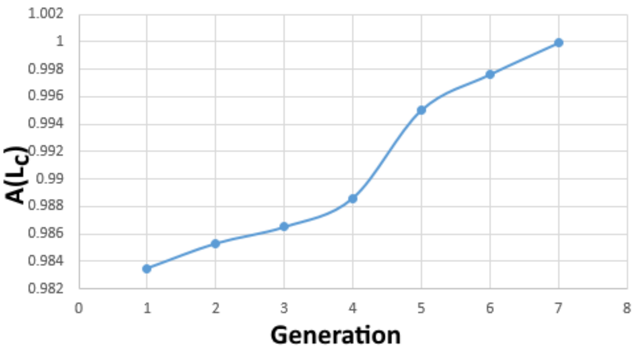

FIGURE 10. The evolution of $A(L_C)$.

Homer is a famous shareware widely used for the sizing of sources in the case of microgrids and distributed power systems [24]. This shareware uses the complete enumeration method. Fig.11 represents a comparison between the composition of sources proposed by HOMER and that by the proposed solution in order to reach the requested high availability.

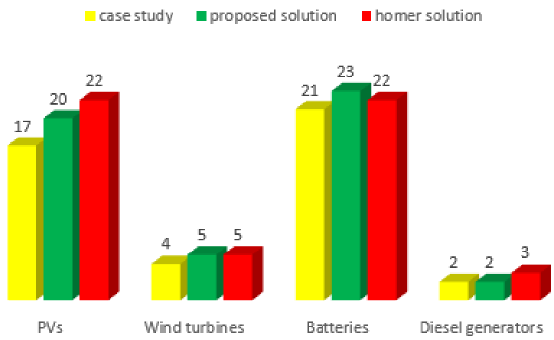

FIGURE 11. Proposed solution and Homer solution.

By comparing the results of the two methods about the effect of sources resizing on availability and additional cost (Fig.12), we notice that with the solution proposed in this paper we can reach a higher availability at a lower cost. By takin into account the flexibility of the loads (requested power supply availability), we can reduce the source sizing cost.

By increasing the availability of the energy production from 0,9835 to 0,9999, the added availability is 0,0164%. The platform earns about 6 days (143 hours) of production per year.

2) RESULT OF DISTRIBUTION SYSTEM OPTIMIZATION

The distribution system is modeled in matpower. AC power flow version of the optimal power flow (OPF) problem is used to determine the power transmitted in each branch [36]. By applying the optimization methodology to the electrical distribution system, three new connections should be added (($E^{3^2}_{3^3}$), ($E^{3^2}_{4^1}$) and ($E^{4^1}_{5^3}$)), three others should be replaced (($E^{1^1}_{2^2}$), ($E^{2^2}_{3^3}$)), and ($E^{2^2}_{3^2}$)), as seen in Table 5 and Fig.13.

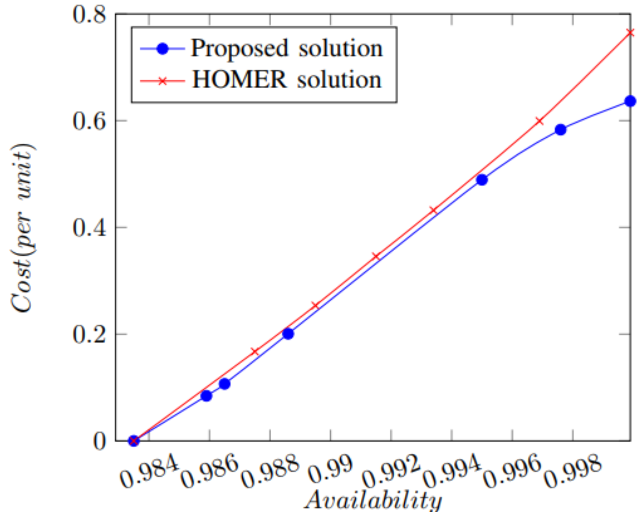

FIGURE 12. Proposed solution and Homer solution cost evolution.

TABLE 5. Added and replaced connections.

Line	length (m)	Power (Kw)	Current (A)	Section (mm^2)	Cost ($)
$E^{3^2}_{3^3}$	13	49,7	84,39	50	148,252
$E^{3^2}_{4^1}$	80	26,7	45,33	25	1580,72
$E^{3^2}_{4^1}$	53	8,7	14,77	10	257,103
$E^{1^1}_{2^2}$	72	74,4	12,84	70	2003,976
$E^{2^2}_{3^3}$	9	74,4	126,84	70	250,497
$E^{2^2}_{3^3}$	15	74,4	126,84	70	417,495

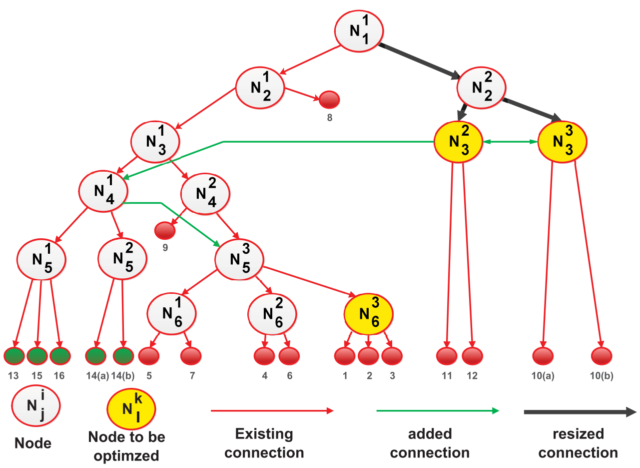

FIGURE 13. Optimized electrical distribution system.

The type of cables used in the platform is U1000RV-FV. The cost The cost of the requested cables in the distribution system optimization is 4658,043 Dollars according to the tariffs of a local manufacturer.[2] The cost of installing the cables (242 meters) is 6776 dollars. The cost of dismantling the cables to be changed (96 meters) is 1152 dollars.

[2]http://www.chakira-cables.com.

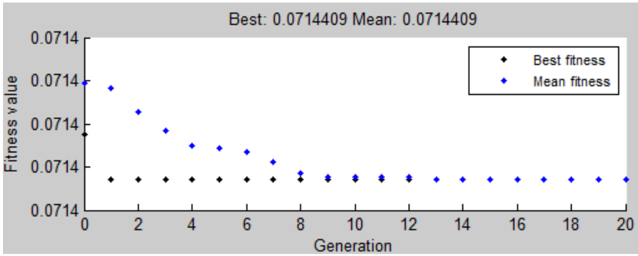

FIGURE 14. Fitness value evolution.

In this case ρ (as defined in Equation (36)) becomes equal to 100%.

By using equation 37, Fig.14 shows that fitness value does not vary after $t = 13$, the proposed genetic algorithm reaches the solution after 13 generations. After this optimization, the recoverability index increases as shown in Table 6 and ρ is equal to 100%. This value shows that the Equation (36) is verified in all the nodes of the distribution system.

TABLE 6. Power rate of nodes.

Node	Optimized power availability
N_1^1	1
N_2^1	0.9999
N_2^2	0.9999
N_3^1	0.9999
N_3^2	0.9999
N_3^3	0.9999
N_4^1	0.9999
N_4^2	0.9999
N_5^1	0.9999
N_5^2	0.9999
N_5^3	0.9999
N_6^1	0.9999
N_6^2	0.9999
N_6^3	0.9999

In our case, the platform earns about 24 thousand dollars by years (cost of additional production profits and avoided maintenance action).

V. CONCLUSION

For many application areas (such as petroleum platform), power supply availability is regarded as a paramount factor because of its technical and economic influences, the unavailability of the energy engenders an interruption of production. Several factors (such as source types and sizing, component reliability) influences the level of power availability in a microgrid, especially in case of the island operation mode of a microgrid, when an energetic self-sufficiency should be ensured (compared with conventional power systems and connected microgrids). In this paper, we are interested in the power supply availability in island microgrids in which the power production insufficiency and distribution system failure present a major problem. This paper presents a new methodology that can optimize an existed microgrid in order to reach a requested level of power supply availability at a lower cost. This methodology that is done in two step. In the first step, this methodology focuses on the optimization of the source sizing by adding some microsources in order to ensure the balance between sources production and loads requirement. The loads are classified according to their priorities. Each class is characterized by its required power and availability. The proposed methodology aims to ensure the power requirement of each class in quantity and availability rate of production level. This proposed solution highlights the influence of the load shedding strategy on the reduction of the energy requested by the loads as well as on minimization of the size of sources to add. In a second step, this methodology aims to enhance the distribution system design by using transmission paths redundancy in order to guarantee ensure the transfer of the produced energy from sources to loads. The objective of this step is to achieve the requested availability rate requested by each load. A recoverability index ρ is defined and used to evaluate the performance of the distribution system modification. ρ will be equal to 100% only if the new distribution system architecture become able to meet the availability requirement of each load. Matpower tool and Matlab are used to facilitate the calculation of the optimization cost. In each optimization step, an genetic algorithm is proposed. Although they are simple, genetic algorithms present an effective solution for the combinatorial problems, especially if genomes can have a limited number of values. In this case, the optimization problem will be less complex, and the optimization algorithm converges quickly to an optimized solution.

The proposed methodology can optimize the power production by acting in the sources sizing. It can also optimize the power transfer by adding some electrical lines in order to create new paths of power transmission. In its two optimization steps, load priorities have an important factor to consider. Non-critical loads give some flexibility to the sources sizing. This methodology presents several technical and economic advantages. The experimental results demonstrate that the solution is effective and can avoid short-term stops in a Tunisian platform. By using this methodology this platform can avoid losses estimated at least up to 20,000 US dollars per year caused by the distribution system unavailability and its corrective maintenance actions, and 320,000 US dollars per year caused by the production unavailability.

By increasing the number of nodes or loads, the population becomes more diverse and the search for the most appropriate solution becomes more complex. In future research, we can consider using Monte Carlo simulation to solve more complex networks [13].

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