Optimization of the operations and maintenance for wind farm using genetic algorithms

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Article Info

Article history:

Received Jul 5, 2023
Revised Aug 8, 2023
Accepted Aug 30, 2023

Keywords:

Energy production
Genetic algorithms
O&M
Optimization
Turbine maintenance
Wind farm

ABSTRACT

In Morocco, with the growing wind installed capacity it becomes crucial to perform further the operation and maintenance (O&M) process, the wind assets are exposed to several constraints and raindom of maintenances for incidents. The target of this work is to optimize the gross and net production while simultaneously adhering to the minimum turbine unavailability and minimizing all contractual power curtailments due to unforeseeable factors. The proposed system is modeled using technical and mathematical formulas composed of the main function and the associated constraints. The project's modularization ends with a complex mathematical system that is non-linear, non-differentiable and requires the genetic algorithm for optimal resolution. Using MATLAB to determine the optimized solution that represents the number of operational turbines per day, allowing for maximum production, minimizing curtailment, and reducing the unavailability of turbines. The 365-vector containing the numbers of turbines per day will opimally define the long-term O&M strategy.

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1. INTRODUCTION

As Morocco and neighboring countries work towards boosting renewable energy (RE), the challenge emerges regarding the optimized management of the substantial ongrid RE generation. With the rapid and cumulative deployment of projects, the influx of intermittent and variable power sources poses operational complexities that impact the normal production plan. The proper strategy is needed to ensure an efficient energy system while maximizing the potential benefits of a clean energy transition. This study is dedicated to the use of genetic algorithms (GA) for improving the production and achieving optimal management of the assets.

While previous research has delved into GA's applications for power generation, its focus has primarily been on optimizing layouts, evaluating layers, the associated costs and managing hybrid systems [1]. However, this work expands beyond those areas by employing GA to the comprehensive optimization and effective management of wind projects. The assets are basically designed to generate as much electricity as possible while minimizing their operating costs and technical constraints. Therefore, optimizing the procedures ensures that the main technical parameters are optimised using the least charges and the most rate of availability for turbines, it also involves increasing the grid availability and reduce the different curtailments.

The maintenance contractor plans preventive works in a systematic manner. The tasks follow a plan previously designed by the manufacturer to maintain the turbines in good working order while respecting the allowed availability [2]. As the contractual availability is a calculated rate based on downtime and running hours, it does not reflect the undelivered energy caused by preventive maintenance or corrective stops. The losses in energy depends on how windy the day is. So, the question is how can we ensure that production is maximized while maintaining correct maintenance and respecting all the constraints. The following parts of this work will refer to GA optimizing process to define the most accurate configuration of the complex system for the 131 turbines. The adopted configuration will be analysed and transformed to Mathlab scripts allowing the resolution iterations of the GA tools [3].

2. METHOD

2.1. Modeling the problem

This work is mainly based on an operational asset of 301MW. The project has 131 machines supplied by SG with a unit capacity of 2.3 MW. It operates in a wind range from 3 to 24 m/s. Starting from 12 m/s, it reaches the maximum power. The unavailability of resources disturbs the efficiency of production, the optimization of the objectives must be implemented by a method of multi-objective optimization and which allows more flexibility for key decisions. We consider the problem of production and losses of 131 turbines over 3 zones, the objective function defines the goal to maximize the production while taking into account various constraints [4]: **Max=(Production-Losses)**. In Figure 1, the wind trubines are represented by (i,j) coordinates system for better modelisation. The process requires transforming the turbines into a form of data that is well recognized by the optimization models. Referring to the Figure 2, the graph theory is a set of points where the pairs wind turbines (WTG) which are directly connected by one or more links.

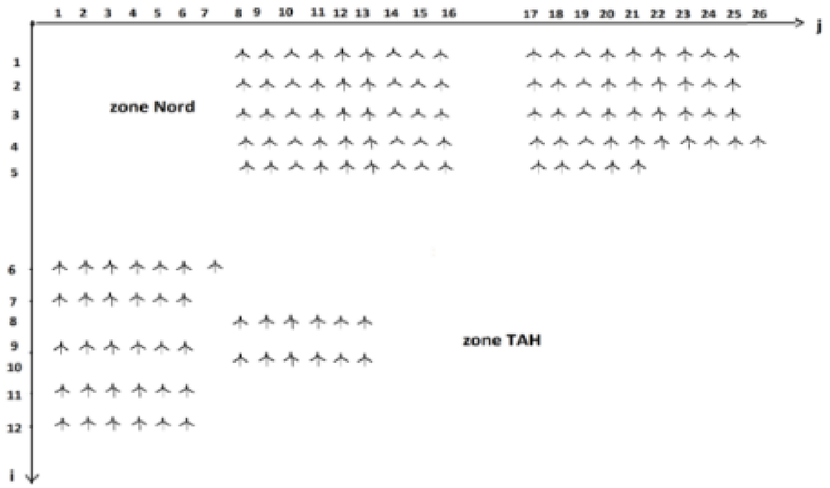

Figure 1. Wind turbine coordinates using (i,j) system

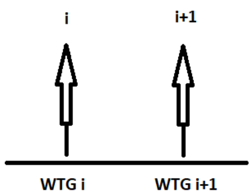

Figure 2. Graph theory for 2 WTG (i, i+1)

The graph theory consists of a set of vertices denoted as “V” and a set of edges denoted as “E”. A simple directed graph is a type of graph with no multiple edges or loops, meaning each pair of vertices has at most one directed edge between them. It can be defined by its set of vertices and edges. The incidence function $\boldsymbol{\gamma}$ associates each edge with a pair of vertices, defined as $\boldsymbol{\gamma}: E \rightarrow V \times V$ [5]. Thus, the following definition:

$$\mathbf{G}=(\mathbf{E},\mathbf{V}) \ \& \ \mathbf{G}=(\mathbf{E},\mathbf{V},\boldsymbol{\gamma})$$

as shown by the numbering of turbines in Table 1, zone 1 is equipped with 44 turbines. As well as figured in Table 2 with 87 turbines.

Table 1. Zone 1, turbines numbering

Grappe	Ligne	Turbines	Number
15	1	113-114-115-116-117-118	6
14	2	107-108-109-110-111-112	6
13	3	101-102-103-104-105-106	6
12	4	95-96-97-98-99-100	7
11	5	88-89-90-91-92-93-94	6
17	6	126 -127-128-129-130-131	6
16	7	119-120-121-122-123-124-125	7

Table 2. Zone 2 and 3, turbines numbering

Grappe	Ligne	Turbines	Number
1	12	1-2-3-4-5-6-7-8-9	9
5	10	37-38-39-40-41-42-43-44-45	9
6	10	46-47-48-49-50-51-52-53-54	9
7	9	55-56-57-58-59-60-61-62-63-64	10
10	8	82-83-84-85-86-87	6
2	12	10-11-12-13-14-15-16-17-18	9
3	11	19-20-21-22-23-24-25-26-27	9
4	11	28-29-30-31-32-33-34-35-36	9
8	9	65-66-67-68-69-70-71-72-73	9
9	8	74-75-76-77-78-79-80-81	8

The wind turbine is dimensioned to provide a nominal power at a defined range of nominal wind speed following a determined power curve [6]. The annual production of is calculated from the measurements of the power curve which follows a Rayleigh distribution of the wind speed. For each turbine (N=8,760 h and P_i: Power at turbine indexed -i- and F(V): cumulative probability distribution of Rayleigh & Vm: Mean wind speed).

$$P = N \cdot \sum_{i=1}^{131} [(F(V_i) - F(V_{i-1})].[P_{i-1} + P_i]/2 \quad F(V) = 1 - e^{-\pi/4\left(\frac{V}{Vm}\right)2}$$

The logic function with binary real values which will take into account the startup per turbine. It takes two main values that represent the status of each turbine, it eliminates several calculations that are not needed:

$$\zeta\ i: [1\ldots131] \rightarrow [0.1]$$

ζi=1 means that the turbine of index i is in service and **ζ**i = 0 is out of service. The electrical losses are primarily due to the Joule effect, consequently, for overhead and underground lines with equivalent manufacturing material and section, the losses are theoretically equal [7], [8]. Referring to the complete internal grid presented in Figure 3 combining the 3 zones of the wind farm to better model the data of the global system of functions (note that I_i is the current passing through the line between wind turbine number i and i+1).

$$P_{LT1} = \sum_{i=1}^{131}(R_i \cdot {I_i}^2) \ \& \ P_{LC} = \sum_{i=1}^{12}(R_{ci} \cdot {I_{ci}}^2) + \sum_{i=1}^{7}(R_{ciTAH} \cdot {I_{ciTAH}}^2)$$
$$P_{LP} = \sum_{i=1}^{2}(R_{lpi} \cdot {I_{lpi}}^2) + (R_{lpTAH} \cdot {I_{lpTAH}}^2)$$
$$P_{HT\ internal} = R_{HV} \cdot {I_{HV}}^2 \ \& \ P_{HT\ grid\ access} = R_{HV} \cdot {I_{HV}}^2$$

2.2. Technical constraints

The theoretical power present in a kinetic energy from of a crossing wind, where P_w is the power (W), rho is the air density, A is the surface area and V is the wind speed. The power available increases dramatically with speed, as the cube of speed is the most important factor in the equation. It estimates the maximum amount of power that can be extracted: $P_w = 1/2\,\varphi A V^3$. The turbine can only recover part of this power. It is the mechanical power available on the transmission shaft calculated according to $P_m = 1/2\,C_P \varphi \pi R^2 V^3$. The torque C is deduced as follows ($W_{2i} = 1500$ & $m = cte$): $\sum_{i=1}^{131} W_{2i}.(C_{1i}/m - C_{2i})$). The electrical losses in the internal grid are limited to 2.3% of the total energy over a given period (1). The voltage drops must not exceed certain values respectively 3% [9], 5% and 8% for LV, MV and HV [10].

$$\sum_{i=1}^{131} R_i\, {I_i}^2 + \left[\sum_{i=1}^{12}(R_{ci}\, {I_{ci}}^2) + \sum_{i=1}^{7}(R_{ciTAH}\, {I_{ciTAH}}^2) + \sum_{i=1}^{2}(R_{lpi}\, {I_{lpi}}^2) + (R_{lpTAH}\, {I_{lpTAH}}^2) + (R_{HV}\, {I_{HV}}^2) \leq 2.3\%.\mathrm{P}_{\mathrm{Total}} \quad (1)$$

- $\Delta U/U_{\ LV} = \sum_{j=1}^{131} (\mathrm{P}_j.\mathrm{L}_j/{\mathrm{U}_j}^2)(\mathrm{R}_j.\cos\rho + \mathrm{X}_j.\sin\rho) \leq 3\ \%$
- $\Delta U/U_{\ MV} = \sum_{j=1}^{12} (\mathrm{P}_{ci}.\mathrm{L}_{ci}/{\mathrm{U}_{ci}}^2)(\mathrm{R}.\cos\rho + \mathrm{X}.\sin\rho).\mathrm{c}_i + \sum_{i=1}^{7}(\mathrm{P}_L/\mathrm{U}_2)\,\mathrm{c}_{iTAH}.[(\mathrm{R}.\cos\rho + \mathrm{X}_j.\sin\rho)].\mathrm{c}_{iTAH} \leq 5\ \%$
- $\Delta U/U_{\ HT} = (P.L/U^2)_{HT}.(\mathrm{R}.\cos\rho + \mathrm{X}.\sin\rho)_{HT} \leq 8\ \%$

The availability is a contractual commitment between the project company and the turbine supplier. It is calculated per turbine for each month but the yearly average rate is the final ration to consider for the official reporting (monthly rate serves as internal key analysis) [11].

$$[T_2 - (T_1 - (T_4 + T_3)]/T_2$$

- T2: means the total time and T1: the during the period T2 during which the wind Turbine is stopped.
- T3: time in T2 where the turbine cannot operate due to site conditions.
- T4: time in T2 where the turbine cannot operate due to any interruption by the grid or force majeure [12].

$$\text{Turbine Availability} = \frac{[T2 - (T1-(T4+T3)]}{T2} \geq 97\ \%\ \&\ \text{Turbine Unavailability} = 1 - \frac{[T2 - (T1-(T4+T3)]}{T2} \leq 3\ \%$$

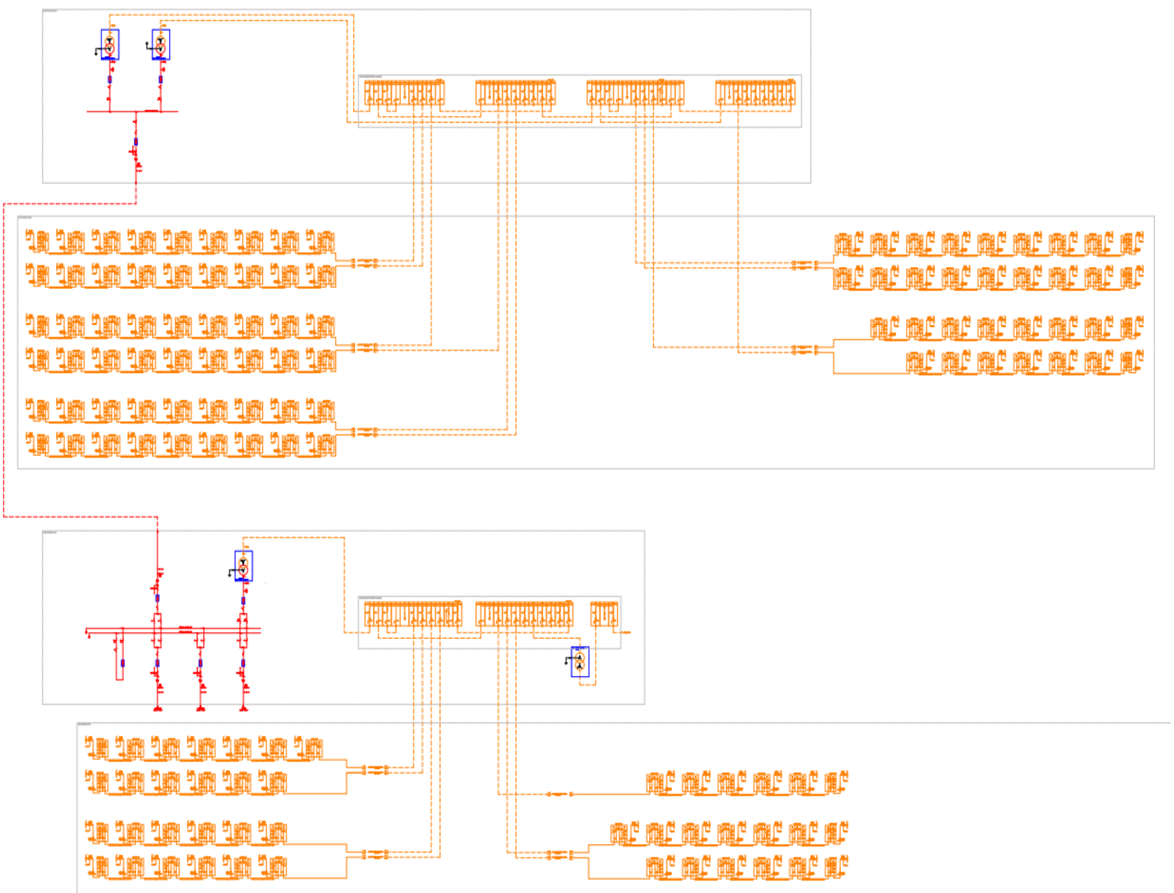

Figure 3. Internal electrical grid configuration for the 3 zones

2.3. Final formulation of the complex system

The final configuration and optimization of the wind farm signifies the culmination of extensive engineering analysis and design. This comprehensive formulation has been intricately tailored to harness the potential of wind resources in the area, considering factors such as turbine placement, grid integration and technical.

$$\text{Max}\Big[\textstyle\sum_{i=1}^{131} \zeta_i \Big[\Big(N.[e^{-\pi/4\left(\frac{vi}{vm}\right)2} + e^{-\pi/4\left(\frac{v(i-1)}{vm}\right)2}].\frac{[Pi-1+Pi]}{2}\Big)\Big] - W_{2i}(C_{1i}/m - C_{2i}) - R_i.I_i{}^2 - [\sum_{i=1}^{12}(R_{ci}.I_{ci}{}^2) + \sum_{i=1}^{7}(R_{ciTAH}.I_{ciTAH}{}^2) + \sum_{i=1}^{2}(R_{lpi}.I_{lpi}{}^2) + (R_{lpTAH}.I_{lpTAH}{}^2) + (R_{HV}.I_{HV}{}^2)]\Big]$$

- $\sum_{i=1}^{131} \zeta_i \leq 131$
- $1 - [T_2 - (T_1 - (T_4 + T_3)/T_2] \leq 3\ \%$
- $\sum_{j=1}^{131} (P_j.L_j/U_j{}^2)\,(R_j.cos\rho + X_j.sin\rho) \leq 3\ \%$

- $(P.L/U^2)_{HT} . (R.cos\rho + X.sin\rho)_{HT} \leq 8\ \%$
- $\sum_{j=1}^{12} \left(P_{ci}.L_{ci}/{U_{ci}}^2\right)(R.cos\rho + X.sin\rho).c_i + \sum_{i=1}^{7}(P_L\ /U_2)\ c_{iTAH}.\left[\left(R.cos\rho + X_j.sin\rho\right)\right].c_{iTAH} \leq 5\ \%$
- $\sum_{i=1}^{131} R_i\, {I_i}^2 + \left[\sum_{i=1}^{12}(R_{ci}\, {I_{ci}}^2\right) + \sum_{i=1}^{7}(R_{ciTAH}\, {I_{ciTAH}}^2) + \sum_{i=1}^{2}(R_{lpi}\, {I_{lpi}}^2) + \left(R_{lpTAH}\, {I_{lpTAH}}^2\right) + \left(R_{HV}\, {I_{HV}}^2\right) \leq 2.3\%.P_{Total}$

- V_m: average wind speed & V_i : average wind speed at the point i & P_i : production of turbine i.
- W_2: fast arm rotation speed, W_1 : slow arm rotation speed & m : multiplication ratio.
- C_1 : the torque at the level of the slow arm & C_2 : the torque at the level of the fast arm.
- R_i: line resistance between generator and foot station & I_i : line current between generator and foot station.
- R_c: the resistance of the 33 kV line & I_c : the line current flowing in the 33 kV lines.
- R_{ciTAH}: resistance of 33 kV line in TAH zone & I_{ciTAH} : line current flowing the 33 kV lines in the TAH zone.
- R_{lp}: resistance of the 33 kV line & I_{lp} : the line current flowing in the 33 kV lines.
- R_{HV}: resistance of the 225 kV line & I_{HV}: the line current flowing in the 225 kV lines.

3. RESULTS AND DISCUSSION

In GA a population of individuals is represented by strings of symbols called chromosomes, that represents a potential solution to the complex system. In the case of optimizing the production of a wind farm, each chromosome could represent a different configuration of the turbines and other components of the system. To evaluate each chromosome, a fitness function is used to measures the quality of the solution in terms of its ability to generate energy while respecting the constraints [13]. The objective function is typically nonlinear and nondifferentiable, which makes it difficult to use traditional optimization techniques. In a typical GA, the optimization process proceeds through a series of iterations, each of which involves selecting the fittest individuals from the current population as parents for the next generation. This selection is often based on a stochastic process that favors individuals with higher fitness scores. Once the parents are selected, a crossover operator combines their chromosomes to generate one or two offspring that inherit some of the traits of each parent [14]. The offspring may then be subject to random mutations that introduce small changes to their chromosomes, thereby increasing the diversity of the population.

The new generation of offspring is then evaluated using the objective function, and the same steps are repeated till a stopping criterion is reached. This criterion can be based on a maximum number of iterations, a minimum level of fitness. In the case of optimizing wind energy production, GA could be used to explore configurations of turbines and other components, in order to find the optimal balance between energy production and maintenance requirements. The GA could also take into account environmental factors such as wind patterns and weather conditions to further improve the performance of the wind farm.

3.1. System model

GA involves creating a population of candidate solutions and fitness functions for assessment. GA searches through a large space of candidates to find an optimal or nearoptimal solution. GA is highly effective at finding solutions to complex problems, especially when the problem space is large and difficult to search using traditional techniques [15], [16]. The different steps of a genetic algorithm are the creation of individuals, creation of the space of configurations, then, the adaptation to the environment (fitness), and last, the crossing and mutation to avoid genetic drift. Within the complete framework of this work, referring to the main goal of the objective function and the constraints, the proposed individual for the GA scripts is defined as:

N=[N_1, N_2, N_3,......, N_{365}]

the "N" is the vector representing the number of turbines that needs to be available per day. The daily number "N_i" ensures the maximum of production in respect of the applied limitations, curtailment, maintenance schedule and other constraints. Starting from the defined individual "N", the GA lunch the reproduction using the selection, crossover, and mutation operators to create a new population of individuals. The selection identifies the fittest individuals in the current population to be chosen as parents for the next generation. Crossover then combines the genetic information of the selected parents. Mutation introduces random changes into the offspring's genetic information to increase diversity in the new population.

3.2. Scripts for the functions and constraints

Referring to the project basic design, the data on Table 3 shows the values for the current and different levels of voltge at all sections of the internal grid. Also, the exact lengths and distances with the cable sections for all sections of 690 kV, 33 kV, and 225 kV. These values are critical for optimizing the flow of electricity and ensuring efficient simulation and optimization of the formulated system.

Table 3. HV 225 kV grid and internal grid 33 kV technical data (including distances)

Line i	Line j	S(mm²)	L (m)	R (Ω)	X	I (A)	U (V)
1	2	240	280.2	0.042	0.042	64	33000
1	3	240	280.2	0.042	0.042	128	33000
1	4	240	280.2	0.042	0.042	192	33000
1	5	240	279.3	0.0418	0.0418	256	33000
1	6	240	280.6	0.042	0.042	320	33000
1	7	240	280.2	0.042	0.042	384	33000
1	8	400	279.3	0.025	0.0418	448	33000
1	9	500	280.2	0.02	0.042	513	33000
A9	PYLONE MV	630	200	0.02	0.042	576.62	33000
PYLONE LV	ATR LV/HV	181	3450	0.63	0.51	409	33000
ATR LV/HV	AG1	630	100	0.02	0.042	576.62	33000
1	11	240	280.2	0.042	0.042	64	33000
1	12	240	280.2	0.042	0.042	128	33000
1	13	240	280.2	0.042	0.042	192	33000
1	14	240	279.3	0.0418	0.0418	256	33000
1	15	240	280.6	0.042	0.042	320	33000
1	16	240	280.2	0.042	0.042	384	33000
1	17	400	279.3	0.025	0.0418	448	33000
1	18	500	280.2	0.02	0.042	513	33000
A18	PYLONE MV	630	200	0.02	0.042	576.62	33000
PYLONE MV	ATR MV/HV	181	3450	0.63	0.51	409	33000
ATR MV/HV	AG2	630	100	0.02	0.042	576.62	33000

The following objective function script (fitness function Algorithm 1) represents the conclusive maximization process. It encapsulates a comprehensive set of constraints in Algorithms 2 and 3 and limitations in Algorithm 4, that the resolution process must meticulously account for, ensuring that the final outcome aligns with specified criteria and regulatory requirements. These adaptable scripts can be seamlessly integrated into various programming codes, facilitating the iterative optimization process by displaying each step's evolution with variable parameters and fixed values:

Algorithm 1. Fitness function represents the conclusive maximization process

```
function F=fitness (a,b,c,d,y,f,g,h,k1,k2,k3,k4,k5,k6)
N=8760;F=0;a=0;b=0;c=0;s1=0;F=0;d=0;y=1500;f=0;g=0;h=0.04;k=64;v=12;m=85;k2=0;k3=0;k4=0;k5=
0;k6=0;l2=0;l3=0;k4=0;l4=0;
 for i= 1:131
 s=-N*[((- exp ((-(3.14/4) *(a/v) ^2))) + exp ((-(3.14/4) *(b/v) ^2)) *((c+d)/2)) -(y*(f/m-
g)) -(h*(k^2))]; s1=s1+s;
 end
 for i= 1:12 j2=(0.63*(k2^2)); l2=l2+j2;
 end
 for i= 1:7 j3=(0.63*(k3^2)); l3=l3+j3;
 end
 for i= 1:2 j4=(0.63*(k4^2)); l4=l4+j4;
 end
 j5=(0.63*(k5^2)); j6=(0.02*(k6^2)); c1=l2+l3+l4+j5+j6; F=(s1-c1);
 end
```

Algorithm 2. It represents the main technical constraints related the electrical line losses into the internal grid of the project

```
function c1=contraint (k,k1,k2,k3,k4,k5);l1=0;l2=0;l3=0;l4=0;k=0;k1=0;k2=0;k3=0;k4=0;k5=0;
 for i= 1:131; j1=(0.04*(k^2)); l1=l1+j1;
 end
 for i= 1:12; j2=(0.63*(k1^2)); l2=l2+j2;
 end
 for i= 1:7; j3=(0.63*(k2^2)); l3=l3+j3;
 end
 for i= 1:2; j4=(0.63*(k3^2)); l4=l4+j4;
 end
 j5=(0.63*(k4^2)); j6=(0.02*(k5^2)); c1=l1+l2+l3+l4+j5+j6; if c1 <= 0.23; c1 = c1;
 end
```

Algorithm 3. It represents the availabilty limitations that is contractualy limited in the time rates

```
function c2=contraint2(m, l, n); l=0; n=0; m=0; a=8760;
 for i= 1:131; s=1-((8760-(l-(m+n)))/8760);
 end
 if (s <= 0.03); c2=s;
 end
```

Algorithm 4. It represents the tensions drops limitations for the different levels of voltage

```
function c3=contraint3(p); p=1;
 for i= 1:131; s=((p*83)/ (690^2)) *(0.04*0.8+0.04*0.6); c3=s;
 end
 if (s <= 0.03); c3=c3; else c3=0;
 end
```

3.3. Results of the simulation

The final modelisation ends with a linear constraint representing the system **A*X ≤ B**, where "A" is the matrix which contains the coefficients of the vector "X" and "B" is the vector of constants which delimits the constraints. Table 4 presented below shares the final results of Matlab Simulink, the outputs that the operation and maintenance (O&M) team must adopt to effectively schedule operations and maintenance on the turbines. These results provide critical insights into the availability of the turbines on a daily basis over the course of one operational year. Importantly, the number of available turbines per day is carefully calibrated to comply with all the constraints and limitations specified in the asset case study.

Refeering to the based inpust in Table 3 that shows the reel values calculated or adopted for all technical limitations and constraints of the full GA system represented the equation **A*X ≤ B**, where successively:

- A: Is the matrix data,
- X: Is the variable vector & B: Is the constraints vector.

$$\begin{bmatrix} -1 & 1 & -1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 98.4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.001 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.001 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.001 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 5.5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.76 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.76 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.063 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.063 \end{bmatrix}$$

$$X = [C1 = a \quad C2 = b \quad T2 = c \quad T1 = d \quad T4 = e \quad T3 = f \quad Pb = g \quad Ph = h \quad Pm = i \quad I = k \quad Ic = l \quad Ip = m \quad Ih = n]$$

$$B = [0.05 \quad -0.97 \quad 0.03 \quad 0.08 \quad 0.05 \quad 249 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]$$

The result in Figure 4 allows a clear vision about the yearly O&M mode. It is worth that the scheduled stops accounted for in the results reflect an average of 3 to 4 hours of continual work for planned interventions and up to 12 hours on average for incidents [17]. These stops are crucial and important for maintaining the optimal performance of the wind turbines and ensuring that they operate safely and efficiently over the long term. By careful consideration of the availability in the results, the O&M team can effectively plan and execute maintenance activities to minimize downtime and optimize turbine performance [18].

3.4. Discussions

The fields of O&M optimization were not treated in complete and full scope, means (data, grid, maintenance, contracts, limitations, and EIA). The modelisation as proposed for this work covers the main KPIs that are crucial for the reel operational management of the wind assets in Morocco. However, incidents and hazards that are not possible to be predicted in advance will remain at the O&M team for a daily or hourly handle referring to the incurred criticality. The presented method of this works contains all the steps needed to duplicate the same approach for others assets, it includes the functions and the scripts for MATLAB Silumink.

GA process is effective in finding optimal solutions for many problems, there are some limitations and challenges to the reliability and efficiency levels [19], [20]. The challenges with GA are that they can sometimes get stuck in local optima, rather than finding the global optimum. This happens when the algorithm converges to a suboptimal solution that is the best in the local neighborhood, but not the best possible overall solution [21]. This can be especially difficult for problems with many variables and complex landscapes, as there may be many local optima that need to be avoided to find the global optimum.

A 5-year warranty for turbine technologies can be a significant factor in the decision making process of RE projects [22]. It provides levels of inssurance to buyers that the technology is reliable and backed by the manufacturer. It can also provide protection against unexpected failures or maintenance issues that may arise during the first years. For limited cases it may not be sufficient to address all potential issues that could arise with wind turbine technologies [23], [24], for example, some issues may not become apparent until several years into the turbine's lifetime, after the warranty has expired. In addition, the warranty may not cover all potential failure modes or maintenance issues, leaving the buyer responsible for additional costs or repairs.

WTG suppliers offer guarantees that cover repairs for certain components or systems [25], [26]. The wind farm operators may choose to purchase insurance to protect against unexpected losses. In the event that a wind turbine stops functioning and requires repairs, the insurance policy may cover some or all of the costs associated with the downtime. It's worth noting that the specifics of guarantees and insurance coverage can vary depending on the manufacturer, the insurance provider, and the specific terms of the policy [27], [28].

Table 4. Results of GA simulation showing the must number of turbines per day

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
N1	131	131	129	131	131	126	131	131	131	131	131	131
N2	131	131	129	131	131	126	131	131	131	131	131	131
N3	131	131	129	131	131	126	131	131	131	131	131	131
N4	131	131	129	131	131	126	131	131	131	131	131	127
N5	131	131	129	131	131	126	131	131	131	131	131	137
N6	131	131	129	131	131	126	131	131	131	131	131	127
N7	131	131	129	131	131	126	131	131	131	131	131	127
N8	131	131	129	131	131	126	131	131	131	131	131	127
N9	131	131	129	131	131	126	131	131	131	131	131	127
N10	131	131	129	131	131	126	131	131	131	131	131	127
N11	131	131	129	131	131	126	131	131	131	131	131	127
N12	131	131	129	131	131	0	131	131	131	131	131	131
N13	131	131	129	131	131	0	131	131	131	131	131	131
N14	131	131	129	131	131	131	131	131	131	131	131	131
N15	131	131	129	131	131	131	131	131	131	131	131	131
N16	131	131	129	131	131	131	131	131	130	131	131	131
N17	131	131	129	131	131	131	131	131	130	131	131	131
N18	131	131	0	131	131	131	131	131	130	131	131	131
N19	131	131	129	131	131	131	131	131	130	131	131	131
N20	131	131	129	131	131	131	131	131	130	131	131	131
N21	131	131	129	131	131	131	131	131	131	126	131	131
N22	131	131	129	131	131	131	131	131	131	126	131	131
N23	131	131	129	131	131	131	131	131	131	126	131	131
N24	131	131	129	131	131	131	131	131	131	126	131	131
N25	131	131	129	131	131	131	131	131	129	126	131	131
N26	131	131	129	131	131	131	131	131	129	126	131	131
N27	131	131	129	131	131	131	131	131	129	126	131	131
N28	131	131	129	131	131	131	131	131	129	126	131	131
N29	131	131	129	131	131	131	131	131	130	126	131	131
N30	131	Na	129	131	131	131	131	131	130	126	131	131
N31	131	Na	129	Na	131	Na	131	131	Na	126	Na	131

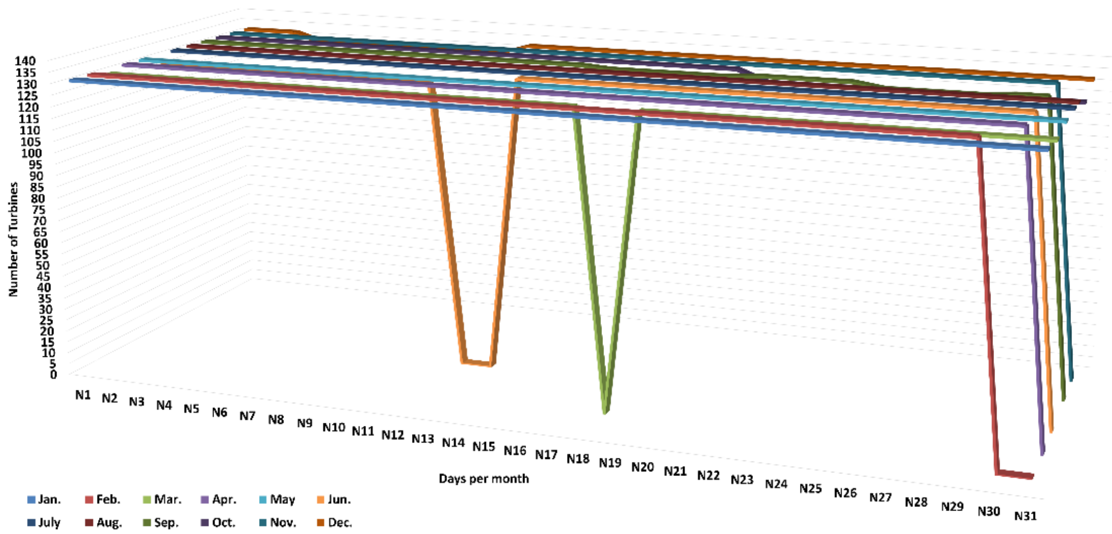

Figure 4. Results of simulation on MATLAB Simulink

4. CONCLUSION

The wind farms are exposed to several types of stops for maintenance or curtailments, some turbine's stops are previously scheduled however others are hazardous depending on the criticality of the incident. The team that manages the operations refers to contractual clauses with the grid operator and the turbine manufacturer, also for some cases to the environmental limitations, those listed contractual clauses impact hugely the production profile and the finance balance. The target is to maximise the gross and net production while respecting the minimum rate for turbine unavailability and the forced contractual power curtailments. The modelization of the project ends with a complex mathematical system that requires the genetic algorithms script for optimal resolution. Through MATLAB, the GA refers to a proposed configuration of an individual that represents the solution format and then after the GA generates the population regrouping a family of individuals that will be exposed to the test in order to come out with the optimised individuals that represents the best theoretical solution. The optimised solution outputted by the GA trough Mathlab represents the numbers of turbines that must to be operational per day allowing to generate the maximum of energy production and minimise the curtailment through reduce the unavailability of the turbines.

The solution shared in this work is practical during the lifetime of the O&M phase. The corresponding number of turbines that must be operational per day is the most optimised schedule to maximise the annual production and for better management of the assets during 20 years. Similar wind assets can follow the same process described in this article for the optimisation of the main KPIs. Overall, optimizing a wind farm requires a multidisciplinary approach, bringing together experts in wind energy, electrical engineering, and environmental science. With the right approach and expertise, it is possible to maximize the energy output of the wind farm while minimizing the costs and environmental impact associated with its operation. Actual needs of green energy (competitive LCOE) are now more oriented to the large-scale production of green hydrogen, knowing the technical process of water electrolysis, the full control and optimisation on the green energy supply is more critical for the efficiency of the O&M strategy.

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