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Application of the JAYA Algorithms in Standalone PV system sizing optimization: A case study of French Guyana

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Abstract— **In this paper, Jaya algorithm is applied to find an optimal unit sizing of standalone PV system with the objective of reducing the cost in a stand-alone system. This Algorithm achieves the optimum number of photovoltaic panels and storage units, guaranteeing a minimum cost, high efficiency system and reliably meeting electricity demand. The methodology is based on the real solar irradiation, real temperature data and real consumption profiles. A case study was conducted to an electrification project with the standalone PV systems, which is intended to remote housings in Maripasoula, French Guyana. Further, the results of Jaya algorithm are compared with a genetic algorithm.**

Keywords— **Standalone PV System Sizing, PV System Modeling, Jaya Algorithm, Genetic Algorithm**

I. INTRODUCTION

French Guiana is an overseas department and region of France, located in northeastern South America, between Suriname and Brazil. This department has a humid tropical climate. Its area is 83,853 km² which 80% is covered by the rainforest, it is including 414 km of coastline.

It has an electrical distribution network of 90 kV, that is not interconnected with neighbouring countries [1]. The dominant sources used in French Guyana are renewable energy with 68% of the electricity produced, which 61% of the hydraulic power generated by the Petit Saut dam, 6% by solar photovoltaic and 1% by biomass [1]. Only regions located in the littoral zone are connected to the network, the inland regions have their standalone power generation system. The photovoltaic solar in French Guiana enjoys favourable conditions with an annual average global solar radiation of 1222 kWh / m² / year. It should be noted that over the last twenty years, 1 MW photovoltaic was installed in the territory to supply the inland regions.

To find an optimal standalone PV system, it is essential to select the number of photovoltaic panels, batteries and their installation details such that ensuring the minimal cost, high efficiency system and reliably meeting electricity demand. It is possible to list the methods used to the sizing of the standalone PV system as intuitive, numerical, analytical, stochastic, software tools, and hybrid methods. Heuristic and metaheuristic algorithm can be included in stochastic algorithms. These algorithms can be classified such as genetic algorithm (GA), differential evolution (DE), artificial bee colony (ABC), and particle swarm optimization (PSO). The complexity of these algorithms lies, however, in the design of system components [2].

In the [3], the optimization sizing of the standalone PV in remote areas using the genetic algorithm (GA) is proposed. This algorithm is based on synthetic hourly meteorological data, in Adrar city in South Algeria. In this work, a single objective function is used to minimize the system cost without considering other system variables. This algorithm was compared to the LPSP method using worst-month meteorological data. The results showed the superiority of the GA method.

In [4] the authors utilized an artificial bee colony (ABC) to optimize the sizing of the Standalone PV system in Helwan city, Egypt. Two objective functions were mentioned, which included LLP to enlarge the output power of the PV arrays and LCC to minimize the cost of the system. The result showed that the proposed ABC was better than genetic algorithm (GA).

All the evolutionary and swarm intelligence algorithms are probabilistic algorithms and involve common controlling parameters such as population size, elite size, number of generations, etc. Besides the common control parameters, various algorithms need their own control parameters unique to the algorithm. For example, GA uses mutation probability, crossover probability, selection operator; ABC uses number of onlooker bees, employed bees, scout bees and limit [5].

A very crucial factor influencing the efficiency of the above-mentioned algorithms is the tuning of the algorithm specific parameters. Improper algorithm specific parameter tuning either increases the computational effort or provides the optimal local solution.

In view of this fact, Rao and al [6] introduced the algorithm of teaching-learning-based optimization (TLBO) that does not require any parameters specific to the algorithm. The TLBO algorithm needs only common control parameters

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for its operation, such as population size and number of generations. The TLBO algorithm has used wide by the optimization researchers [7].

Another algorithm without specific parameter is proposed keeping the performance of the TLBO algorithm. However, unlike the two phases of the TLBO algorithm, the JAYA algorithm has only one phase and is relatively easier to implement [5].

Based on the reviewed literature, the JAYA algorithm has not been applied for sizing of standalone PV systems. This method proposed to resolve the obstacles of accurate results of the evolutionary and swarm intelligence algorithms. In addition, JAYA algorithm can look with two goals synchronously based on techno-economic criteria. Finally, JAYA provides an optimum configuration considering the constraints and the objectives. Therefore, this approach aims to propose optimal number of PV panels, optimal number of storage battery and minimal cost.

The performances of the proposed algorithm are evaluated with hourly meteorological data and typical load demand. The validation of the JAYA algorithms is checked by using software method.

The rest of this article is arranged as follow, section 2 the mathematical model of PV system with batteries storage, is developed, in section 3, the techno-economic analyses criteria of the Standalone PV system are given. The proposed algorithm is elaborated and discussed in section 4. Section 5 illustrates simulation results. Finally, in section 6, a conclusion along is reported.

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II. MODELING OF PHOTOVOLTAIC GENERATOR WITH BATTERIES STORAGE:

In this part we present the photovoltaic characteristics in operating real conditions. The output energy generated by photovoltaic panel is estimated according to the solar radiation available on the inclined surface, the ambient temperature, and the photovoltaic panel data. The photovoltaic energy Ppv is presented as follows [8]:

$$P_{pv} = P_r \times f_{pv}\left(\frac{G}{G_0}\right)\left[1 + \alpha_p (T - T_0)\right]$$

Where, fpv is the photovoltaic factor, Pr is the rated power photovoltaic panel, G0 is the incident radiation at standard test conditions, G is the global insolation, αp is the temperature coefficient, T is the photovoltaic panel temperature, T0 is the photovoltaic module temperature at standard test conditions.

Energy storage is at the heart of current issues, whether it’s optimizing energy resources or promoting access to them. It makes it possible to adjust the "production" and "consumption" of energy by limiting losses. Energy, stored when its availability is greater than needs, can be returned at a time when demand is more important. In the face of intermittent or fluctuating production of certain energy sources, such as renewables, this operation also makes it possible to meet constant demand.

A battery’s state of charge (SOC) is given as follows [9], [10]:

During charging process

$$SOC(t) = SOC(t-1) + \eta_{bat}\left(E_p(t) \times \eta_{inv} - E_d(t)/\eta_{inv}\right)$$

During discharging process

$$SOC(t) = SOC(t-1) + \left(E_p(t) \times \eta_{inv} - E_d(t)\right)$$

where SOC(t) is the energy stored in batteries, ηbat is the battery charge efficiency, Epr(t) is the power produced by photovoltaic panels, Ed(t) is the power demand by the load and ηinv is the inverter efficiency.

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III. CRITERIA FOR SIZING THE STANDALONE PV SYSTEM

Among the parameters that influence the size of the stand-alone PV system, the location of the PV system, weather data and load demand. In fact, stand-alone PV systems must be dimensioned with great care to increase the reliability of the system. Technical and economic parameters are developed to meet the load demand at a lower cost.[11].

A. Technical criteria

The reliability of the power system is the capacity of the PV system to satisfy the load. The excess energy is used to charge the battery in the case that the demand is less than the total energy produced. In the case of a deficit energy, the energy will be supplied by the batteries, if the storage level is greater than the minimum threshold. [12].

$$P_{pv}(t) \times N_{pv} + S_{bat}(t) \times N_{bat} \geq E_d(t)$$

Where S_{bat} is the state of charge of a battery, $E_d(t)$ is the load demand, Ppv power PV panel.

B. Economic criteria

In this research work, the life cycle cost (LCC) of the standalone PV is designed to be the economic profitability criteria of system cost analysis [9]. The LCC can be defined as the total cost of all components of the standalone PV system. In this system, there are four main parts proposed: PV collection, battery storage, bidirectional converter, and regulator of charge. The LCC takes into calculation the initial capital cost (C_{icap}), the value of replacement cost (C_{rep}), and the value of operation and maintenance cost (Cm)[4].

The total cost of the system is represented by:

$$LCC = C_{icap} + C_{rep} + C_m$$

The initial capital cost:

$$C_{icap} = N_{pv} \times C_{pv} + N_{bat} \times C_{bat} + N_{con} \times C_{con} + C_{in}$$

The maintenance cost:

$$C_m = N_{pv} \times M_{pv} \times H + (H - Y_{bat} - 1) \times N_{bat} \times M_{bat} + (H - Y_{con} - 1) \times N_{con} \times M_{con}$$

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The replacement cost:

$$C_{rep} = N_{pv} \times C_{pv} \times Y_{pv} + N_{bat} \times C_{bat} \times Y_{bat} + N_{con} \times C_{con} \times Y_{con}$$

Where N_{pv}, N_{bat} and N_{con} are PV panels, batteries, and converter number, respectively. C_{pv}, C_{bat} and C_{con} is the unit cost of each component of the system. C_{in} is the installation cost. M_{pv}, M_{bat} and M_{con} is the maintenance cost of each component of the system. Y_{pv}, Y_{bat} and Y_{con} is the number of replacements of each component over the system life period. H is the lifespan.

IV. OPTIMIZATION METHOD FOR SIZING THE STANDALONE PV SYSTEM USING JAYA ALGORITHM:

The optimization algorithm is a tool which can deal with complex optimization problems. Optimization is necessarily in all domains from the engineering design to economics study. Giving the optimal solution, in terms of cost, resources and time is an important step.

The optimization of the size standalone PV system us to obtain the optimum number of photovoltaic panels and storage units, ensuring the minimal cost, high efficiency performance and reliably meet electricity demand.

The necessary control parameters of JAYA algorithm are population (POP) size, termination criteria, etc.. At iterations i having n number of decision variables (j = 1, 2,..., n), and m number of candidate solutions for a POP size, (k = 1, 2, 3,.... m), the objective function f(x) is minimized.

In the entire candidate solution, the best candidate achieves the best f(x) value and is defined by $f\,(x)_{best}$. Similarly, the worst value of f (x) is given to the worst candidate in the entire POP, denoted as $f\,(x)_{worst}$.

If $X_{j,k\,i}$ represents the value of j^{th} variable for the kth candidate during the i^{th} iteration, then it will be changed as per criteria defined by the following formula [5]:

$$X'_{j,k,i} = X_{j,k,i} + r_{1,j,i}\left(X_{j,best,i} - |X_{j,k,i}|\right) - r_{2,j,i}\left(X_{j,worst,i} - |X_{j,k,i}|\right.$$

where, $X_{j,best,i}$ is the value of the variable j for the best candidate and $X_{j,\,worst,i}$ is the value of the variable j for the worst candidate. $X'_{j,k,i}$ is the updated value of $X_{j,k,i}$. $r_{1,j,i}$ and $r_{2,j,i}$ are the two random numbers for the j^{th} variable during the i^{th} iteration in the rang [0,1].

If $X'_{j,k,i}$ gives better function value, it is agreed. At the end of the iteration, all agreed function values are retained, and these values become the input for the next iteration. Fig.1 presents a flowchart of the JAYA algorithm.

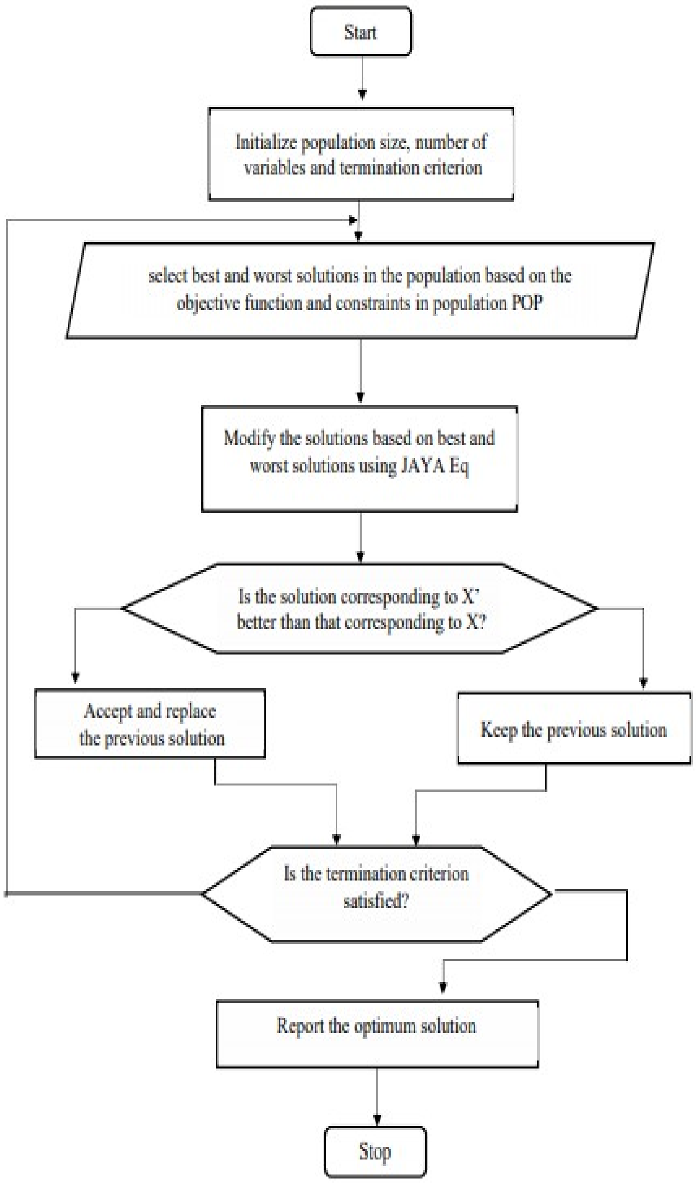

Figure 1. Flowchart of JAYA algorithm

V. 5. RESULTS AND DISCUSSION:

In this paper, the comparative study between JAYA and GA algorithms are proposed for determining optimal standalone PV configuration. The hourly meteorological data collected by French Guyana Meteorological Station in MARIPASOULA with latitude (3.64°) north and longitude (54.08°) west for three years is used in the optimization process. The proposed Standalone PV system is used to supply the load demand for remote area housings. A load demand is represented in Fig. 2.

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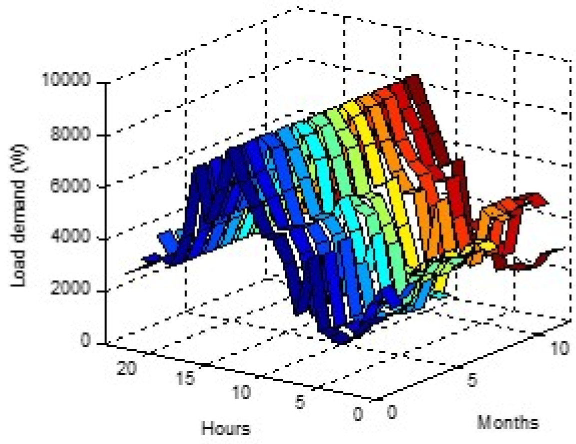

Fig 2. The load demand.

The annual hourly meteorological data from MARIPASOULA, French Guyana, were obtained and shown in Fig.3.

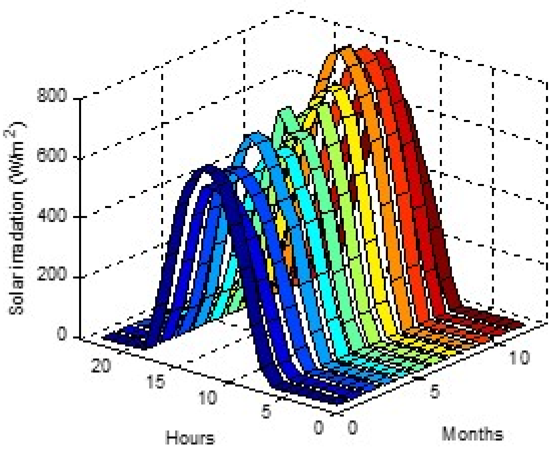

Fig 3. The monthly average of daily solar irradiation

The table I show the optimal sizing of the standalone PV system using JAYA algorithm and GA. Both methods are given the satisfactory results, but the JAYA algorithm showed the best result in term of times and the percentage having the optimal solution.

TABLE I
OPTIMAL SIZING OF THE SAPV SYSTEM USING JAYA AND GA

ALGO	cost	N_{pv}	N_b	Times	Iteration number	The percentage having the optimal solution
GA	456686	189	95	4.62	200	60
JAYA	456686	189	95	2.93	200	98

The Fig.4 shows that the JAYA algorithm converges more rapidly the GA on the first 5 iteration. Hence the effectiveness of JAYA algorithm.

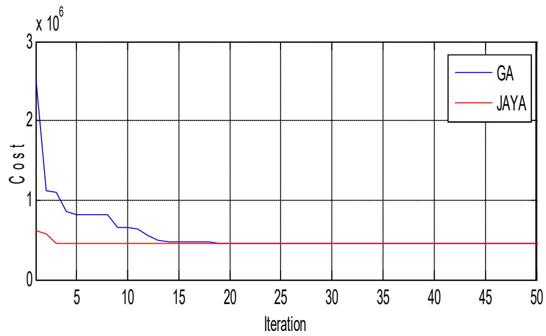

Fig. 4 Convergence of the JAYA algorithm and GA.

VI. CONCLUSIONS

The techno-economic and environmental feasibility study to find optimal configurations of the standalone PV system electrification in MARIPASOULA, French Guyana is assessed in this paper.
In this research, the optimum sizing of standalone PV system using the JAYA algorithm and Genetic algorithm is proposed. The optimization sizing us to obtain the optimal number of photovoltaic panels and batteries storage units, ensuring the minimal cost, high efficiency system and reliably meet electricity demand. The results showed the superiority of the JAYA algorithm f in term of convergence and simplicity.

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