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Comparison of Crow Algorithm and Genetic Algorithm in Controlling Autonomous Renewable Hybrid Energy Systems

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Abstract

Renewable Hybrid Autonomous Power Systems are very important for remote and isolated zones. These systems are characterized by the diversity of energy systems that can solve power problems in isolated and remote zones that cannot be connected to electric grids. The energy from sun exists during the day and the wind is intermittent. Thus, for solving such problem, different renewable energy technologies represented in hybrid renewable energy systems are needed. The hybrid system includes PV plus Wind, PV plus Diesel, PV plus Wind and Diesel, etc. "Autonomous Hybrid Renewable Energy System" (AHRES) consists of two or more energy sources; one of them at least is renewable and integrated with power control equipment and an optional storage system. This paper aims at comparing between the utilization of new optimization technique, namely (Crow Algorithm), and the Genetic algorithm in controlling the autonomous system where this technique is used for controlling suggested autonomous system in the Egyptian Island located in the Red Sea namely "Al-Fanadir Island". The wind speed and solar irradiance parameters are obtained for Al-Fanadir Island. The Load Profile of Al-fanadir Island is obtained from Ministry of electricity and renewable energy in Egypt. The selection between the system's Reliability and Cost is a basic compromise for designing hybrid systems. In this technique, optimization of "Autonomous hybrid renewable energy system" is investigated. The study showed that both the Crow Algorithm and GA are effective t ools in controlling the autonomous hybrid renewable energy system.

Keywords*; *Autonomous renewable energy system, Crow algorithm, "Al-Fanadir Island", Cost of Electricity, Reliability

1-Introduction

Autonomous Hybrid Renewable Energy Systems present electricity at the local level which can be achieved by mixing the renewable energy with a diesel generator that works as a support system. These systems range from 5 kW single phases to provide electricity for a single home to a large 3-phase network that represents a huge power supply for the whole society. However, as the society increases in population, their capacity can be easily elevated and connected to the National Network.[1]

The complementary action between solar energy and wind energy are based on the annual and regional basis; and this is the reason beyond, using both as major renewable energy resource in hybrid

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autonomous renewable energy systems [2,3]. These hybrid autonomous renewable energy systems need to efficient optimization techniques for obtaining optimal cost and loss of power supply probability(LPSP).

In the beginning of the fifties of the last century, computer specialists studied evolutionary systems as an optimization technique, introducing the basics of evolutionary computing. The area of evolutionary systems was working until 1960s in parallel with genetic Algorithm (GA) research. The interaction between evolutionary system and GA produced a new field of evolutionary programming. Holland, the father of the GA[4] introduced the concept of the GA as a simulation of the Darwin's theory of evolution.

The Genetic Algorithm (GA) starts with a population characterized by random chromosomes. Then evaluating these structures and allocating reproductive chances in a manner that allow chromosomes that represent a better solution to the problem are taken more opportunity to “reproduce”. After choosing the best individuals, new offspring (fitter) are generated and reinserted, and thus the weaker is removed. Using mutation and crossover processes lead to new properties of the chromosomes. The appropriateness of a solution is identified according to the current population [4]. GA methods have a rigid theoretical base [4], based on the Schema Theorem [5]. GAs are often appeared as optimisers of function, although the wideness of problem's range that includes: pattern discovery [6], signal processing [7], and training neural networks [8].

1-1 GENETIC ALGORITHM OPERATION

To explain the working process of GA, the steps to achieve a basic GA are listed:

First Step: Representing the variable domain of the problem as a chromosome has fixed length; select the chromosome population's size N, the mutation probability Pm and the crossover probability Pc.

Second Step: Defining an objective (fitness) function for measuring the individual's performance chromosome within the domain of the problem. The objective (fitness) function constructs the basis to select chromosomes that will be used (mated) during reproduction.

Third Step: Generating an initial population of size N: x , x ,..., xN 1 2

Fourth Step: Calculating the objective (fitness) of each individual chromosome.

Fifth Step: Selecting a pair of chromosomes for using (mating) from the present population. Parent chromosomes are chosen with a suitable probability related to their fitness. Chromosomes with high fitness have a higher probability of being chosen for mating than those have less fitness chromosomes.

Sixth Step: constructing a pair of offspring chromosomes by performing the genetic operators.

Seventh Step: Placing the resulted offspring chromosomes in the new population.

Eighth Step: Repeating the fifth Step until reaching a state of equal sizing between the new population and the initial population, N.

Ninth Step: Replacing the initial original (parent) chromosome population with the new generated (offspring) population.

Tenth Step: Going to the fourth Step, and repeating the process until achieving the termination criterion.

A GA is an iterative process. Each iteration is called a generation. A typical number of generations for a simple GA can range from 50 to over 500. A common practice is to terminate a GA after a specified number of generations

and then examine the best chromosomes in the population. If no satisfactory solution is found, then the GA is restarted [9].

1-2 Crow Search Algorithm (CSA) for Optimization

The step-wise method used for the implementation of CSA is shown in the following steps:

First Step: Initialization of the Problem and Adjustment of Parameters:

First, the optimization of the problem, variables and constraints are defined; then, the adjustable parameters of the Crow Algorithm (maximum number of iterations ($iter_{max}$), Flock Size (N), Awareness Probability (AP) and Flight Length (fl) are valued.

Second Step: Initialization of Memory and the Position of Crows:

A number of crows (N) are placed randomly in search space (with d-dimensions) representing the flock's members, where each crow identifies problem's feasible solution.

$$Crows = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_d^1 \\ x_1^2 & x_2^2 & \cdots & x_d^2 \\ \vdots & \vdots & \vdots & \vdots \\ x_1^N & x_2^N & \dots & x_d^N \end{bmatrix}$$

The process of initialization of each crow's memory is important because the crows own no experiences at the first iteration, assuming that at the first selected positions, the crows have hidden their foods.

Third Step: Estimation of Objective (Fitness) Function:

The crow's position quality is computed for each crow, through substituting the values of decision variable into the (Fitness Function).

Fourth Step: Generation of a New Location (Position):

Within the space of search, Crows can generate new positions as follows: Assume that i^{th} crow desires to allocate a new position. This crow randomly selects one of the crows in the flock (e.g. j^{th} crow) and traces it up until discovering the selected location (position) of the hidden foods by the crow (m^j). Once the new location of crow (i) is determined, repeat the process for all other crows.

Fifth Step: Checking the Feasibility of New Selected Places:

Checking the feasibility of the new selected place of each crow where the crow updates its location (position) if this new location is feasible. Otherwise, the crow remains in the current location without moving to the new generated location.

Sixth Step: Estimation of the Fitness Function of New Positions.

Calculations of the value of the objective (fitness) function according to the new location of each crow.

Seventh Step: Updating the Crow's Memory

The crow renews its memory as follows:

$$m^{i,iter+1} = \begin{cases} x^{i,iter+1} & f(x^{i,iter+1}) \text{ is better than } f(m^{i,iter}) \\ m^{i,iter} & \text{Other wise.} \end{cases}$$

Where, f (.) is the value of fitness function.

Notice that the crows renew their memory by the new location if the fitness(objective) function value of the new location of a crow is better than the fitness function value of the memorized location.

Eighth Step: Checking the Termination Condition

Repeating steps (4–7) until the value of ($iter_{max}$) is achieved. When achieving the termination condition; the best position of the memory in terms of the objective function value is determined as the optimal solution of the problem. [10]

The fitness function in this paper is expressed as the lowest value between two factors; the first is (Loss of Power Supply Probability) and the second is (Cost of Electricity).

The objective of this study is to compare the performance of both crow algorithm and GA algorithm for providing a high reliability and cost effective system for chalets in Alfanadir Island, Red Sea, Egypt. It is required to select the autonomous hybrid renewable energy system (AHRES) components. To accomplish this objective, a crow optimization technique (multi-objective) is used for obtaining certain criteria that help in finding the optimal Cost of Electricity (COE) that meets the optimal Loss of Power Supply Probability (LPSP). Another important factor namely renewable factor is used to judge that the system basically works depending on renewable energy resources. The weather data for the chosen zone in Egypt are obtained.

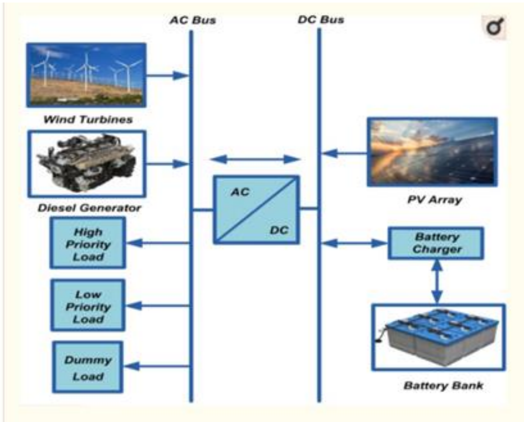

Fig (1) Hybrid Autonomous Renewable Energy System

2- Load Profile

Al-Fanadir Island has a load profile that is obtained from the Ministry of Electricity and the Renewable Energy Source as shown in Fig. (2)

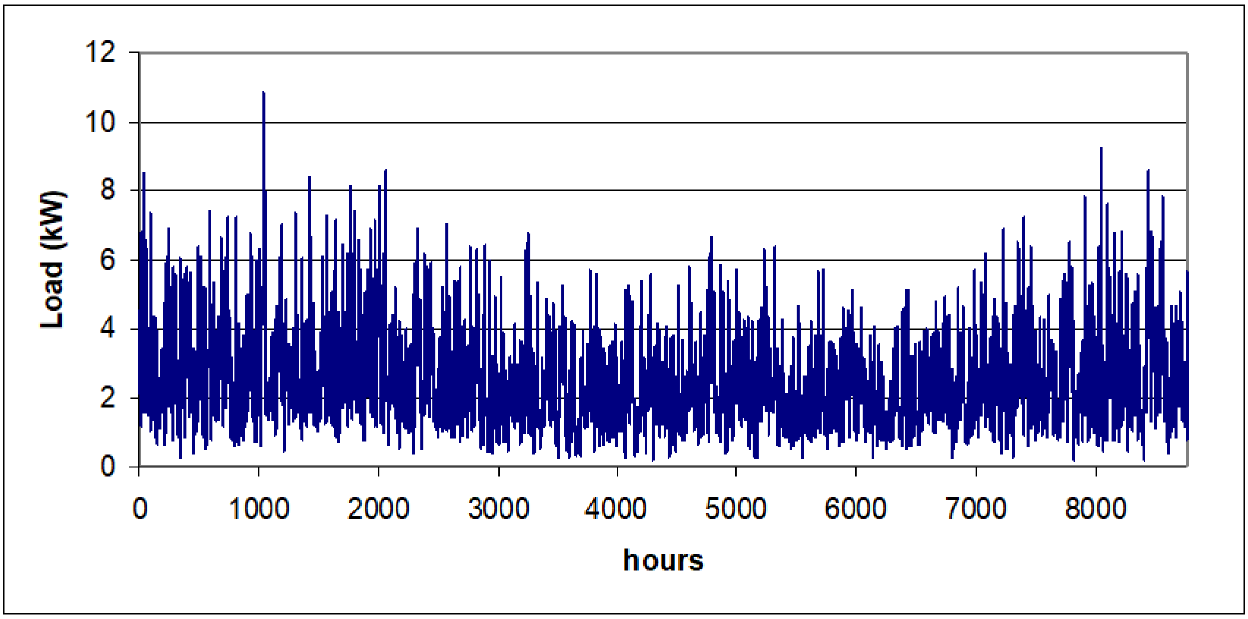

Fig (2) Hourly Load profile (kWatt) during the year in Al-Fanadir Island (Red Sea, Egypt). Source (New and Renewable Energy Authority, Egypt)

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3. Specifications

3-1 The Components Specifications

The characteristics of the autonomous renewable hybrid system are indicated in Table (1) shown below:

Table (1) The System Parameters

Parameter	Unit	Value
Diesel generator Life time	hours	25,000
Initial cost	$/kW	1000
Rated power	kW	4
Inverter Efficiency	%	92
Life time	year	24
Initial cost	$	2500
Battery Efficiency	%	85
Life time	year	12
Initial cost	$/kWh	280
Rated power	kWh	40
PV PV regulator efficiency	%	95
Life time	year	24
Initial cost	$/kW	3400
Rated power	kWh	7.3
PV regulator cost	$	1600
Economic parameters Discount rate	%	8
Real interest	%	13
Operation &Maintenance running cost Fuel inflation rate	% %	20 5
Project life time	year	24
Wind turbine Model		ZEYU FD-2KW
Wind regulator cost	$	1000
Blades diameter	m	6.4
Swept area	m2	128.6
Efficiency		0.95
Cut out	m/s	40
Cut in	m/s	2.5
Rated speed	m/s	9.5
Rated power	kW	5
Price	$/kW	2000
Life time	year	25

3-2 Specification of the Study Zone

3-2-1 Study Zone Location

The (Zone) is an Egyptian Island located in the Red Sea, which is in a remote area in Egypt called Al-Fanadir Island, Red Sea, where this zone is characterized by good wind speed and good irradiance characteristics. So, this means that this island owns good characteristics for Hybrid Autonomous Plants. Al Fanadir. The Coordinates, Latitude are: 27°17′46.75″N Longitude: 33°49′51.53″E.

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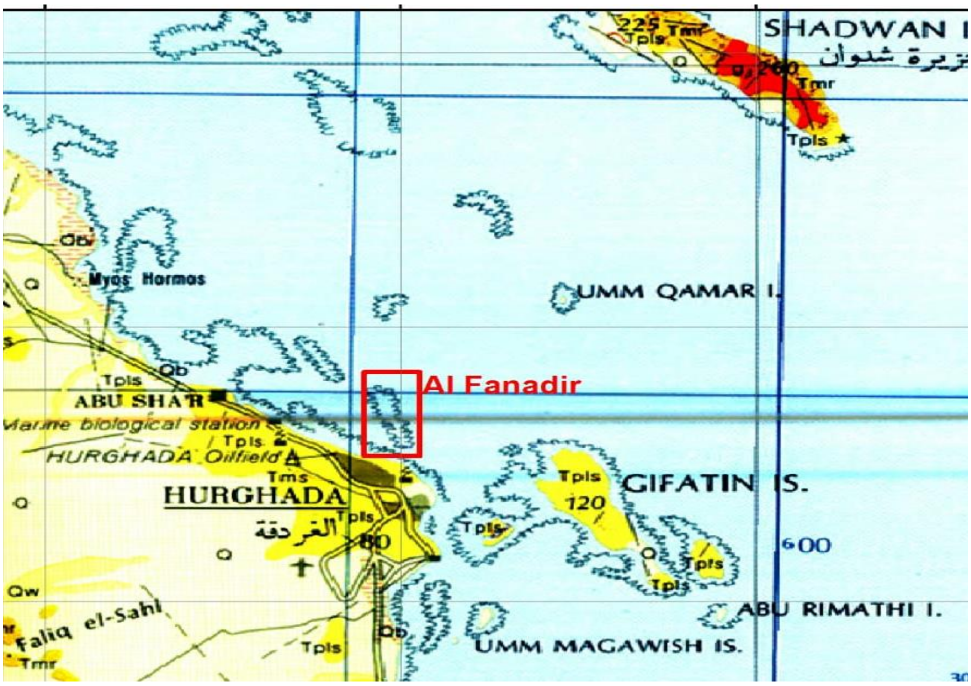

Map (1) Location of Al-Fanadir Island

(Source: Egyptian Survey Authority)

3-2-2 Meteorological Characteristics of the Study Zone

The Metrological Characteristics of the study zone were obtained from the Egyptian Meteorological Authority where the meteorological data include**:** temperature variation (^{o}C) during months of the year as shown in Fig. (3), Solar Radiation (kWh/m^2) during months of the year as shown in Fig. (4), Sunshine Duration (h) as shown Fig. (5) and Wind Speed (m/s) as shown in Fig.(6)

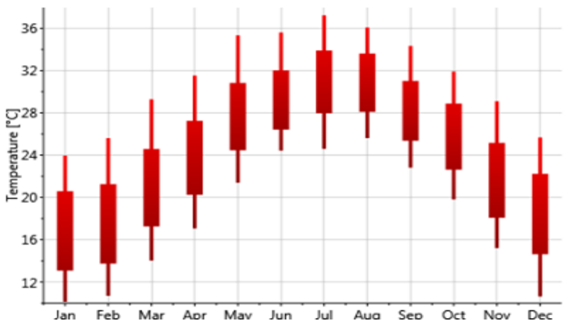

Fig. (3) Temperature variations over months of the year in Al-Fanadir Island (Red Sea, Egypt)

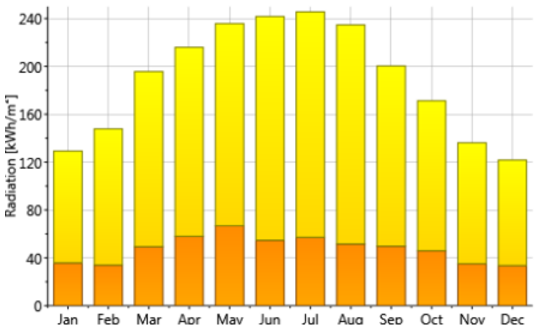

Fig. (4) Solar Radiation (kWh/m2) during months of the year in Al-Fanadir Island (Red Sea, Egypt)

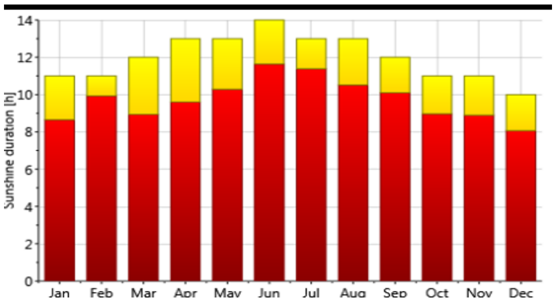

Fig. (5) Sunshine duration during the months of the year in Al-Fanadir Island (Red Sea, Egypt)

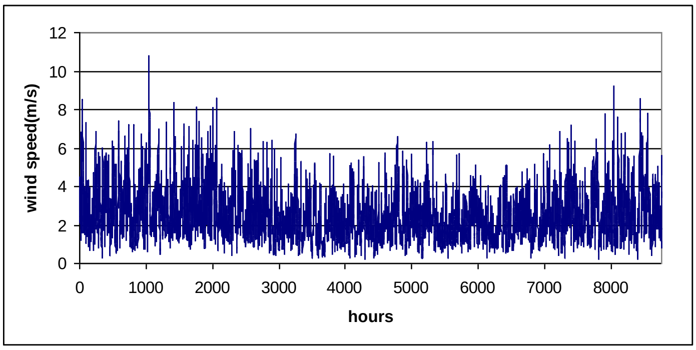

Fig. (6) Hourly Wind Speed (m/s) during the year in Al-Fanadir Island (Red Sea, Egypt)

Optimization

In order to design a highly efficient autonomous and low cost renewable energy system, then we must start with sizing the system components. The combination of using generation sources and the high quality components also has a considerable impact on the system's life time, and can reduce the electricity costs in remote and isolated zones.

Cost Analysis

Cost of Electricity (COE) is one of the most used and well-known indicators of the economic profitability of the autonomous renewable energy systems [8] which is expressed as cost per unit of electricity. COE can be estimated via the following expression

$$COE\left(\frac{\$}{kwh}\right) = \frac{\text{total net present cost } (\$)}{\sum_{h=1}^{h=8760} P_{load}(h)(kwh)} \times CRF$$

[7]:

The maintenance and operational costs, replacement cost, and present costs constitute the total net present cost. The hourly power consumption is denoted as $P_{load(h)}$. The Capital Recovery Factor (CRF) is expressed as the Ratio for estimating the system components' present value over a certain period of time taking into account the interest rate value that is computed according to the following equation:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

Where, (i) is the value of real interest rate and (n) is the number of years representing the life period of the system, (it is assumed that life period equals to life time of the photovoltaic panels, which possess the longest life time in the system) [9].

Analysis of Reliability

Failure probability of power supply occurs either due to technical failure or due to low renewable energy to satisfy the demand; this failure probability is estimated through Loss of power supply probability (LPSP).

Two techniques are used for calculating LPSP**:** the first technique is the chronological simulation whereas the second technique is a probabilistic technique. The first technique utilizes the data of time-series in a pre-determined period of time; whereas the second technique depends on the accumulated effect of the energy storage system which can be estimated as follows [7]:

$$LPSP = \frac{\sum (P_{load} - P_{pv} - P_{wind} + P_{Socmin} + P_{diesel})}{\sum P_{load}}$$

Renewable Factor

The Renewable Factor is defined for crow algorithm as a limit used for determining the amount of diesel generator energy to the renewable energy. If the renewable factor reached to 100%; this indicates that the system uses renewable resources only.

However, if the renewable factor reached 0%; this means that the generated amount of diesel power is equivalent to the power from the renewable resources. Consequently, the renewable factor estimated as follows:

$$\text{Renewable Factor }(\%) = \left(1 - \frac{\sum P_{diesel}}{\sum P_{pv} + \sum P_{wind}}\right) \times 100$$

Multi Objective Optimization

The multi-objective optimization is a suitable technique for autonomous hybrid renewable energy system; there are many techniques for solving such problem. However, the linear scalarization technique is a common approach that is characterized by its simple character where in this technique a multi-objective problem is transformed into a problem with single objective where objectives may either merge in a linear system or manipulated as problem's constraints. The objective is to find the optimal solution for the linear function as well as to fulfill some constraints (inequalities) for finding the best solution as a single point in Pareto Front [9]. The fitness function is computed as follows:

$$\text{Fitness} = \min\mathit{imize}\left\{\sum_{i=1}^{k} w \frac{f_i(x)}{f_{i\max}}\right\} \text{ with } w_i \geq 0 \text{ and } \sum_{i=1}^{k} w_i$$

And the problem's constraints are expressed as follows:

Minimize $g_i(x) \geq 0$ for $i \in \{1, ..., m\}$ where (x) is the decision variables vector; the weights (w_i) show the relative importance of each objective; (k) is the number of objectives; (f) is the objective function, and $f_{\max i}$ is the upper bound of i^{th} objective function.

In Autonomous Hybrid Renewable Energy Systems, both the LPSP and the COE are considered as equally has the same importance for achieving the optimum system which guarantee un-interrupted and reliable supply of energy that compete cost with the traditional energy obtained from the fossil fuel and the network extension. For obtaining balance of both objectives, it is suggested to adjust the weights (w_i) at 0.5.

Description of the Implemented Software

The designed software aimed at finding the optimal cost for controlling hybrid autonomous renewable energy system using the Genetic Algorithm and Crow Search Optimization Technique (CSA).

The used software had been implemented using Matlab code supported by Graphical User Interface (GUI) for facilitating the data entry process. This program is based on Crow Algorithm where the interface of the program included windows for selecting input Excel files (Load profile, wind speeds, temperatures and solar radiation) and other windows for single valued parameters such as (Project life time and interest rate) and other windows for parameters with ranges such as (PV panel numbers - kW range, wind turbine range, range for number of diesel engines and range for autonomy days and). The GUI included using the selection window for selecting the required algorithm for optimization. The GUI also contains a certain button called "Run" button for running the program. An area within the interface is assigned for the outputs that are represented in: PV power, Autonomy days, number of wind turbines, number of diesel engines and electricity price.

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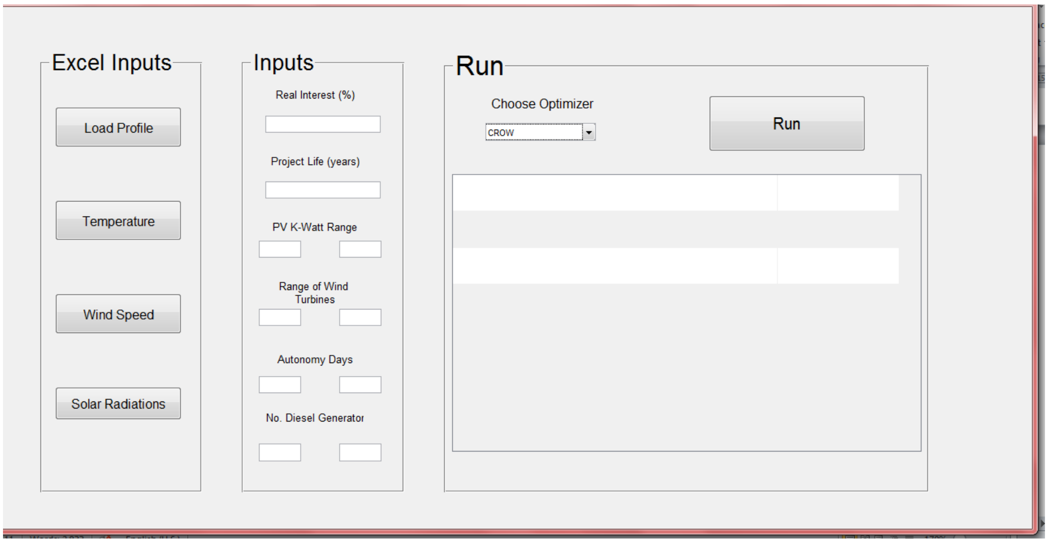

Fig. (7) Description of the Graphic User Interface (GUI) of the Designed Software

5- Results and Discussions

The locations of Alfanadir Island, Red Sea, Hurgada are used in this study for investigating the optimization of Autonomous Hybrid Renewable Energy System.

Table (2) The Software Output

Item of comparison	GA	CROW
Number of iteration	100	100
Power of PV panels (Kw)	44	43.5
Days of autonomy	3	3
Number of wind turbines	10	10
Power of diesel generator (KW)	4	4
LPSP (%)	8	8
COE ($/KWh)	0.35	0.451
Renewable factor (%)	60	59.5

Daily load is utilized for each chalet in the Island. Moreover, the society consists of 17 chalets where the input parameters are indicated in Table (1).

The Software Outputs are shown in Table (2). To obtain a continuous power to the load according to different modes of operations the power management strategy for a Hybrid Autonomous Renewable Energy System is implemented. Both the Crow Algorithm (CSA) technique and GA are used for obtaining the optimal configuration of the system and for sizing the components. Loss of Power Supply Probability (LPSP) combined with Cost of Electricity (COE) represents the multi-objective function.

Results

The results show that both CSA and GA presented optimum wind, solar and batteries ratings where the optimal founded solution is indicated in Table (3). As shown, both the CSA optimization and GA models produced a suitable sizing for Autonomous Hybrid renewable energy system in Alfanadir Island.

CSA and GA optimization showed that the optimal reliability with lowest cost and high contribution of renewable energy were achieved for this location.

Fig. (8) indicated the estimated optimal cost of energy according to both the GA and CSA.

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In Al-Fanadir Island, the result of optimization shows that the autonomous hybrid renewable energy system can be utilized for this Island with a high value for the renewable factor (i.e. high renewable dependence). Therefore, in other Egyptian islands, the use of renewable energy is a good alternative for enhancing energy access.

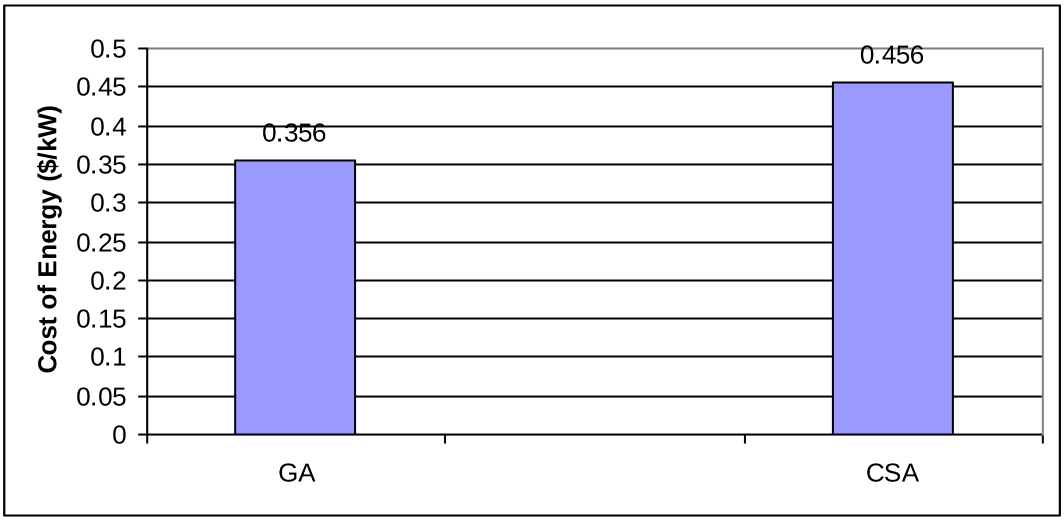

Fig.(8) cost of energy (after 100 iterations) by both GA and CSA

Fig. (9) and Fig. (10) indicated energy percentages supplied by: wind turbine, PV, diesel generator, and batteries over one year as estimated by both optimizer GA and CSA.

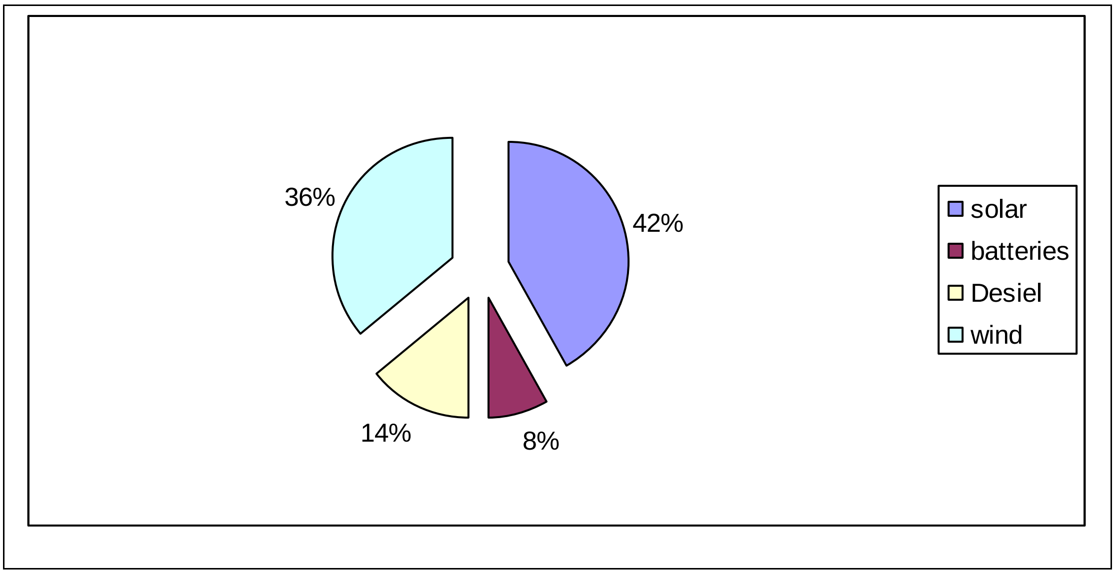

Fig. (9): Energy percentage supplied by**:** Diesel Generator, Wind Turbine, PV, and Batteries during one year using GA Algorithm (after 100 iteration)

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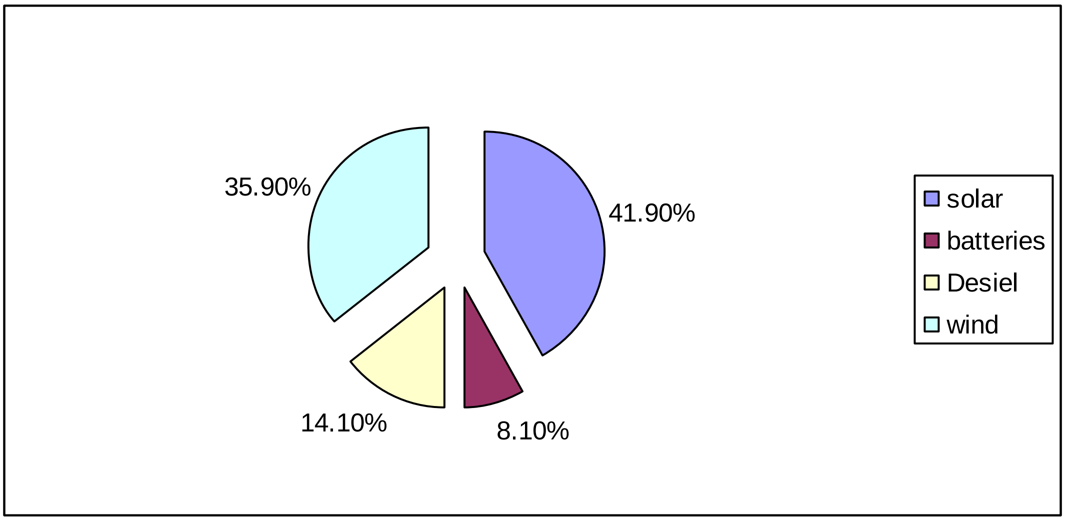

Fig. (10): Energy percentage supplied by**:** Diesel Generator, Wind Turbine, PV, and Batteries during one year using Crow Algorithm (after 100 iteration)

The convergence of the Crow Algorithm is shown in Fig. (9).

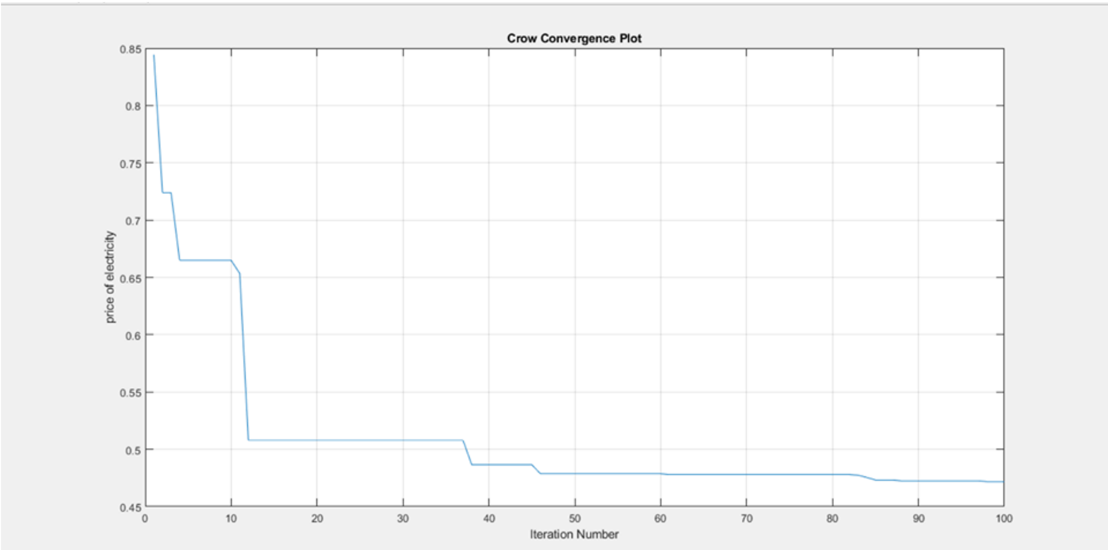

Fig. (9) Convergence of Crow Algorithm

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DISCUSSION

The strength of GAs is in the parallel nature of their search. A GA implements a powerful form of hill climbing that preserves multiple solutions, eradicates unpromising solutions, and provides reasonable solutions. Through genetic operators, even weak solutions may continue to be part of the makeup of future candidate solutions. The genetic operators used are central to the success of the search. All GAs require some form of recombination, as this allows the creation of new solutions that have, by virtue of their parent's success, a higher probability of exhibiting a good performance. In practice, crossover is the principal genetic operator, whereas mutation is used much less frequently.

Crossover attempts to preserve the beneficial aspects of candidate solutions and to eliminate undesirable components, while the random nature of mutation is probably more likely to degrade a strong candidate solution than to improve it. Another source of the algorithm's power is the implicit parallelism inherent in the evolutionary metaphor. By restricting the reproduction of weak candidates, GAs eliminate not only that solution butalso all of its descendants. This tends to make the algorithm likely to converge towards high quality solutions within a few generations.Table (3) comparison between GA and CSA

Technique / Comparison items	GA	CSA
increase the diversity of generated solutions	**Increase**	**Increase**
Explanation for CSA CSA is not a greedy algorithm since if a crow generates a new position which is not better than its current position, it will move to the new position. Non-greedy algorithms can increase the diversity of generated solutions.		
Memory	**Not exist**	**Exist**
Explanation: CSA includes memory in which good solutions are memorized.		
Number of parameters	**6**	**2**
Explanation Algorithms which have fewer parameters to adjust are easier to implement		
Parameters	**1-selection method, 2-crossover method, 3-crossover probability, 4-mutation method, 5-mutation probability 6- replacement method**	**1-flight length 2-awareness probability**
Convergence	**Fast**	**slow**

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6. Conclusions

One of the basic needs of any society is to have access to a reliable source of electricity; where accessing reliable electricity can improve the quality of living by enhancing healthcare, education, and the local economy. Implementation of a Autonomous Renewable Energy System can be considered as the most promising solution for isolated and remote zones' electrification by both increasing the supply quality and decreasing the installation costs. This paper introduces a strategy for controlling autonomous renewable hybrid energy system to keep continuity of power supply to the load in different modes of operations. The collection of wind, diesel generator, PV, and battery storage with variable loads is selected for this aim. The crow search algorithm technique (Multi-Objective) is implemented for obtaining the optimal configuration of the system and components' sizing. The objective function included both Cost of Electricity (COE) and the Loss of Power Supply Probability (LPSP). The Optimization results are obtained by using the meteorological data of Alfanadir Island, Red Sea, Egypt. The result of optimization in this site showed a high renewable factor, which means that renewable energy in this location, covers a considerable percentage. Therefore, the utilization of autonomous hybrid renewable energy is considered a good tool for supplying energy in other nearby islands in the Red Sea, Egypt. Overcoming some technical obstacles that still bound the distribution of autonomous renewable energy projects can be assisted by the utilization of the proposed technique. It can also be utilized as a faster design of efficient electrification projects support tool to enhance electrification projects.

The results showed that both crow and GAs can be used in the optimisation of Autonomous hybrid renewable energy system. Regarding the computational speed, the GA approach is faster than the crow approach. Regarding the accuracy of the solution, the GA determines values which are closer to the known values than does the crow at the same number of iteration. Finally, the GA seems to arrive at its final parameter values in fewer generations than the crow. Thus it must be concluded that for the process of process modelling, the GA approach is superior to the crow approach. Techniques such as Crow and Genetic Algorithms are inspired by nature, and have proved themselves to be effective solutions to optimization problems. However, these techniques are not a panacea, despite their apparent robustness. There are control parameters involved in these meta-heuristics, and appropriate setting of these parameters is a key point for success. In general, some form of trial-and-error tuning is necessary for each particular instance of optimization problem. Additionally, any meta-heuristic should not be thought of in isolation: the possibility of utilizing hybrid approaches should be considered. Additionally for both approaches the major issue in implementation lies in the selection of an appropriate objective function.

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