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Optimal Sizing and Economical Analysis of PV-Wind Hybrid Power System for Water Irrigation using Genetic Algorithm

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ABSTRACT

In the present study three renewable power systems are proposed to select the most optimum one for powering an irrigation pumping system and a farmer's house in two different locations in Sinai, Egypt. Abu-Rudies in south Sinai and El-Arish in north Sinai are the two selected locations. The three suggested power systems are; standalone photovoltaic (PV) system, standalone wind system and standalone PV-wind hybrid system. HOGA (Hybrid Optimization by Genetic Algorithms) simulation software tool based on genetic algorithm (GA) is used for sizing, optimization and economical evaluation of three suggested renewable power systems. Optimization of the power system is based on the components sizing and the operational strategy. The calculated maximum amount of water required for irrigating ten acres of olive per day is 170 m^3. In terms of cost effectiveness, the optimal configurations are the hybrid PV-wind system and the standalone PV system for Abu-Rudies and El-Arish locations respectively. These systems are the most suitable than the others for the selected sites metrological data and the suggested electrical load.

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1. INTRODUCTION

Nowadays, water resources of the world have been limited due to global climatic changes. Water shortage is the main characteristic of agriculture on the Mediterranean southern coast, which induces plant water deficits during the dry spring-summer period. In addition, it is the major constraint to expand the agricultural area which is essential to narrow the country's food gap [1]. Accordingly, seeking and exploit alternative available water sources have become necessary. Rainwater is one of the available water sources that can be exploited for irrigation [2]. One of the proposed solutions is harvesting and storing rainwater during rainy season by constructing any of the proper reservoir structures. The stored rain water can be used as a great alternative to treated drinking water for irrigation [3]. Because rainfall is scarce in arid regions, it is best to select plants with low water requirements and control planting densities to reduce overall water need. Native plants are well-adapted to seasonal, short-lived water supplies. Olive is widely cultivated in semiarid areas with Mediterranean climate, where long periods of soil water deficit are usually present during the dry season [4], [5]. Olive tree has been traditionally grown under rain-fed conditions and is considered one of the best adapted species to the semiarid environment. However, under this condition it usually shows a decrease in photosynthesis that reduces root growth. The introduction of irrigation in olive groves can be attaining considerable increases in olive production. Irrigation, even at rates which are relatively small compared to those used for other crops, can raise olive production, in some cases by a factor of six compared to the dry-land output [6]. Olive production plays an important role in the economy of many Mediterranean countries and it is considered one of the important crops in Egypt. The Egyptian government supports the cultivation of Sinai olive to increase production and attention to its quality especially after the global standing occupied by Sinai olive worldwide. Therefore, two different locations in Sinai with different meteorological conditions are selected for cultivation ten acres of olive that irrigated by harvest rainwater. Olives have many proven health benefits; it is used for good nutritional (as fresh pickling and for oil production) and medical purposes. The health benefits of olive oil include treatment for cancers of the colon, breast and stomach. In addition to its benefits for treatment diabetes, heart problems, arthritis pain, high cholesterol, metabolism and digestion [7].

The widely utilization of water pumping systems for irrigation applications with attention of scarcity of fossil resources used in traditional water pumping systems, prices' rise and undesirable environmental impacts, it seems essential to replace them with new energy sources. Renewable energies exploit energy sources of natural origin (sun, wind, water...). They represent energies of future in the measure where they are inexhaustible and preserve the environment [8]. Wind and solar systems in form of hybrid systems can operate as independent power provider, which can supply loads without connecting to the network and island mode [9]. Small scale renewable power system can make a significant contribution for pumping operation in agriculture [10], [11]. This paper presents an economic optimization methodology using Genetic Algorithms (GA) for standalone PV system, standalone wind system and standalone PV-wind hybrid system for powering an irrigating pumping system and a farmer's house. Abu-Rudies and El-Arish regions in Sinai, Egypt are the two sites under consideration. The optimization has been carried out using HOGA, the powerful software tool which successfully determined the best technical and economic system to adopt for the site [12]. An irrigation pump of 1.5 kW and a discharge rate of 34 m^3/h is used for irrigating ten acres of olive in Abu-Rudies and El-Arish regions to increase their productivity and hence to contribute on the economic development.

2. SYSTEM COMPONENTS

For the optimization and economical evaluation of renewable power systems, it is required to provide the availability of renewable energy sources over a period of one year. The details of the selected components such as technical and economical data must be entered. The cost of each component includes capital cost, replacement cost, operation and maintenance cost. Also, the detailed data of the electrical load should be identified. The block diagram of the suggested PV-wind hybrid system which is considered in this paper is shown in Figure 1. It consists of solar PV array, wind turbines, battery bank and inverter. The costs and specifications of different system components are shown in Table 1, Table 2, Table 3 and Table 4 respectively.

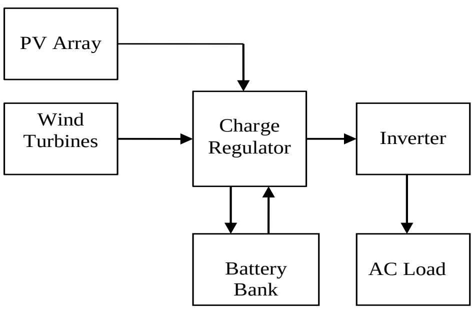

Figure 1. Block diagram of the suggested PV-wind hybrid system

Table 1. PV modules costs and specifications

Type	Nominal voltage (V)	Short circuit current (A)	Nominal power (Wp)	Acquisition cost($)	Replacement cost($)	Operation and maintenance cost per year ($/year)	Life span (years)
Panel 1	12	3.17	50	387	Null	40	25
Panel 2	12	4.18	80	564	Null	40	25
Panel 3	12	7.54	125	892	Null	40	25

Table 2. Wind turbines costs and specifications

Type	Nominal power (Wp)	Acquisition cost($)	Replacement cost($)	Operation and maintenance cost per year ($/year)	Life span (years)
WT1	275	2273	Null	50	25
WT2	640	3013	Null	50	25
WT3	3500	7500	Null	50	25

Table 3. Batteries costs and specifications

Type	Nominal capacity(Ah)	Voltage (V)	Acquisition cost($)	Replacement cost($)	Maintenance cost per year ($/year)	Life span (years)
Battery 1	43	12	155	155	40	10
Battery 2	96	12	258	258	40	10
Battery 3	200	12	555	555	40	10
Battery 4	462	12	1017	1017	40	10

Table 4. Inverters costs and specifications

Type	Nominal power (kVA)	Acquisition cost($)	Replacement cost($)	Maintenance cost per year ($/year)	Efficiency (%)	Lifespan
Inverter 1	2.2	2300	2300	40	85	10
Inverter 2	3.3	3200	3200	40	85	10
Inverter 3	4.5	4300	4300	40	85	10
Inverter 4	5.5	5200	5200	40	85	10

3. RESOURCES DATA

The first step for determining the optimal configuration of the suggested renewable power systems is studying the availability of solar and wind energy sources at a particular location. The annual data of wind speed and solar radiation for Abu-Rudies and El-Arish locations are presented in the following sections.

3.1. Abu-Rudies Location

Abu -Radius region was exposed every year to heavy rain and torrents leading to a heavy financial losses and human damages. This water is flowing and stored in a lake, it is estimated to ranging from 8 to 12 million cubic meters which can be utilized for the purposes of agriculture. This water can be used for irrigating a farm of ten acres of olive. Abu-Rudies is located in the south of the Sinai at 28° 53' N latitude and 33° 11' E longitude with annual average wind speed of 4.5 m/s and annual average solar radiation of 6.62 KWh/m²/day. The yearly wind speed and yearly solar radiation of Abu-Rudies region are shown in Figure 2 and Figure 3 respectively [13].

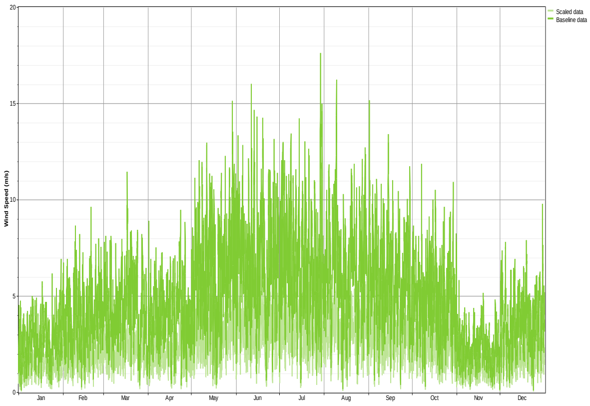

Figure 2. Abu-Rudies yearly wind speed variation

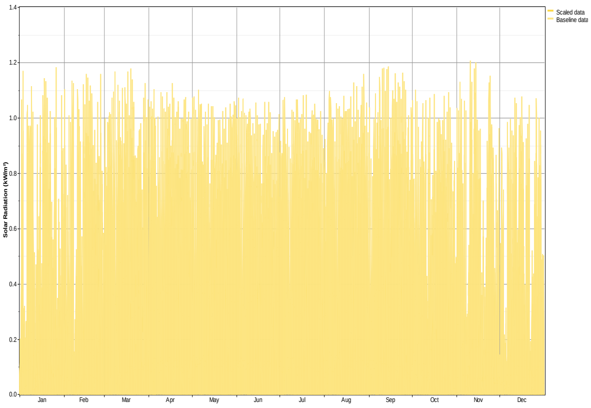

Figure 3. Abu-Rudies yearly solar radiation variation

3.2. El-Arish Location

El-Arish is located in the north of the Sinai. El-Arish is one of the main water storage areas; especially this place is characterized by very prolific rain. In addition, it has rainwater harvesting projects, which is the collecting of falling water from over the mountains and stored in dams and reservoirs such as El-

Arish dam and Terre valley Dam. Table 5 indicates the maximum monthly amount of rainfall in El-Arish recorded by the meteorological station in El-Arish [14].

The latitude and longitude of this site is 31° 16' N and 33° 45' E respectively. The meteorological conditions during the year, i.e., the yearly wind speed and solar radiation of this location are illustrated in Figure 4 and Figure5 respectively. The annual average solar radiation and the annual average wind speed obtained from the Egyptian solar radiation atlas are 5.78 KWh/m^2/day and 2.1 m/s respectively [13].

Table 5. The maximum monthly amount of rainfall in El-Arish

Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max. amount of rain(mm)	9.8	10.1	4.6	2.7	6.4	0	0	0	0	6	6.6	18.5

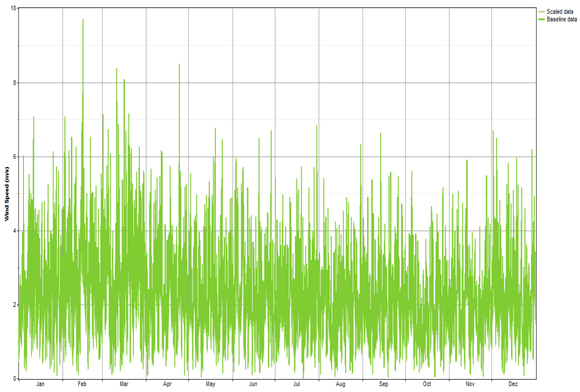

Figure 4. El-Arish yearly wind speed variation

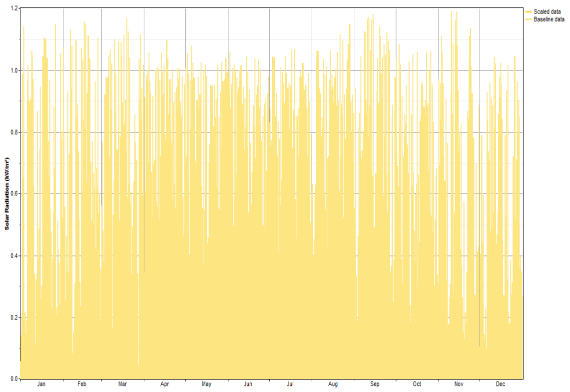

Figure5. El-Arish yearly solar radiation variation

4. ELECTRICAL LOAD ESTIMATION

The energy required for the irrigation pump depends on the number of the irrigated acres, the amount of water per acre and the total head. Therefore, the first step for designing water irrigating system is to determine the daily amount of water required for the irrigating plant. Table 6 shows the amount of water required for irrigating one tree of olive per day at different months and different growth ages in Egypt [15]. For irrigating ten acres of olive, we must calculate the number of trees of ten acres as follow:

a. The required area for one tree growth is 4 m×6 m = 24 m^2
b. Number of trees per acre: 4026/24= 167.75 tree /acre
c. We assumed the number of trees per acre to be about 170 trees
d. Number of trees for10 acres = 170*10 = 1700 trees

Electrical load estimation is based on the maximum amount of water required for irrigating 10 acres of olive. It is observed that, the maximum amount of water required for irrigation is during the sixth year of growth. Also, it is observed that the water demand is the highest during Apr-Sep. months, while it is the lowest during Nov-Feb. months as shown in Table 6. Accordingly, the amount of water required for irrigating 10 acres per day at different months is indicated in Table 7. The peak water requirement is selected for estimating the size of the irrigation pump which is needed for lifting this amount of water to a height of 10 meter.

During the heavy rainy months (Nov. - Feb.) the daily electrical load decreases, since the irrigation pump will be out of operation at all. Also, olive irrigation is needed only for a few hours a day; therefore, this pump operates only for five hours daily. In this study, the design of irrigation system is based on the following assumptions and criteria: Total irrigated area is 10 acres; Peak water requirement is 170 m^3/day, number of irrigation hours is 5 hours/day (from 6:00 AM to 9:00 AM and from 5:00 PM to7:00 PM), pump discharge rate is 34 m^3/hour for pumping the water to a head of 10 meter. Based on these assumptions, it is found that the appropriate pump is ICH - ICH200/6BRM single-phase centrifugal pump [16]. The specifications of this pump are given in Table 8.

The electrical energy consumption of the irrigation pumping system is 7.5kWh per day. The total electrical load consists of an irrigation pump and some electrical appliances for the farmer's house such as television, compact fluorescent lamps, ceiling fan, refrigerator and washing machine as indicated in Table 9. Figure 6 illustrates the daily load profile for a typical two days of winter and summer seasons.

Table 6. The amount of water required for irrigating one tree/day of olive at different months and different growth ages in Egypt

Ages by years	Quantity of water by liter/ tree/day				
	Jan. & Feb.	Mar.	Apr.—Sep.	Oct.	Nov. & Dec.
1	10	20	30	20	10
2	20	30	40	30	20
3	25	40	50	40	25
4	30	50	60	50	30
5	35	60	70	60	35
6	40	70	80	70	40
More than 6	50	80	100	80	50

Table 7. The amount of water required for irrigating 10 acres per day

Month	Jan. - Feb. &Nov. - Dec.	Mar. & Oct.	Apr.— Sep.
Quantity of water (m^3/day)	85	136	170

Table 8. Irrigation pump specifications

Pump Model	Power(KW)	Max. head(m)	Max. discharge (m3/h)
ICH200/6BRM	1.5	12	36

Table 9.The daily electrical load requirement

Load type	No. of units	Load power (W)	No. of operation hours
TV	1	100	10 AM -12 AM & 7 PM -10 PM
Energy saving lamp	5	10	7 PM -12 PM
Outdoor lamp	2	20	7 PM - 6 AM
Refrigerator	1	600	24 hour
Washing machine	1	500	12 PM - 3 PM
Ceiling fan	1	80	9 AM - 6 PM
Pump	1	1500	6 AM - 9AM & 5 PM - 7 PM

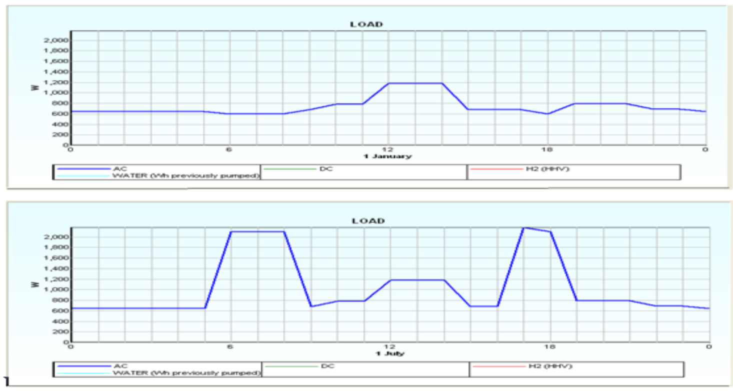

Figure 6. Hourly electrical load profile for a typical day in winter and a typical day in summer

5. MATHEMATICAL MODELING OF RENEWABLE POWER SYSTEM COMPONENTS

The mathematical models of the proposed three renewable power system components will be described in the following sections.

5.1. PV Array Model

Output electric power from PV module is given by the following Equation [11]:

$$P_M = \eta_M A_M I_r \tag{1}$$

Where η_M is the power conversion efficiency of the PV module, A_M (m^2) is the surface area of PV module and I_r (W/m^2) is the solar irradiance. For PV generator, voltage and current of PV module is usually scaled-up by connecting PV modules in series and parallel to constitute the PV array. The output power of the solar PV array can be represented as follow [17]:

$$P_{array} = N_s \times N_p \times P_M \tag{2}$$

Where, N_s, N_p and P_M are the PV modules in series, parallel and the PV module power respectively.

5.2. Wind Turbine Model

Power output of the wind turbine generator at a specific site depends on wind speed at hub height and speed characteristics of the turbine. The power extracted from the wind turbine can be calculated using the following Equations [18]:

$$p_{wind} = \frac{1}{2} C_p \rho A V_{wind}^3 \tag{3}$$

Where, ρ is the air density (kg/m^3), A is the rotor swept area (m^2), V_{wind} is the wind speed (m/s) and C_P is the power coefficient of the wind turbine.

5.3. Battery Model

When there is an excess of energy produced by the PV generator and the wind turbine, after meeting the load demand this energy will be used to charge the battery bank and store it for future use. Equation (4) represents the total power generated by the PV array and the wind turbines at the time t [19].

$$P_G(t) = P_{PV}(t) + P_W(t) \tag{4}$$

During the charging process, when the total output of all generators exceeds the load demand, the available battery bank capacity at hour t can be described by [18]:

$$P_{BAT}(t) = P_{BAT}(t-1) + (P_G(t) - P_L(t)) \tag{5}$$

When the available power generated from the PV and wind generators is less than the load demand, the battery discharges, and therefore, the available battery bank capacity at time t can be expressed as [18]:

$$P_{BAT}(t) = P_{BAT}(t-1) - (P_L(t) - P_G(t)) \tag{6}$$

Where P_{BAT} (t) is battery capacity at time t, P_{BAT} (t-1) is battery capacity at an earlier time (t-1).

6. ECONOMICAL MODELING

The aim of this study is to achieve an optimally designed standalone renewable power system in terms of cost of energy and system power reliability. The best possible or optimum system configuration is the one that satisfies the user-specified constraints at the objective function. In this study the objective function is the minimization of total Net Present Cost (NPC) of renewable power system which can be represented by [20], [21]:

$$C_T = \sum_{i=1}^{m} CI_i + CM\&O_i + CR_i - CS_i \quad (7)$$

Where C_T is the total system cost, m is the number of energy sources used, CI_i is the initial capital cost, $CM\&O_i$ is maintenance and operation cost, CR_i is replacement cost and CS_i is the salvage cost at the end of the project. In order to calculate the present value of the future expense for a single payment such as replacement cost and salvage value that occurring in a specific year n at given interest rate i, the following formula can be used [20], [21]:

$$P_F = \frac{F}{(1+i)^n} \quad (8)$$

For accounting the present value of an annual expense such as operation and maintenance cost over a period of years n the following formulas can be used [21], [22]:

$$P_A = \frac{A}{CRF} \quad (9)$$

The initial capital cost CI_i is converted into annual capital cost A using the following capital-recovery factor (CRF) [19], [21]:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (10)$$

Where, P_F and P_A are the present worth for the sum of money for the single payment and annual payment respectively, F is the single payment, A is the annual payment, n is the project life time and CRF is the capital recovery factor which determines the periodic payment necessary to pay back that sum of money at interest rate i over n periods. The cost of energy (COE) is the cost of generating 1 kWh of energy utilized by the load, and can be calculated as follows [23], [24]:

$$COE = \frac{TAC}{TALE} \quad (11)$$

Where TAC is the total annual cost and TALE is the total annual load energy.

7. CONSTRAINS

Genetic algorithm is used as optimization tool; where the objective function is to minimize the cost of the system over its 25 years of operation subject to power balance reliability constrains. For each time t, the total power of PV-wind -battery system, must supply the load (P_L) demand with a certain reliability criterion. This relationship can be represented by [23]:

$$P_{PV} + P_W + P_{BAT} \geq P_L \quad (12)$$

Constraints of battery capacity

$$P_{BAT\,\min} \leq P_{BAT} \leq P_{BAT\,\max} \quad (13)$$

To keep the battery from being undercharged or overcharged, the battery state of charge (SOC) can not exceed the largest charge quantity and least charge quantity of battery. It must stay between the minimum and maximum state of charge, SOC_{min} and SOC_{max}, respectively. This can be described by the Equation [23]:

$$SOC_{\min} \leq SOC \leq SOC_{\max} \quad (14)$$

The battery keeps at high state of charge, 100% as a maximum value and 40% as a minimum value.

8. OPTIMIZATION METHODOLOGY

The proposed sizing methodology for the cost minimization (objective function) of renewable power system is carried out using a genetic algorithms (GA) approach. GA is selected for power system optimization because it has shown to be highly applicable to cases of large nonlinear systems; it is emerging as popular method for the solution of complex engineering problems. GAs have been applied to the design of large power distribution systems and the solution of power economic dispatch problems because of their ability to handle complex problems with linear or non-linear cost functions both, accurately and efficiently[25], [26]. The GA possesses superior features that make it common for optimization purposes, especially for hybrid systems. Its performance for searching the global optimum is extremely efficient, and is very suitable for optimization problems of a great number of optimized parameters [27].

8.1. GA Principles

HOGA is a software package which used for optimizing both, the system components (main genetic algorithm) and the control strategy (secondary genetic algorithm). GA is used to evaluate both conditions in minimizing the total net present cost for optimum configuration [28]. GA is based on the principles of natural genetics and natural selection and uses three operators to imitate the natural evolution processes. GA operators: selection, crossover and mutation are used to evolve the population from its current generation to the next whose average fitness value should ideally be better. New generations are thus evolved from the knowledge of previous generations and since the fitter individuals in the population are the ones selected for crossover their good genes (good solutions) over time dominate the population and the algorithm converges to an optimum. With proper parameter selection, GA's are capable of obtaining a suitable global optimum solution [29].

8.2. GA Implementation

The GA flowchart which is used in sizing calculation is depicted in Figure 7. GA selects individuals at random from the current population to be parents and uses them to produce the children for the next generation by using the three main operations, which are the selection, crossover, and mutation operations. Then, it can repeatedly modify a population of individual solutions, where, over successive generations, the population evolves toward an optimal solution. Implementation of the GA to find the best system parameters that met the objective function can be summarized in the following steps [30], [31]:

1. Initially, the main algorithm randomly assigned a set of vectors Nm for sizing the hybrid system, each vectors representing a possible configuration of PV panels, battery and wind generator.
2. The secondary algorithm is a GA that searches for the best control strategy for each combination of components in the main algorithm in order to minimize the NPC.
   a) The control strategy vector N_{sec} is randomly assigned by the secondary algorithm for each Nm vector, each vector representing a possible dispatch strategy in order to minimize the NPC.
   b) The N_{sec} vectors are evaluated by means of their aptitude.
   c) The Nest vectors have a greater probability of reproducing themselves, crossing with other vectors. In each cross of two vectors, two new vectors are obtained (descendents). The descendents are evaluated and the best of them replace the worst individuals of the previous generation (iteration).
   d) To find the optimal solution and not to stay in local minimal, some solutions randomly change some of their components (mutation). The mutations can effect the change of the control strategy or the change of a bit of SOC set point
   e) The individuals (vectors) obtained from reproduction and mutation is evaluated, making the next generation.
   f) The loop of generation is repeated (from b to e) until the best individuals identified and the determined number of generations (Ngen_main_max) have been evaluated
3. N_m solutions will have been obtained (vectors of the main algorithm with their optimal dispatch strategies). The N_m solutions are evaluated by means of their aptitude.
4. Reproduction, crossing and mutation are carried out on the obtained solutions, making the next generation.
5. Go to Step #2 and repeat the above steps sequentially until a determined number of generations ($N_{gen\_sec\_max}$) have been evaluated. The best solution obtained is that which has the lowest value of NPC.

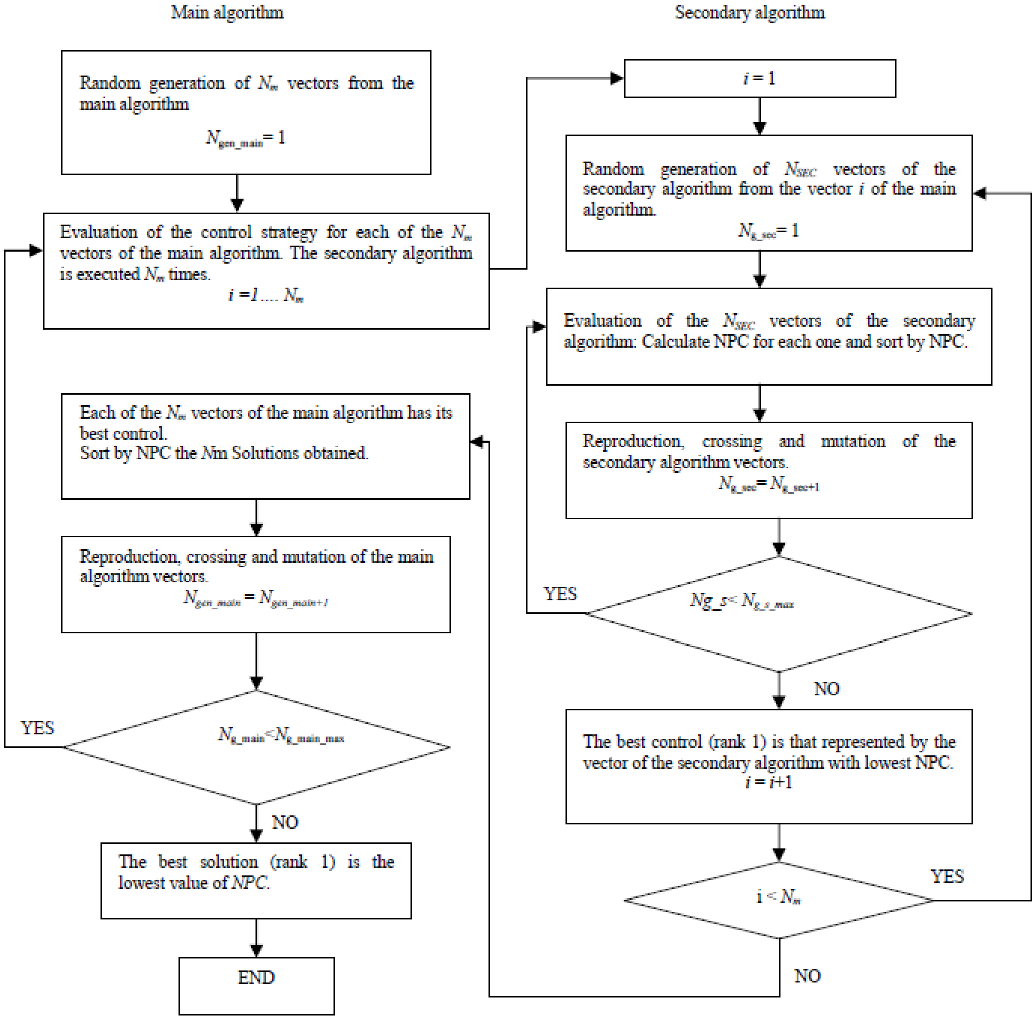

Figure7. Flow chart of the Genetic Algorithm (GA)

9. SIMULATION RESULTS AND DISCUSSION

For the proposed three system configurations, PV array and wind turbines represent the power generators. While the battery bank is used for storing the surplus energy and supplying it when there is a deficit of available power to cover the load demands. The optimal simulation results have been obtained with the following values: main algorithm generations are 20, main algorithm populations are 20, secondary algorithm generations are 20, and secondary algorithm populations are 20, the crossover rate is 0.9 and the mutation rate is 0.1 The economical comparison between the three proposed renewable power systems was carried out by calculating the NPC of the proposed power systems in the two selected locations. The simulation results are discussed in the following sections.

9.1. Abu –Radius Location

9.1.1. Standalone PV System

Based on the optimization results, the optimal size of each component of standalone PV system is illustrated in Figure 8. The components type and their number are; the rated power of PV array is 1.44 kW_p (2s× 9p of 80 Wp module), the battery bank's rated capacity is 43.7 kWh (2s×19p battery with nominal capacity of 96 Ah) and 2.20kW inverter. The battery charge regulator current is 407.6A and the minimum SOC for the battery is 46% (control strategy is to achieve minimum SOC for the battery at 40%). The optimal system NPC is $ 38122. The cost of the different components of this system as a percentage of the NPC is shown in Figure 9. It is observed that, the PV panels cost 26.84% ($ 10152) of the NPC, the battery bank has the largest share of 54.23% ($20515) and the inverter plus the auxiliary components e. g. charge regulator have cost of 18.93% ($7171).

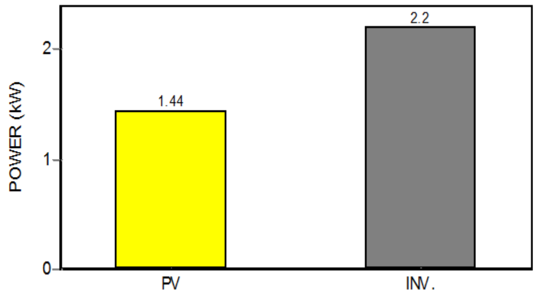

Figure8. Optimal unit size of standalone PV system

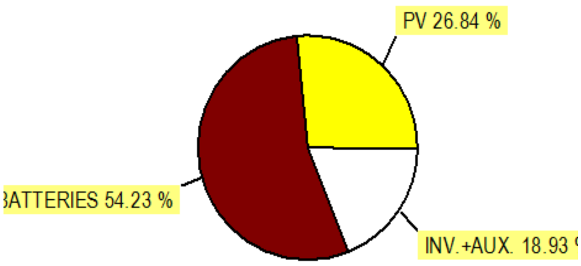

Figure 9. Cost of the different elements in percentage of the total net present cost

The annual energy balance of standalone PV system is described in Figure 10. The overall load energy is 8338 kWh/yr and the unmet load is 19.8 KWh/yr. The convergence of NPC towards the optimum value as a function of the main algorithm generations is presented in Figure11. Also, this figure shows that there is no CO_2 emission since the used renewable energy sources produce zero CO_2 during operation.

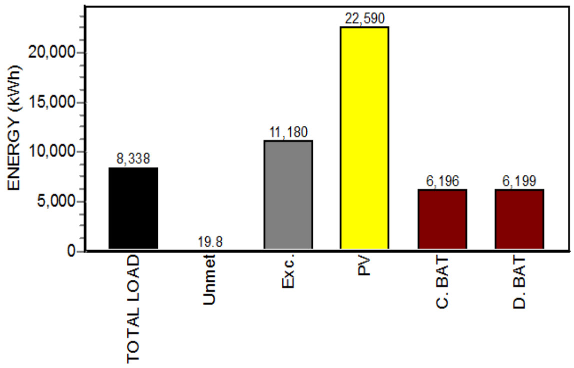

Figure10. The annual energy balance of PV system

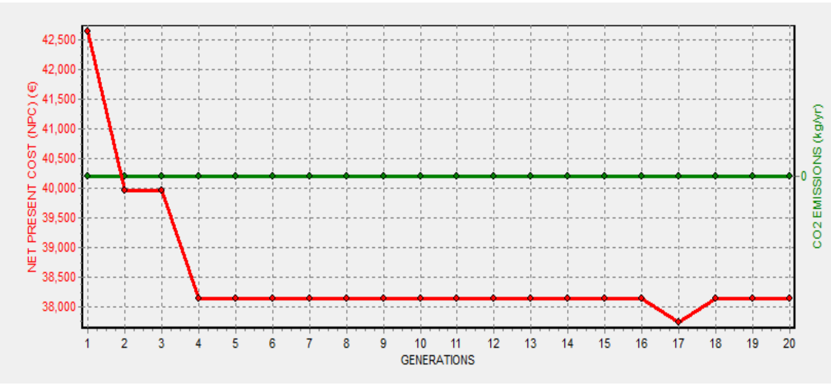

Figure11. Net present cost versus the number of generations

9.1.2. Standalone Wind System

Figure 12 shows the optimal size of each component of standalone wind system. Based on the optimization results, the components type and their number in this system are; wind generator rated power is 21 kW (6×3500 W of DC wind turbine), the battery bank's rated capacity is 33.6 kWh (2s×7p battery with nominal capacity of 200 Ah) and 2.2 kW inverter. The battery charge regulator current is 830 A and the minimum SOC allowed for the battery is 40%. The NPC of the standalone wind system is $65079. Figure 13 shows the cost of the different components of this system as a percentage of the NPC, it is observed that, the wind turbines have the highest share of 66.42 % ($ 43028) of the NPC, the battery bank shares by 17.92% ($11610) and the inverter plus the auxiliary components share by 15.65% ($10141). Figure 14 shows the annual energy balance of wind system. The unmet load is 65.1 KWh/yr. Figure 15 shows the convergence of NPC towards the optimum value as a function of the main algorithm generations.

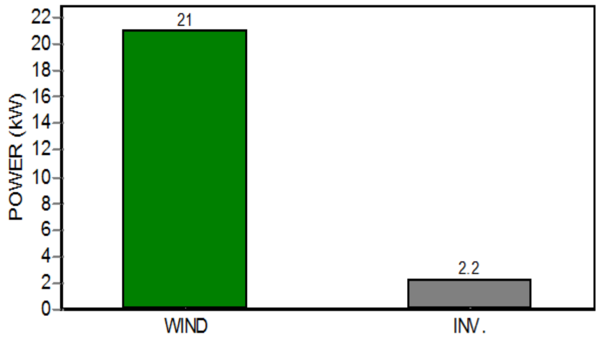

Figure12. The optimal unit size of standalone wind system

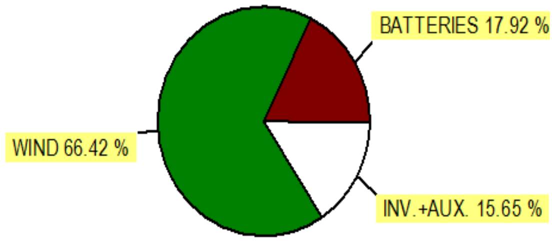

Figure13.Cost of the different elements in percentage of the total net present cost

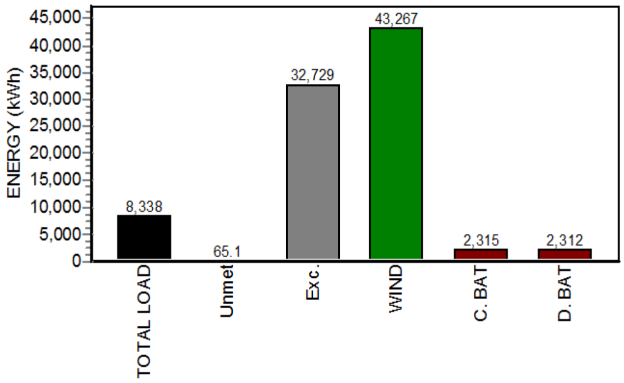

Figure14. The annual energy balance of standalone wind system

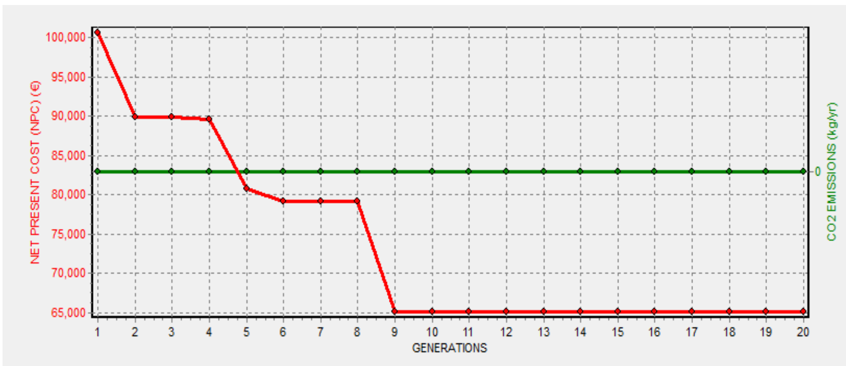

Figure15. Net present cost versus the number of generations

9.1.3. Standalone PV-Wind Hybrid System

The optimal components size of PV--wind hybrid system is shown in Figure 16. Based on the optimization results, the components type and their number of this system are; the PV array rated power is

0.5 kW (2s×5p of 50 Wp module), the wind generator rated power is 2.56kW (4 DC wind turbines of 640 W), the battery bank's rated capacity is 25.3 KWh (2s× 11p battery with nominal capacity of 96 Ah) and 2.2 kW inverter. The battery charge regulator current is 218.2A and the minimum SOC for the battery is 46%.

The cost of the different components of this system as a percentage of the NPC is illustrated in Figure. 17. The NPC is $37433, the PV generator shares by 10.42. % ($3870) of the NPC, the wind generator shares by 39.42% ($ 14637), the battery bank shares by 34.47% ($12801) and the inverter plus the auxiliary components share by 15.69% ($5825). It is observed that the battery bank and the wind generator are the most costly items.

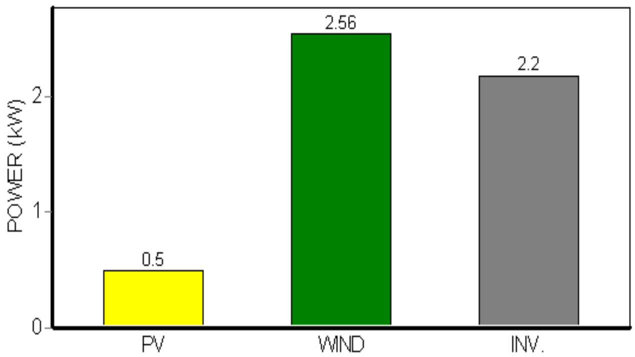

Figure 16. The optimal unit size of PV-wind hybrid system

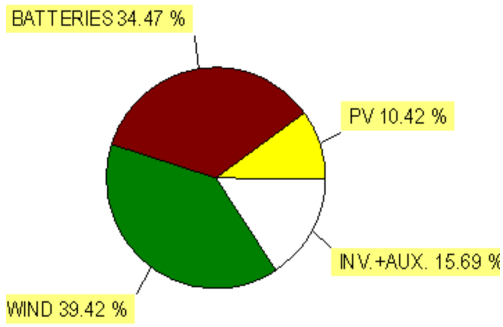

Figure 17. Cost of the different elements in the percentage of total net present cost

Also, the contribution of individual system component participating in the hybrid system is shown in Figure 18. The major share of the energy comes from PV array (8288 kWh) while the contribution of wind generator is small (5247kWh) and the unmet load is 135.6 KWh/yr. The convergence of NPC towards the optimum value as a function of the main algorithm generations is indicated in Figure 19.

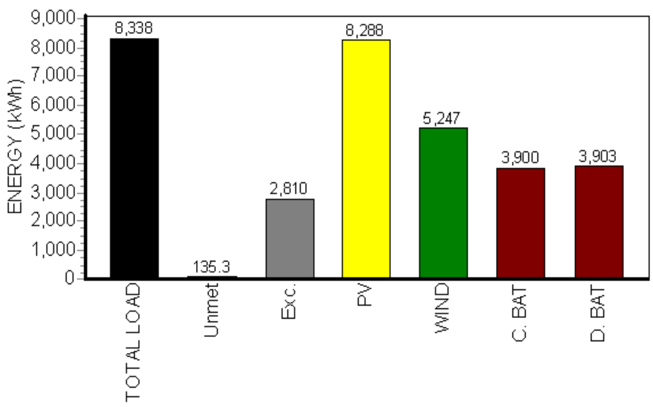

Figure18. The annual energy balance of PV-wind hybrid system

The PV-wind hybrid system with the lowest NPC is recognized as the most economically feasible option at Abu-Rudies location. It is recommended to utilize the hybrid PV–wind system for power generation in Abu-Rudies region rather than wind power system or PV power system alone.

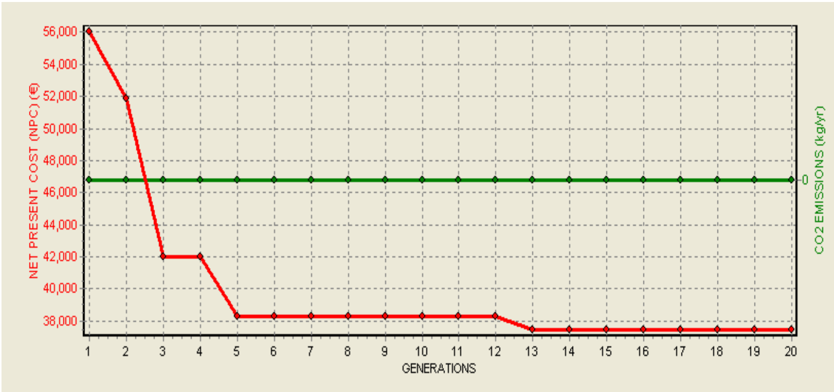

Figure 19. Net present cost versus the number of generations

9.2. El-Arish Location

9.2.1. Standalone PV System

Figure 20 shows the optimal size of standalone PV system components in El-Arish location. Based on the optimization results, the components type and their number of this system are; the PV array rated power is 1.1 kWp (2s ×11p of 50 Wp module), the battery bank's rated capacity is 43.7 kWh (2 s×19p battery with nominal capacity of 96 Ah) and 2.20 kW inverter. The battery charge regulator current is 259.7A and the minimum SOC for the battery is 46%. The NPC is $ 35450. Figure 21 shows the cost of the different components of the system as a percentage of the NPC. It is observed that, the PV shares by 24.22% ($ 8514), the battery bank shares by 58.38% ($20519) and the inverter plus auxiliary components share by 17.4 %($6117). This study revealed that the major share of the cost is for the battery bank. The annual energy balance of standalone PV system is described in Figure 22. The unmet load is 163.4 KWh/yr. Figure 23 illustrates the convergence of NPC towards the optimum value as a function of the main algorithm generations.

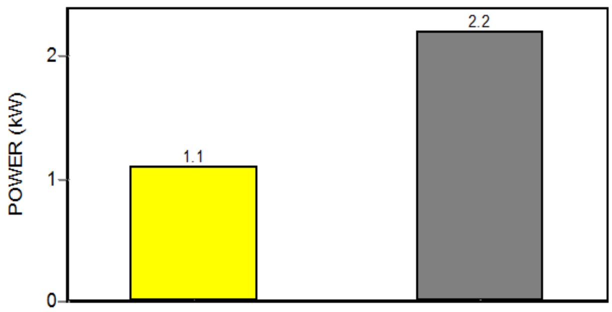

Figure 20. Optimal unit size of standalone PV system

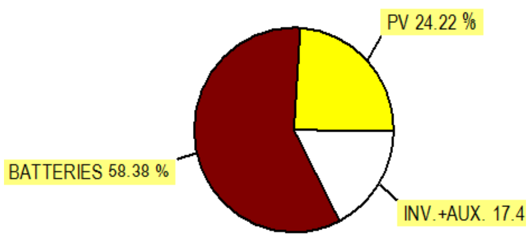

Figure 21. Cost of the different elements in percentage of the total net present cost

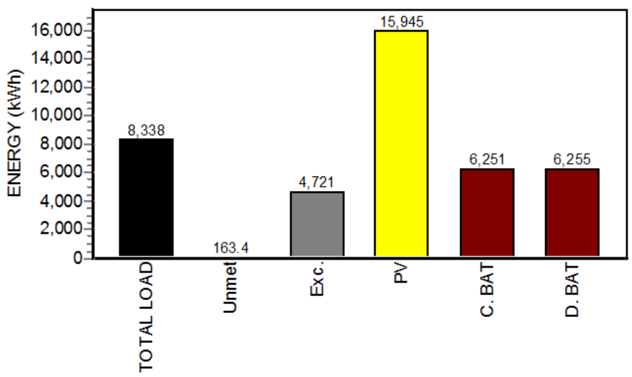

Figure 22. Annual energy balance of PV system

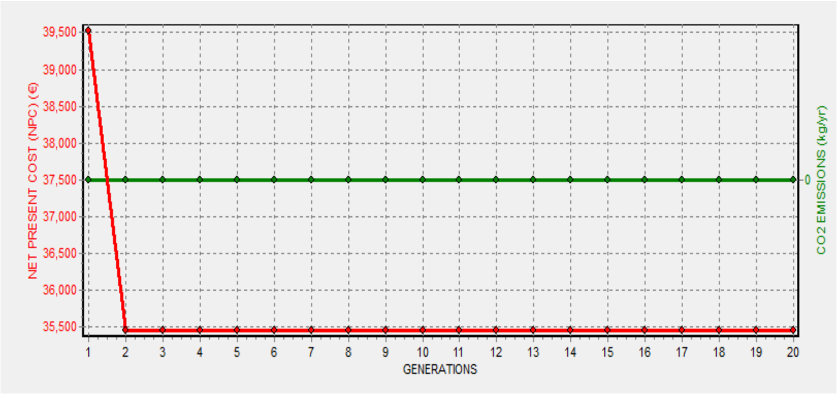

Figure 23. Net present cost versus the number of generations

9.2.2. Standalone Wind System

The optimal size of the standalone wind system components is shown in Figure 24. Based on the optimization results, the components type and their number are; the wind generator rated power is 45.5 kW (13×3500 W of DC wind turbine), the battery bank's rated capacity is 57.6 kWh (2s×12p battery with nominal capacity of 200 Ah) and 2.2 kW inverter. The battery charge regulator current is 1219.9A and the minimum SOC allowed for the battery is 58%. The NPC is $127450. Figure 25 shows the contribution of system components as a percentage of the NPC, the wind sharing is 73.32 % ($ 93227), the battery bank shares by 16.54% ($21031) and the inverter plus the auxiliary components share by 10.14% ($12892). Figure 26 shows the annual energy balance of the standalone wind system. The unmet load is 343.5 KWh/yr. Figure 27 describes the convergence of NPC towards the optimum value as a function of the main algorithm generations.

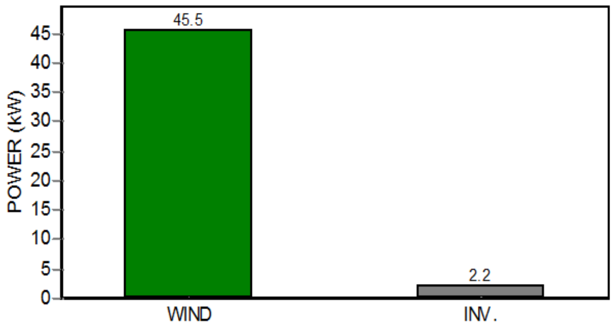

Figure 24. Optimal unit size of standalone wind system

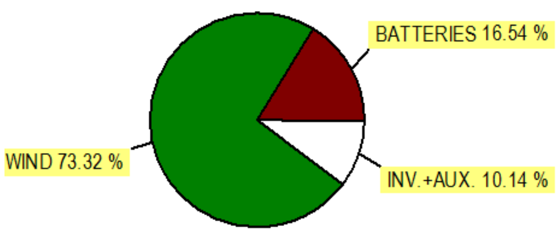

Figure 25. Cost of the different elements in percentage of the total net present cost

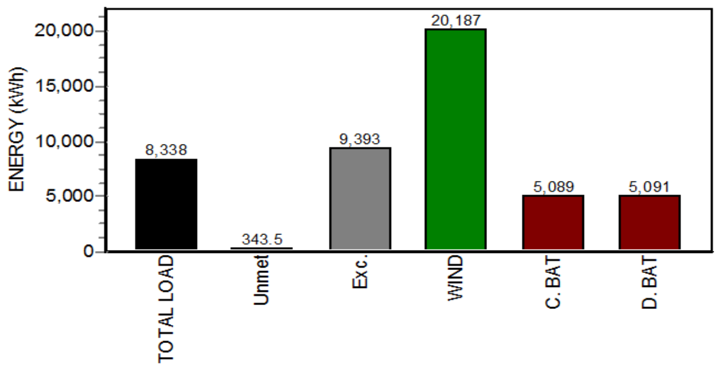

Figure 26. Annual energy balance of wind system

Figure 27. Net present cost versus the number of generations

9.2.3. Standalone PV-Wind Hybrid System

The optimal size of the components of hybrid PV-wind system is shown in Figure 28. The components type and their number of this system are; the PV array rated power is1.1kW (2s ×11p of 50 Wp module), the wind generator rated power is 0.55kW (2 × 275 W of DC wind turbine), the battery bank's rated capacity is 41.4 kWh (2 s×18p battery with nominal capacity of 96 Ah) and 2.2 kW inverter. The battery charge regulator current is 264.4A and the minimum SOC allowed for the battery is 46%. The NPC is $40696. Figure 29 shows the costs of the different components of the hybrid PV-wind system as a percentage of the total NPC, the PV shares by 20.93 % ($8514) of the total NPC, the wind generator shares by 14.35% ($ 5838), the battery bank shares by 49.59%($20166) and the inverter plus auxiliary components share by 15.12% ($6151). The annual energy balance of the hybrid PV-wind system is shown in Figure 30. It is observed that, the major share of the energy comes from solar PV (15945 kWh) while the contribution of wind generator is very small (197 kWh). The unmet load is 153.3 KWh/yr. The convergence of NPC towards the optimum value as a function of the main algorithm generations is presented in Figure 31.

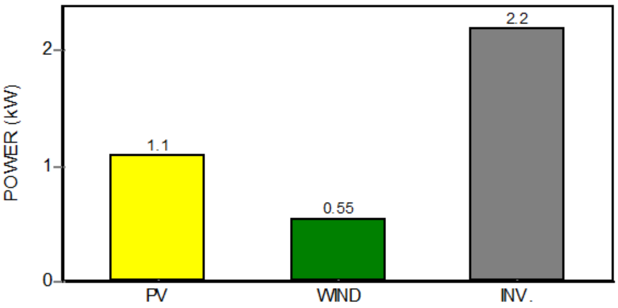

Figure 28. Optimal unit size of hybrid PV-W system

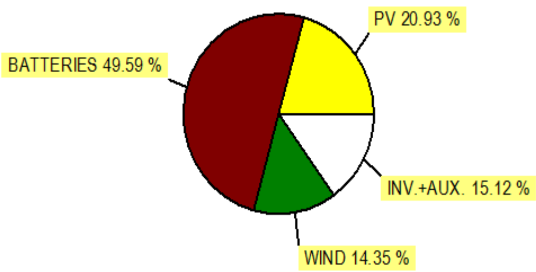

Figure 29. Cost of the different elements in percentage of the total net present cost

Since the solar potential of El-Arish location is more than the wind capacity, energy production by standalone PV system has the lowest NPC. It is observed that, wind speed is relatively weak throughout El-Arish area with an average value of 2.1 m/s. It is too low to be used to produce the electrical energy in an economic manner; this can be confirmed by the highest NPC of the standalone wind system. The standalone PV system is the most economical and practical one. This can be attributed to the high average solar radiation of 6.5 KWh/m^2/day. The cost of hybrid system is between standalone PV and standalone wind systems.

Table 10 summarizes the simulation results of the three suggested system' configurations including the optimal unit size of each component in the system, the optimal NPC and the cost of energy (COE) for the two locations under consideration. With respect to Al-Arish region, comparing the three system configuration with respect to NPC and COE , both the NPC and COE of the PV system is lower than those for both the hybrid PV- wind system and standalone wind system which could be attributed to the abundance of solar energy at this location. For Abu-Rudies, PV-wind system has the lowest NPC and COE compared to PV system and wind system. As the water irrigation demand is seasonal, therefore using the renewable power systems for powering other applications during the rest of the year make these systems more attractive and economical.

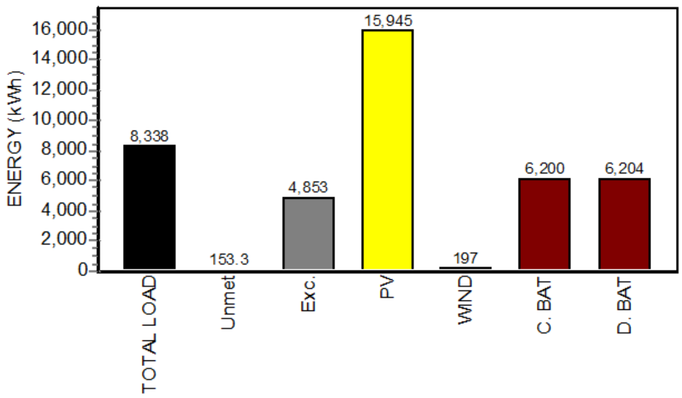

Figure 30. Annual energy balance of PV-wind system

Table 10. Simulation results of sizing components and systems cost

		Abu-Rudies			
System	PV (KW)	Wind (KW)	Battery (kWh)	Total Net Present Cost (NPC)	Cost of Energy (COE), $/KWh
Standalone PV System	1.44	---	43	$38128	$0.183
Standalone Wind System	-----	21	33.6	$65079	$0.312
Hybrid PV-Wind System	0.5	2.56	25.3	$37433	$0.179
		El-Arish			
System	PV (KW)	Wind (KW)	Battery (kWh)	Total Net Present Cost (NPC)	Cost of Energy (COE) $/KWh
Standalone PV System	1.1	----	43.7	$35450	$0.170
Standalone Wind System	---	45.5	57.6	$127450	$0.611
Hybrid PV-Wind System	1.1	0.55	41.4	$40696	$0.195

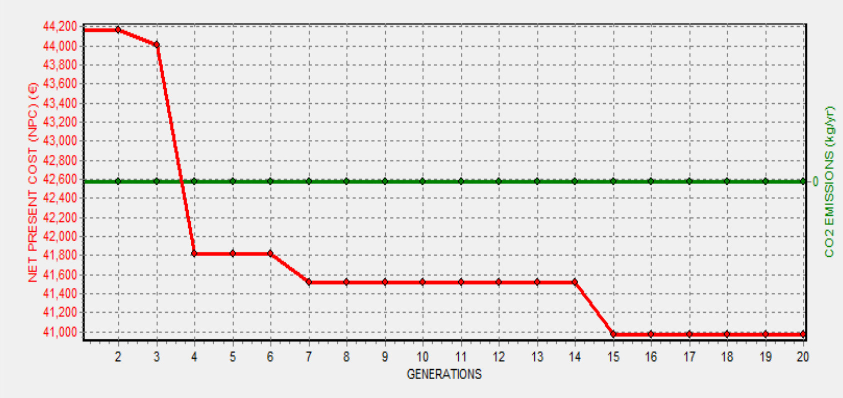

Figure 31. Net present cost versus the number of generations

10. CONCLUSION

Optimal sizing of system components is important in designing renewable power system. A comparative study between three different system configurations (PV-battery standalone, wind -battery standalone and PV-wind-battery hybrid system) for supplying an irrigating pumping system and a farmer's house with the required electrical demand in two different regions is presented. HOGA simulation tool gives the best solution of all possible combinations. The best solution is determined with the help of GA. The NPC and the COE for each configuration is calculated and the combination with the lowest costs is selected to represent the optimal system. The simulation results verified that for El-Arish region, standalone PV system has the lowest system cost compared to cases where either only standalone wind system or hybrid PV-wind system. Also, simulation results revealed that a hybrid PV-Wind system was recognized the most economically feasible option for Abu-Rudies with the lowest COE as well as the NPC. The NPC of the optimal hybrid PV-wind and standalone PV systems configurations are $ 37433 and $35450 respectively. For the two considered locations, using wind generator as a standalone system to supply load is not economical or optimal choice because of low availability of wind potential in these two locations.

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