Optimal Sizing of Standalone PV-Wind Hybrid Energy System in Rural Area North Egypt

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Abstract- **This paper studies the sizing of stand-alone renewable energy system applied in rural areas in the north of Egypt. The available renewable energy sources in these areas are investigated to be integrated to supply the different types of electrical loads. The quality and quantity of these sources over various weather and climate changes are studied to construct a robust energy system. The load demand in such areas is determined according to all activities require electrical energy. This study considers the different economic levels and technologies which affect the load demand value. The technique and economical indices required to obtain the optimal are investigated and applied in the various estimated cases. The genetic algorithm (GA) technique is applied to determine the size and number of photovoltaic panels and wind turbines. The obtained solution takes into account the loss of power supply probability and the minimization of system cost. This study presents an essential phase in the sustainable development of such rural areas.**

Keywords: **rural areas, solar energy and wind energy.**

I. INTRODUCTION

No doubt that, the energy is considered one of the main contributors to community's development. The connection of many communities, especially in rural areas, to the main power grid may have some difficulties. Therefore, the stand-alone generation system represents a promising solution for these communities [1]. The renewable sources of energy RSE may be considered as alternatives to the fossil fuels. But, the dependency on one renewable source, such as solar or wind, isn't recommended due to the sustainable variation in the produced energy. The hybrid renewable energy sources in combined with storage systems are considered the recommended solution to overcome the variable nature of RSE. The main advantages of hybrid power systems are to reduce dependence on traditional fossil fuel sources and to increase the reliability of renewable energy systems. These systems are usually more suitable than using a single power supply within stand-alone power grid where high reliability is required [1].

The main disadvantage of the resources of solar and wind energy is their random nature which depends on weather and climate changes. In addition, the presence of solar and wind energy may not meet the requirements of the load. Nevertheless, the problems caused by the variability of these resources can be partially solved by combining them in an appropriate combination [2]. This research aims to design A hybrid stand-alone energy system suitable for rural areas in the north of Egypt Nile Delta. The extension of the main power grid to these areas has some technical and economic difficulties [3]. These areas are characterized by the availability of renewable energy sources which can supply the load demand. These areas have various promising economical activities require continuous energy feeding. The domestic energy demand represents an essential factor in the development of these areas [4].

In this paper, optimal hybrid stand-alone renewable energy system is introduced to be applied in some villages in the north of Egypt. The design of this generation energy system requires the identification of all activities which require electrical energy such as domestic, agriculture and other investment activities. The various economical levels and electrical technologies are taken into account during the estimation of load demands. The available renewable energy sources in this area in combined with suitable energy storage system are studied to construct a robust energy system which can supply the predetermined loads under different seasonal changes. The indices to formulate the objective function of the proposed generation energy system are developed in this paper. The optimal design of the proposed stand-alone generation energy system represents a promising solution for the sustainable development in such areas in Egypt.

II. ANALYTICAL STUDY OF THE POWER SYSTEM ELEMENTS WITHIN VILLAGES IN RURAL AREA IN THE NORTH OF EGYPT

The main feature of a hybrid stand-alone system in rural areas, is the supplying the residential buildings with electricity [5]. The most common renewable energy sources that are used to combine in such a reliable and practical hybrid energy system is combined photovoltaic (PV) and wind turbine (WT) system [6]. Furthermore, for reliability and satisfactory performance in hybrid energy system a battery bank system is involved to keep available excess energy as well energy demand variability management in case of reduction of solar irradiation conditions or wind speed [7]. The aim of the work is to realize the optimum sizing of hybrid PV-WT-Storage system which can guarantee a proper state of stability in the power system and a minimum cost of energy system installation.

Fig. 1 illustrates the methodology used in this research It is represented in evaluating renewable energy resources, evaluating loads, and determining the specifications and number of different generating units. Here, genetic algorithm (GA) optimization technique is proposed to obtain the optimal solution with the specified constraints. The design procedures will be explained in details along this paper.

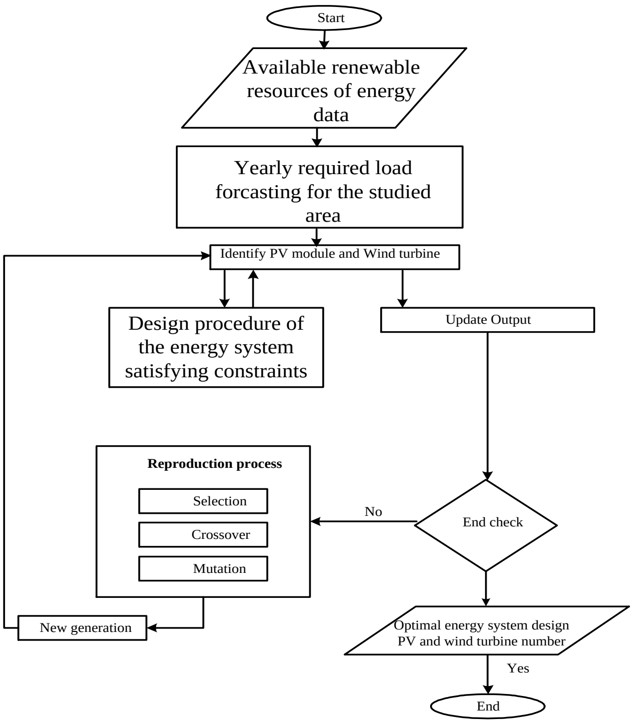


Fig. 1. Flowchart illustrate the methodology used in this research

A. Demographic and living profile of the studied village

As already indicated, the nature of remote areas, the difficulty of delivering electricity to it and trying to use the available energy resources available in these areas represent the frame to install a proper stand-alone energy system. Within this frame, the following essential processes should be achieved: creating a framework for visualizing the data of the remote villages, anticipating the electrical loads of these villages, studying the availability of renewable energy sources throughout the year and finally determining the number, capacities (sizing) and sites of these sources.

Figure 2 shows the studied village No. 69 in the Riyadh Center, below Lake Burullus, is an example of dozens of villages targeted for development through this research. Fig. 2 shows the studied village No. 69 in the Riyadh Center, below Lake Burullus, is an example of dozens of villages targeted for development through this research.

Fig. 2. The studied village No. 69 in the Riyadh Centre below Lake Burullus

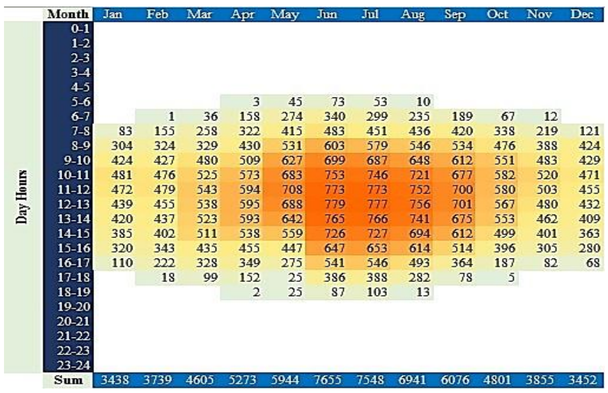
The studied villages have around 100 families with a whole resident of 600 person. Maximum number of people in these villages are engaged in agriculture. As well, fishing is one of the livelihoods and other slight business activities for example cattle farm and poultry. Local societies mostly rely on some diesel engine for lighting purposes and farming leftover.

B. Renewable resources

1) Solar Irradiation and PV Systems

After studying the location, all available weather measurements should be analyzed. These measurements may involve the yearly solar irradiation values, air temperature, and wind speed and direction which may be obtained from Global Solar/Wind Atlas site. The analysis of the available renewable sources of energy can provide the essential data required to design an appropriate hybrid stand-alone energy system. The design includes the ratio of the contribution of each resource and the storage system (sizing) and the proper placement of these resources (siting).

Global Solar Atlas Site Affiliated to the World Bank and interested in managing renewable energy sources around the world with the aim of encouraging investment in them. According to Global Solar/Wind Atlas site, the studied area (North of Egypt Delta Nile) has about 180 kWh/m^2 monthly solar radiation distributed as shown in Fig. 3.



Day Hours / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0-1												
1-2												
2-3												
3-4												
4-5												
5-6				3	45	73	53	10				
6-7		1	36	158	274	340	299	235	189	67	12	
7-8	83	155	258	322	415	483	451	436	420	338	219	121
8-9	304	324	329	430	531	603	579	546	534	476	388	424
9-10	424	427	480	509	627	699	687	648	612	551	483	429
10-11	481	476	525	573	683	753	746	721	677	582	520	471
11-12	472	479	543	594	708	773	773	752	700	580	503	455
12-13	439	455	538	595	688	779	777	756	701	567	480	432
13-14	420	437	523	593	642	765	766	741	675	553	462	409
14-15	385	402	511	538	559	726	727	694	612	499	401	363
15-16	320	343	435	455	447	647	653	614	514	396	305	280
16-17	110	222	328	349	275	541	546	493	364	187	82	68
17-18		18	99	152	25	386	388	282	78	5		
18-19				2	25	87	103	13				
19-20												
20-21												
21-22												
22-23												
23-24												
Sum	3438	3739	4605	5273	5944	7655	7548	6941	6076	4801	3855	3452

Fig. 3. Average hourly profile of solar irradiation measurements according to Global Solar Atlas site

Fig. 3 shows the solar irradiation values over the day hours represented by the vertical axis by one day for each month of the year represented by the upper horizontal axis. The appearance of solar radiation begins at 5 am in the summer with a simple irradiation that gradually increases to reach its peak at noon and begins to recede gradually until sunset according to the values shown in the Fig. 3. Below each day is the sum of the solar irradiation energy for hours per day, represented by the lower horizontal axis.

The power to be generated is proportional to the amount of irradiation on the clean photovoltaic panels. The area required to install the PV power generation unit may be the main obstacle to obtain the amount of generated energy, especially when generating high capacities. Thus, a 5 kW solar power generation unit is suitable to be placed above an average house of 100 square meters such as those houses in the studied area. Fig. 4 illustrates the average monthly and hourly profile solar irradiation which confirms the efficient of solar PV potential for electricity generation at the studied location.

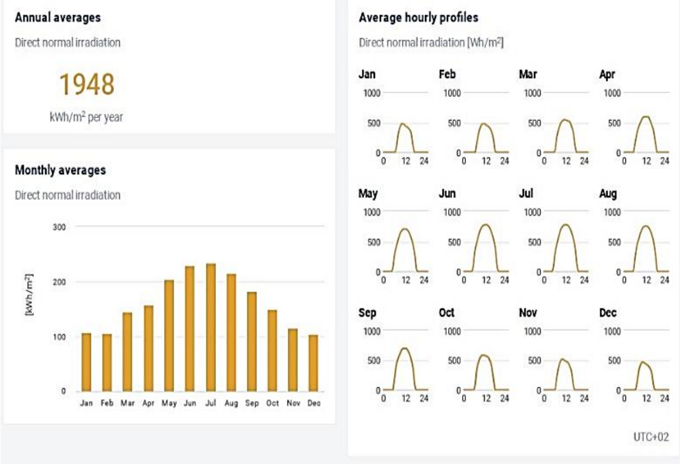
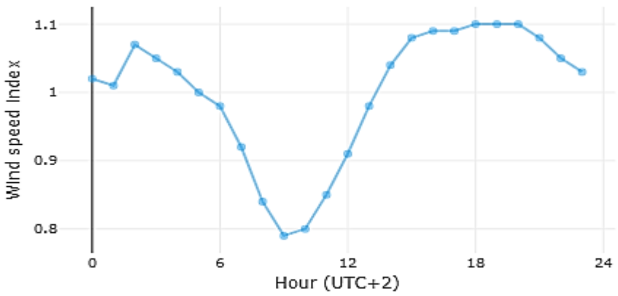


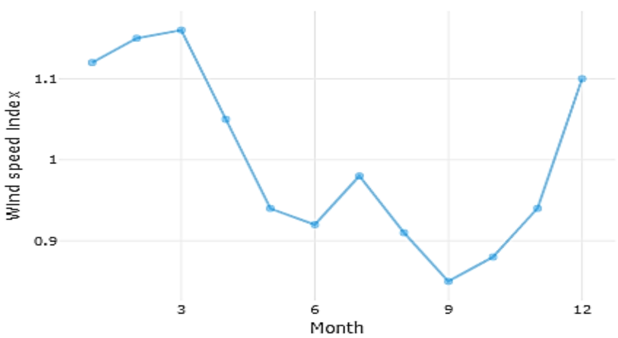
Fig. 4. Average monthly and hourly profile solar irradiation for the selected village

2) Wind Energy

The average wind velocity in the studied area can be determined by Global Wind Atlas site as in Fig. 5. The typical wind velocity is about (3.25 m/s) at height nearly 10 m above the roof of the house in this area [13]. Based on this speed and this height, a wind turbine with a generating capacity of 5 kW can be installed. The typical average wind velocity in the studied area is shown in Fig.5. It can be noticed that every day the wind speed varies around the average daily value between 0.79 to 1.1 as in Fig. 5(a). While monthly, as in Fig. 5(b), the wind speed varies around the average monthly value between 0.85 to 1.16.



(a)



(b)

Fig. 5. (a) Wind speed index profile for the studied village each hour, and (b) each month (Global Wind Atlas)

C. Load Assessment

Load forecasting is the base of the electrification planning of rural areas. It shows the guidelines not only for the power supply system design but also gives a proposal for the financial benefits and socioeconomic benefits which can be obtained.

The percentage of people live in the remote regions which connected to local electric grid is quite small compared with those in urban regions. Although, it is very difficult for the main grid to be extended to all rural regions at same time as a result of the high budgets of system setting up and repairs. Hence, the hybrid stand-alone renewable power system application is considered an appropriate alternative for providing electricity to the isolated rural regions.

In such rural community, electricity is used for multi-purpose, such as residential, community, commercial, small-scale industrial and agriculture loads. Clearly, the complete demand load forecasting is a vital requirement for full energy system design. The regular growth of the required energy should be estimated to plan the required essential development in the proposed power system.

The following study is related to a detailed estimation of all loads in the studied villages.

1) Domestic load (Green Building)

In rural village it is noted that the electricity needs of most families are approximately the same. The usages and capacities of electricity for domestic loads in these areas are limited.

The domestic loads contain lighting florescent lamps, radio, television, fan, refrigerator and telephone charger. Usually, these loads operate for several hours throughout the day.

The lighting load profile is subjected to certain deviation amongst yearly seasons owing to changes in the hours of sun-down and sun-up. As well as, other loads depend on weather changing between seasons. For various living levels in these areas, the estimated daily domestic energy is about 300 kWh for all 100 houses in village. Thus, the electrical energy used for one house is = 3 kWh.

2) Agriculture load

Agricultural activities in the studied areas are the most important source of income and to raise the standard of living of the inhabitants. The development of traditional agriculture methods to be modern maximizes productivity and reduces expenses as well energy needs and thus increase profits [14].

The availability of electrical energy generated from renewable energy sources in remote areas and then the integration of these sources into a hybrid system enables to develop the agriculture activities. This is one of the important reasons for the development of agricultural activities and then the economic development attracts investors to these areas, especially as the workforce is trained and inexpensive.

Fish farming, greenhouses and irrigation systems are among the most important investment activities targeted for development in these areas to be supplied by the proper amount of energy.

The irrigation load is determined by the daily amount of water required for planted area which differs from crop to another according to the water need of each. The use of modern irrigation methods such as sprinkler and drip irrigation helps to reduce the water used for the planting process and thus reduce the energy required for the irrigation process. By using one of the modern irrigation systems and knowing the amount of water the crop needs, it is possible to determine the electric power of the irrigation pumps.

Irrigation load: the studied agricultural area to be irrigated is about **ten** Acres (Fadden); nearly 42000 m^2 that can be expressed with 205 m in length and 205 m in width as shown in Fig. 6 This area is distributed equally as two sectors, every two days each sector will be irrigated [7].

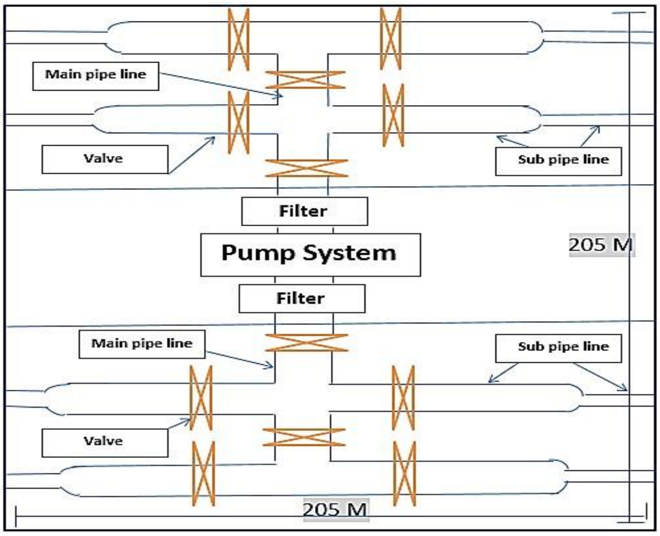


Fig. 6. Schematic diagram of the network irrigation system in the studied area

After designing of irrigation system and calculation of the required power for the load to cover this predetermined area, it was found that the power of the pump motor may be in range of 5 kW.

The pump will operate 20 hours every day in the agricultural area. Then the daily energy needed to irrigate 10 acers may be in range 100 kWh

3) Greenhouse system

The main purpose of greenhouses is to provide ideal growth conditions sustainable of climate for optimum plant growth and for early not based-time producing of ornamental and vegetable crops all year-round. Most hot-season greenhouse vegetable plants grow rapidly at daily temperatures between 20–30 °C and 14–18 °C at night. Therefore, there are two types of electrical loads, heating and cooling [10].

The load varies from place to another and from one country to another according to the difference in the external environment of the greenhouse. In temperate countries like Egypt, the ventilation and heating loads are simple because the weather is moderate for most of the months of the year, and one acre of greenhouses requires an electrical capacity of about 5 kW that works for 6 hours a day, whether in the summer day for ventilation or in the winter night for heating. Then, the daily energy used for investment one acre may in range 30 kWh.

4) Fish farm

The electrical loads required for fish farming ponds are the power of the motor used to fill the pond with water and change this water when necessary if the water loses its natural properties. The motor capacity depends on the area of the pond and the depth (the volume of water to be pumped into the pond) appropriate for the fish growth environment in addition to the light current loads of the used sensors to measure the properties of water [10]. Each acre of fish farm need water pump with power 1 kW. The pump will operate 10 hours to fill an acer of fish farm with water, then the daily energy needed for irrigate an acre of fish farm may in range 10 kWh.

D. Load visibility

The idea of developing remote areas depends on dividing them into small societies consisting of several houses, for example five houses with a developed with various investment methods from traditional farming, greenhouses, and fish farms. Egyptian countryside company may possible adopt the same methodology for other activities such as poultry farms or animal production by creating small communities where young graduates are settled.

An assessment of the different types of loads have been done above and a framework was developed for how to evaluate these loads. Consequently, the scope of work is electrical loads for five homes followed by twenty five acres within a small community unit. These 25 acres are divided into different investment activities between 10 acres for traditional agriculture, 10 acres for fish farming, and 5 acres as greenhouses.

The use of modern technologies with less energy consumption instead of traditional techniques that consume a large amount of energy. These techniques include using LED bulbs instead of regular neon bulbs, drip irrigation instead of traditional flood irrigation, and the use of modern methods in fish farming by using the technology of the Bio-floc system, where the development is continuous and sustainable, and this system is a technology to improve water quality in aquatic farms by creating balance between dissolved carbon and nitrogen in the aquatic environment. In recent years, this technology has received great attention. Whereas, the development of the fish farming system depends on the development of farming systems (smart fish farms) in which all water specifications are detected and measured automatically by sensors to take action by operator [15]. The following table (Table I) summarizes the average required energy per day.

Table I. Details of estimated loads energy in the studied area

Load	**Units No.**	**Energy in kWh/day**
Domestic community,	5 houses	5*3=15 kWh
Agriculture irrigation (Acre)	10 Acres	100 kWh
Greenhouses (Acre)	5 Acres	5*30=150 kWh
Fish farming (Acre)	10 Acres	10*10=100 kWh
Total daily load		365 kWh

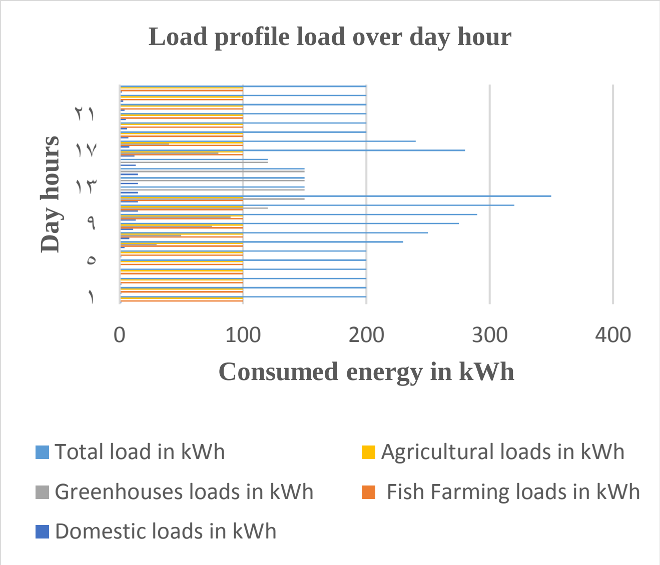


Fig. 7. Electric loads energy throughout the day

Fig. 7 illustrates the loads profile throughout the day. The maximum value of total load profile enables to determine electric power generation system capacity.

E. Renewable energy sources hardware technical details

1) PV Module

Usually, the studied rural region has a promising solar irradiation level, thus the setting up of the PV power generation could be an effective system at the long term of energy availability problem. One module of PV system is proposed due to proper technical specifications, its low-cost and its availability in the Egyptian market. The technical specifications of the proposed module are displayed in the Table II. This PV module has a long lifespan of about 25 years. The generation efficiency factor of each PV panel is nearly 90% owing to some of the surrounding environmental factors such as temperature changes and the dusts that may be formed on the surface of the panels [16].

2) Wind turbine Modules

According to the wind velocity specification of the studied area and the required load demand, small scale wind turbine (5 kW) with 25 years lifetime and generator is proposed to extract the wind energy. The specifications of the wind generator illustrated in Table III are matched with the wind speed parameters in the studied area.

As shown in tables II and III, each proposed generation module or unit generates specific amount of power at the standard condition. Therefore, there is essential need to determine the optimal number of modules and units to supply the required load. The following section studies the optimal sizing of the renewable sources and the storage system which should to be implemented in the studied village.

Table II. The technical parameters of proposed PV module

Specification	**Value**
Model	Astronergy 255 Silver Poly CHSM 6610P
Material	cell Polycrystalline 60
Maximum Power	255W
Voltage at maximum power point	30.68V
Voltage at maximum	38.40V
Short Circuit Current	8.69A
Current at maximum power point	8.33A

Table III. The technical parameters of proposed Wind Turbine

Specification	**Value**
Model	H8.0-10KW
Rotor blade diameter	0.8 m
Number of blades	blades/ horizontal 3 axis
Cut in/ cut off wind speed	3/25 m/s
Rated power	kW5
Rated Voltage	220 V AC

III. PROBLEM FORMULATION

The target of this optimization study is the sizing of elements of the renewable-energy-based power system in the studied areas. The sizing mainly depends on minimum cost criteria within the predetermined constraints.

In an optimization process, the limitations of the system values should to be determined as a primary task in defining the optimum solution. The constraints determine the restriction for the search space obviously. Any restriction contained in the problem determines a factor which limits the search space to determine the optimum sizing of hybrid renewable energy systems.

The first constraint is related to the ability of the supply system (PV, wind and Batteries) to feed the required power. The following equation illustrates the relation between the required power P_{req} the storage system power P_{Batt} the wind system developed power P_{Wind} and the PV system developed power P_{PV}:

$$P_{req} \leq P_{PV} + P_{Wind} + P_{Batt} \qquad (1)$$

The following three equations are related to the limitation of the produced power by each supply element.

$$P_{PV\,min} \leq P_{PV} \leq P_{PV\,max} \quad (2)$$
$$P_{Wind\,min} \leq P_{Wind} \leq P_{Wind\,max} \quad (3)$$
$$P_{Batt\,min} \leq P_{Batt} \leq P_{Wind\,max} \quad (4)$$

where $P_{PV\,max}$, $P_{Wind\,max}$ and $P_{Wind\,max}$ are the maximum produced power by PV, wind and storage power units respectively.

The number of supply units is considered another constrain. The number of installed wind units depends on the physical specifications of wind within the studied area. For example, the distance between wind turbines and between the wind unit and the other buildings are taken into account before the determination of maximum available number of wind units $N_{Wind\,max}$ [16]. Therefore, the optimal integer number of wind unit N_{Wind} should follow the inequality;

$$0 < N_{Wind} < N_{Wind\,max} \quad (5)$$

The all available area for PV panels installation determines the maximum number of PV panels $N_{PV\,max}$ the optimal integer number of PV panels N_{PV} should follow the inequality:

$$0 < N_{PV} < N_{PV\,max} \quad (6)$$

The maximum difference between the minimum generated power and maximum load demand determines the maximum number of battery units $N_{Batt\,max}$. The optimal number of batteries units can be determined according to the following inquality:

$$0 < N_{Batt} < N_{Batt\,max} \quad (7)$$

Additional vital constraint must be taken in consideration is that the demand met regarding specific reliability standards. Owing to the instability nature of wind velocity and solar power, the reliability power system were become a vital element while designing a power system. The loss of power supply probability term (LPSP) indicates the power system reliability. This reliability term (LPSP) may be considered as the ratio between whole energy incapability to the overall load demand for the specific period of time. The value of this ratio must be adjust while defining the overall energy that will be produced, then this means the loads should be increased in certain amount percentage to recover any losses of energy at generation.

Here, the reliability level of the system is determined by the *LPSP* that may be expressed as average part of the demand which the hybrid system is not supplied. A *LPSP* has two values, either (0) which means the demand will be ever covered, or (1) which means the demand will never be covered. The applicable *LPSP* value must be determined by the hybrid power system designer according to the level of satisfaction required for the load and the agreed pricing policy. Hence, A *LPSP* constraint for the recommended hybrid power system, should be specified to confirm that the system *LPSP* for a specific period of time T need to maintain smaller than a definite pre-specified value ($LPSP^*$) which relays on the condition of the load.

The following equation can express this constraint as [4]:

$$LPSP = \frac{\sum_{t=1}^{T} LPS(t)}{\sum_{t=1}^{T} E_1(t)} \quad (8)$$

Where *LPSP* is the loss of power supply probability, *LPS* (*t*) is the loss of power supply for specific number of hours *t* or the extra generated energy used to cover the demand in the case of deficits in load energy when the normal generated and batteries stored energy are lacking to cover the demand $E_l(t)$ for a specific number of hour t.

IV. OBJECTIVE FUNCTION

In any optimization process, the objective function for optimum sizing process aims at reducing of the total cost (*TC*) of the installed power system. *TC* composes of the investment or capital cost (*CAPCOS*), maintenance or repair cost (*MAINCOS*) and replacement or spare cost (*REPLACOS*) through the expected system lifetime, which are transformed to the investment primary moment (Today's cost). The optimization is performed to meet the load demand in view of the energy dependability guide. The system budget is calculating through the following equation:

$$Minimize\ TC(PV, WT) = Minimize(CAPCOS + MAINCOS + REPLACOS) \quad (9)$$

The investment cost that consists of the bulk costs of the PV generation system, wind turbine generation system, battery storage, power electronic component like converter charge regulator. The total capital cost can be calculated by:

$$CAPCOS = (C_{PV}\, N_{PV}) + (C_{WT}\, N_{WT}) + \left(C_{batt,pv}\, N_{batt,pv}\right) + \left(C_{batt,WT}\, N_{batt,WT}\right) + \left(C_{P.E.B,pv}\, N_{P.E.B,pv}\right) + \left(C_{P.E.B,WT}\, N_{P.E.B,WT}\right) \quad (10)$$

where C_{PV} and C_{WT} are the capital cost of PV and wind generation unit, $N_{batt,pv}$ and $N_{batt,WT}$ are the number of battery units for PV and wind systems, $C_{batt,pv}$ and $C_{batt,WT}$ are the capital costs of a battery unit for PV and wind systems, $C_{P.E.B,pv}$ and $C_{P.E.B,WT}$ are the capital costs of power electronics blocks containing converter, inverters, rectifier, charge regulator, etc. for PV and wind systems and $N_{P.E.B,pv}$ and $N_{P.E.B,WT}$ are the number of these blocks. The cyclic maintenance cost of component of PV-Wind system is expressed by:

$$MAINC = CCR\left(\left(C_{M,PV} * N_{PV}\right) + \left(C_{M,batt,pv} * N_{batt,pv}\right) + \left(C_{M,WT} * N_{WT}\right) + \left(C_{M,batt,WT} * N_{batt,WT}\right)\right) \quad (11)$$

where $C_{M,pv}$, $C_{M,WT}$, $C_{M,batt,pv}$ and $C_{M,batt,WT}$ are the yearly cyclic maintenance budgets of PV power plant, wind turbine power plant, PV and wind turbine batteries, respectively. The annual maintenance costs of power electronic devices such as rectifier, inverter and other power electronics component are ignored.

To transform all the costs through the system valuable life to the primary moment of the investment, the accumulative current rate *CCR* is used with the following formula [2]:

$$CCR(f) = f \sum_{t=1}^{T} \left(\frac{1+InfR}{1+IntR}\right)^{t} \quad (12)$$

where $IntR$ and $InfR$ is the interest rate, and inflation rate respectively and *T* is the financial cycle of the hybrid system lifetime.

Table IV. Cost assumption for wind generation unit with **5 kW** output power

Parameter	Value(L.E)
Capital cost	160000
Maintenance &operation cost every year	750*24=18000
Replacement cost every 5 years	33900*4=135600
Lifetime	25
Total Wind generation unit over 25 years life time	313600

Thus, if the inflation rate tends to rise, this means an increase in the project cost over the course of the project, but increasing the interest rate contributes to reduce the effects of this rise in the project cost.

The cost of cyclic replacement process of PV/Wind system elements as regards to its lifetime can be obtained as follows:

$$REPLACOS = CCR\left(\left(C_{batt,pv}\ N_{batt,pv}\right) + \left(C_{batt,WT}\ N_{batt,WT}\right) + \left(C_{P.E.B,pv}\ N_{P.E.B,pv}\right) + \left(C_{P.E.B,WT}\ N_{P.E.B,WT}\right)\right) \quad (13)$$

The replacement cost is only calculated for batteries and power electronics block due to their limited lifetime compared with the PV panel and wind Turbine which will not be replaced during the project life cycle as a result of the long life span of both.

Table V. Cost assumption for PV generation unit with **5 kW** output power.

Parameter	Value(L.E)
Capital cost	102000
Maintenance &operation cost every year	220*24= 5280
Replacement cost every 5 years	19100*4= 76400
Life time	25
Total PV generation unit over 25 years life time	183680

V. OPTIMIZATION OF THE RENEWABLE ENERGY SYSTEM IN THE STUDIED VILLAGE

According to many parameters and factors that should be taken in consideration, the hybrid Wind–Solar systems sizing process is higher difficult than the individual renewable resource generation systems. This category of optimization process contains economical purposes. Obviously, this needs the valuation and analysis the long-term factors that affect the system performance so as to obtain the best accepted solution for both generation cost and power dependability. The minimization of the objective function is applied using a genetic algorithm (GA) that looks for the optimum system formation.

1) Genetic algorithm

A genetic algorithm (GA) is a developed tool for searching and optimizing approach [8, 9]. Scientists were advanced it to simulate the evolutional standard of natural genetics. The most important benefits of the GA is represented in commonly powerful in discovering overall optimum results, mostly in optimization problems that have a varied nature of objectives.

Usually, a GA tool has three operators (selection, crossover and mutation) to mimic the natural development processes. In the first step (selection) a genetic assessment try to decide whether the selected system pattern archives the functional assessment.

After finishing the selection step, the optimum result is starting the crossover and mutation phases so as to produce the following generation population till a pre-identified generation's number were reached or while a standard that defines the rapprochement is accepted.

2) Case study

The advanced approach for Genetic Algorithm were applied to scheme the isolated hybrid PV/ Wind systems to supply the various loads in the area in northern Egypt below Lake Burullus with the electrical energy needed for the development of these areas defined as latitude: 31°21 N, longitude: 31°02 E. The values of sun irradiation, duration and wind velocity were measured at a 10 meters height and recorded 24 hours a day, over the year as in Fig. 3 and Fig. 5 respectively.

In this research, PV, wind turbine generation unit and battery were used. The average daily power consumption for the load is 365 kWh/day at peak time with all loads running. The optimal solution was verified by reviewing the energy profile and determining whether the energy produced from the solar units, wind turbines and batteries is sufficient to cover these loads.

The excessive power generated from each 5 kW-60kWh-wind turbine unit is stored in 24 lead-acid batteries rated at 12 V which has a capacity 200 AH. The capital, annual maintenance and replacement cost of each wind generation unit is 313,600 EGP over the lifetime of the project as shown in Table IV.

For PV generation units, any excessive generated energy from each 5 kW-25kWh were stored in 10 lead-acid batteries rated at 12 V which have a capacity of 200 AH. The capital, annual maintenance and replacement cost of each PV generation unit is 183,680 EGP over the lifetime of the project as shown in Table V.

A lead-acid battery rated at 12 V and has a capacity 200 AH has been used for the proposal generation system. A battery capital and replacement cost is 5,000 EGP and will be replaced every 5 years.

The annual interest (13%) and the inflation rate (3%) has been considered over the project lifetime (25 years). Hence, the cost of any year of the project can be converted to today's price. Several tests have been performed with altered factors values. The GA factors were used in this research are:

1) Size of population: 20
2) Number of generations: 300
3) Number of variables:

The Genetic Algorithm seeking for structures of PV, wind generation units, and batteries with the minimum system cost. The common case should be considered, if the total component (mentioned above) are used. Although, the customer can determine if all these components are totally contained in the system or just some of them. Then, the cases are concluded and studied in this research. The following cases provide several energy system configurations. The first case assumes that the energy system consists of hybrid PW/Wind systems. Then, the second and the third cases illustrate the cost if the system contains only PV or wind system respectively.

a. Case 1 (Hybrid PV/Wind system)

This is the basic case in which solar and wind energy are available. This means the solution will be more reliable and practical. The solution is the number of solar generating units and wind turbines that will be installed to cover the total demand load around the day hours according to Fig. 6 with the lowest cost. In other words, our reliance on a single generation resource could undermine the reliability of the generation system to be designed, hence the equation number one not applied.

The expected solution may rely on more wind generation units than solar power generating units as a result of the lower cost of the kilowatt hour using wind than the cost of generating using solar energy. The GA has been applied to determine the optimal number PV, wind and batteries units. The identified constraint related to LPSP is set at 0.1. Any possible combination of generations units is tested to fulfil the constrain to feed the estimated loads in Fig. 7 daily. The solution of this case is that 6 wind turbines, 1 PV power generation units and 140 batteries is needed. While the ratings and parameters of these units are given in Table II and III.

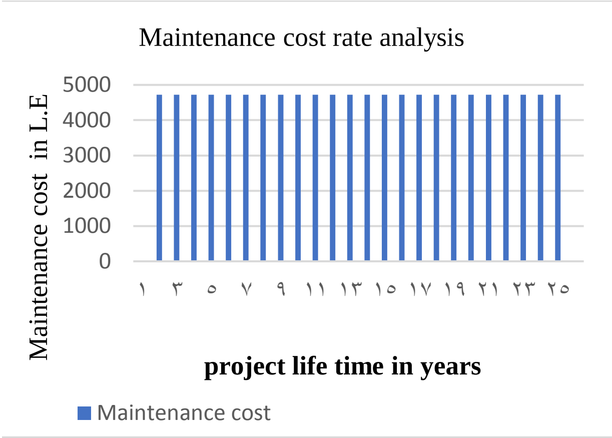
Fig. 8a, 8b and 8c illustrate the rate of maintenance, replacement, capital and total costs spending over the lifetime of the project, which is estimated at 25 years. The total cost is distributed among the initial, the annual maintenance and the 5-years replacement costs. From the financial analysis, the project costs approximately 2065280 L.E. at the end of the project as shown in Fig. 8(c) at the end of year 25.

b. Case 2 (PV system)

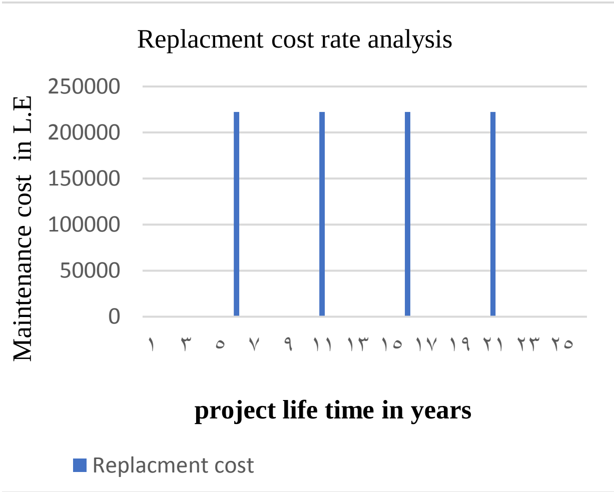
In this case, the total required energy is generated by PV units. This solution may be recommended when there are spaces in which solar panels can be placed and a large amount of money is available to start the project, where the solar generating stations need higher capital cost as shown in Fig. 9(c). The solution of this case is that 16 PV power generation units and 160 batteries is needed. The total cost of the proposed PV based system equals 2935360 L.E. The proposed solution is tested in each day of the year to test whether the specified load is fulfilled. This solution has a serious disadvantage related to higher value of LPSP more than 0.1 which is considered as a reference value. The higher value of LPSP usually occurs in winter season. The studied area may suffer from low solar irradiation along several days in winter.

c. Case 3 (Wind system)

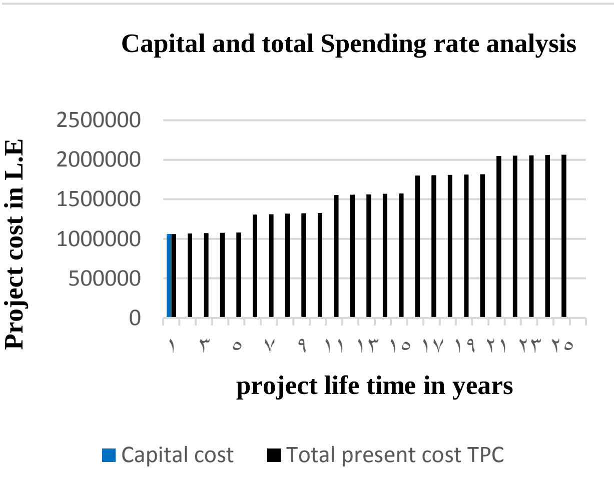
In this case, the total required energy is generated by wind power generation units. This solution may be recommended when the spaces are limited, as the wind turbine towers do not require large areas compared to solar panels.



(a) The rate of maintenance cost



(b) The rate of replacement cost

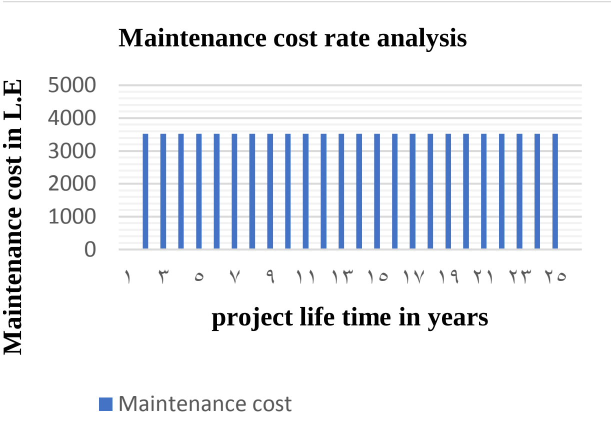


(c) The rate of capital and total cost spending

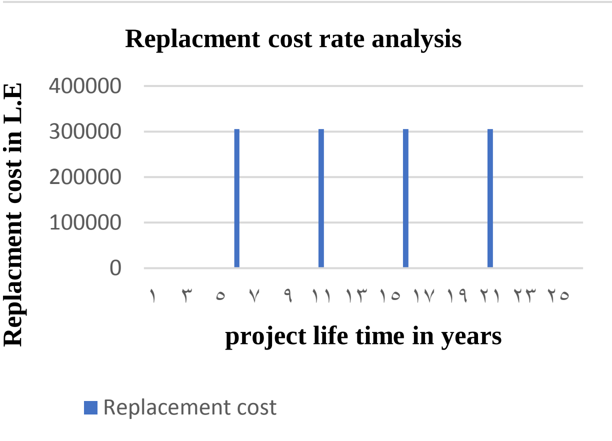
Fig. 8. Financial analysis of the PV-Wind hybrid system over the project time

As that the project start-up cost is relatively less than the solar generating units as shown in Fig. 10(c). The solution of this case is that 7 wind turbine and 144 batteries is needed. Although the total project cost is less than the hybrid and PV system, the proposed wind system doesn't fulfil the required loads over the year. The value of *LPSP* factor exceeds the reference value of 0.1. This is due to the prolonged time interval when the wind speeds are less than the average value as in September as in Fig. 5 (b). Fig. 10 illustrate the details of the required cost over the whole project time. The total cost of the wind-based project equals 2195200 L.E.

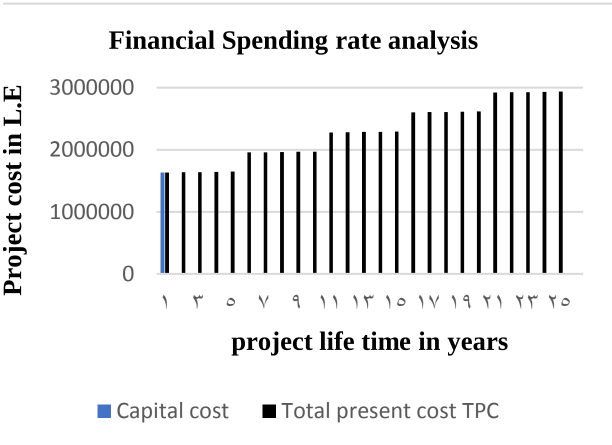
Table VI summaries the results of various studied cases. It should be noted that although the generated energy from PV-case or wind-case is higher than the daily demand energy, the *LPSP* over the whole year exceeds the targeted limit of 0.1. For the hybrid proposed system, the value of *LPSP* equals 0.05 which is less than 0.1.



(a) The rate of maintenance cost

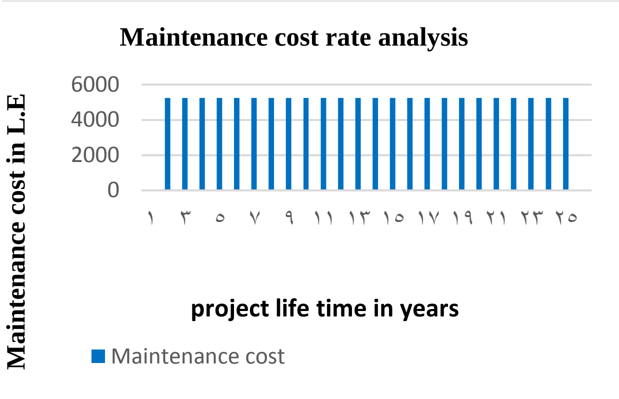


(b) The rate of replacement cost

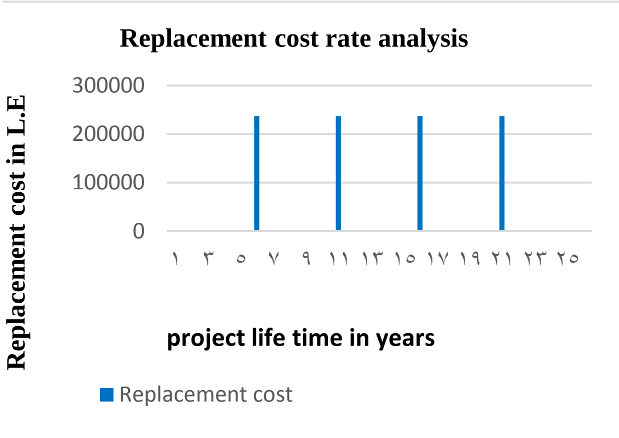


(c) The rate of capital and total cost spending

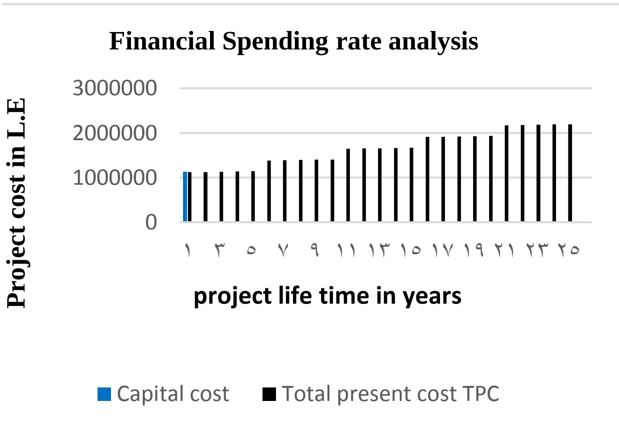
Fig. 9. Financial analysis of the PV system over the project time



(a) The rate of maintenance cost



(b) The rate of replacement cost



(c) The rate of capital and total cost spending

Fig. 10. Financial analysis of the wind system over the project time

Table VI: Summary of the results of the studied cases

NO.	Case	Demand Load	Solution	Generated Energy kWh	*LPSP*
1	Hybrid PV & Wind	365 kWh	6 Wind & 1 PV	6 *60 + 1 * 25 = 385	0.05
2	PV		16 PV	16 * 25 = 400	0.101
3	Wind		7 Wind	7 * 60 = 420	0.15

VI. CONCLUSIONS

The paper has discussed the design of hybrid renewable energy system to feed rural area loads in a village located in the north of Delta Nile in Egypt. The renewable energy resources (solar and wind) in the studied area have be investigated as a step to design the generation system. All of electrical loads in the village have been estimated. Loads include domestic, commercial and agriculture activities loads. According to the local market and the required loads, the practical PV and wind turbines units have been recommended. The optimal design of the generation system requires the formulation of objective function to be minimized. This function contains the various costs such as capital, maintenance and replacement costs. The values of interest and inflation rates are taken into account in this study. In this paper, a Genetic algorithm (GA) strategy has been presented to determine the optimal design of the isolated hybrid PV/Wind system. This strategy depends on the usage of long-term renewable resources values of solar irradiation and wind speed. The continuity of the designed energy system has been considered as a constraint by checking the loss of power supply probability term for various solutions in the search space. The results provide the details of the hybrid system compared with PV-based and Wind-based systems. The hybrid system has been recommended because it is optimized according to cost and fulfil the required the loss of power supply probability term. As mentioned in the paper page no. 8, every PV generation unit 5 kW rated power can generate 25 kWh as well as every Wind turbine 5 kW rated power can generates 60 kWh. It has been noticed that the value of the LPSP is low as the generated energy is about 372 kilowatt-hours and its ratio to the load to be covered (365 kWh) is nearly 1.01. The first case PV & Wind because this is the most reliable case for the presence of two sources of renewable energy. In the case of PV, the value of the LPSP is high as the generated energy is about 402 kilowatt-hours and its ratio to the load to be covered (365 kWh) is nearly 1.1 to face cloudy days. While the value of the LPSP in Wind case is almost non-existent due to the availability of wind throughout the year as it is near the area from the sea.

REFERENCES

[1] Giallanza, Antonio et al. “A Sizing Approach for Stand-Alone Hybrid Photovoltaic-Wind-Battery Systems: A Sicilian Case Study.” *Journal of Cleaner Production* 199 (2018): 817–830. DOI: 10.1016/j.jclepro.2018.07.223

[2] Ahmadi, Saeedeh, and Shirzad Abdi. “Application of the Hybrid Big Bang-Big Crunch Algorithm for Optimal Sizing of a Stand-Alone Hybrid PV/Wind/Battery System.” *Solar Energy* 134 (2016): 366–374. DOI: 10.1016/j.solener.2016.05.019

[3] Mahesh, Aeidapu, and Kanwarjit Singh Sandhu. “Hybrid Wind/Photovoltaic Energy System Developments: Critical Review and Findings.” *Renewable and Sustainable Energy Reviews* 22 Aug. 2015: 1135–1147. DOI: 10.1016/j.rser.2015.08.008

[4] Nafeh, Abd El Shafy A. “Optimal Economical Sizing of a PV-Wind Hybrid Energy System Using Genetic Algorithm.” *International Journal of Green Energy* 8.1 (2011): 25–43. DOI: 10.1080/15435075.2010.529407

[5] Azeem, Fawad, Ghous Bakhsh Narejo, and Usman Ali Shah. “Integration of Renewable Distributed Generation with Storage and Demand Side Load Management in Rural Islanded Microgrid.” *Energy Efficiency* 13.2 (2020): 217–235. DOI: 10.1007/s12053-018-9747-0.

[6] Gebrehiwot, Kiflom et al. “Optimization and Cost-Benefit Assessment of Hybrid Power Systems for off-Grid Rural Electrification in Ethiopia.” *Energy* 177 (2019): 234–246. DOI: 10.1016/j.energy.2019.04.095.

[7] M. Abdel-Salam, A. Ahmed, H. Ziedan, K. Sayed, M. Amery and M. Swify, "A solar-wind hybrid power system for irrigation in Toshka area," 2011 IEEE Jordan Conference on Applied Electrical Engineering and Computing Technologies (AEECT), Amman, 2011, pp. 1-6, doi: 10.1109/AEECT.2011.6132491.

[8] A. E. ELGebaly, "Optimized Design of Single Tum Transformer of Distributed Static Series Compensators using FEM based on GA," 2019 21st International Middle East Power Systems Conference (MEPCON), Cairo, Egypt, 2019, pp. 1133-1138, doi: 10.1109/MEPCON47431.2019.9008227.

[9] El-Nemr, Mohamed K., Belal S. Farrag, and Sameer M. Dawood. "Technical and Economical Investigation of Renewable Energy Sources for Supplying Offshore Oil production Facilities at Gulf of Suez Area." *Journal of Engineering Research* 5.2 (2021): 18-25. DOI: 10.21608/ERJENG.2021.73618.1010

[10] Hassanien, Reda Hassanien Emam, Ming Li, and Wei Dong Lin. “Advanced Applications of Solar Energy in Agricultural Greenhouses.” Renewable and Sustainable Energy Reviews 1 Feb. 2016: 989–1001. DOI: 10.1016/j.rser.2015.10.095

[11] J. Benedek, T. T. Sebestyén, B. Bartók, “Evaluation of renewable energy sources in peripheral areas and renewable energy-based rural development”. *Renewable and Sustainable Energy Reviews*. **90** (2018), pp. 516–535.

[12] Boucar Diouf, Ramchandra Pode,"Potential of lithium-ion batteries in renewable energy", *Renewable Energy*, Volume 76, 2015, Pages 375-380, https://doi.org/10.1016/j.renene.2014.11.058

[13] M. A. Almozayen, M. K. El-Nemr, and E. M. Rashad, “Design procedure of coreless stator PM axial field synchronous machine for small-scale wind applications,” Electrical Engineering, May 2017. [Online]. Available: https://doi.org/10.1007/s00202-017-0540-4

[14] O. Gulec, E. Haytaoglu and S. Tokat, "A Novel Distributed CDS Algorithm for Extending Lifetime of WSNs With Solar Energy Harvester Nodes for Smart Agriculture Applications," in IEEE Access, vol. 8, pp. 58859-58873, 2020, doi: 10.1109/ACCESS.2020.2983112.

[15] Kim, Min-Su, et al. "Growth performance and immunological and antioxidant status of Chinese shrimp, Fennerpenaeus chinensis reared in bio-floc culture system using probiotics." *Fish & shellfish immunology* 47.1 (2015): 141-146.

[16] Ahmadi, Saeedeh, and Shirzad Abdi. "Application of the Hybrid Big Bang–Big Crunch algorithm for optimal sizing of a stand-alone hybrid PV/wind/battery system." Solar Energy 134 (2016): 366-374.

[17] Das, Himadry Shekhar, et al. "Feasibility analysis of standalone PV/wind/battery hybrid energy system for rural Bangladesh." International Journal of Renewable Energy Research (IJRER) 6.2 (2016): 402-412.