Journal of Engineering Research

Volume 5 | Issue 2 Article 3

2021

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Recommended Citation

K. El-Nemr, Belal S. Farrag, Samir Dawoud, Mohamed (2021) "Technical and Economical Investigation of Renewable Energy Sources for Supplying Offshore Oil production Facilities at Gulf of Suez Area," *Journal of Engineering Research*: Vol. 5: Iss. 2, Article 3.
Available at: https://digitalcommons.aaru.edu.jo/erjeng/vol5/iss2/3

Technical and Economical Investigation of Renewable Energy Sources for Supplying Offshore Oil Production Facilities at Gulf of Suez Area

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Abstract—**The Gulf of Suez is highly susceptible to economic and energy security due to the heavy need for imported fossil fuels. The energy produced from fossil fuels causes serious environmental pollution. So, it is important to find other clean sources of energy for stabilizing the released amount of carbon dioxide. Gulf of Suez has the potential to develop clean Solar Photovoltaic (PV) and wind systems to improve economic and environmental performance. This paper proposes a combination of floating solar panels (FSP) and offshore wind turbines to solve the main critical issues, such as the land area required for a large number of cells and the space required for wind turbines. In addition to their good economical and environmental benefits. A simplified model is provided to investigate the replacement of traditional generating units (Diesel and Gas operated) supplying offshore oil production field facilities at the Gulf of Suez area with a mix of renewable resources. The load flow analysis is carried out for the model and the cost is calculated and compared for four schemas, the traditional generating, Wind-Gas, PV-Gas, and PV-Wind-Gas hybrid system. From the techno-economic analysis and comparing environmental benefits, floating solar systems and offshore wind turbines can provide a good solution to the existing problems of energy needs with environmental impacts considered.**

Keywords—Solar Energy, Floating Solar Panels, Techno-Economic Analysis, Offshore wind turbine, Gulf of Suez

I. INTRODUCTION

Using fossil fuels as the main energy source has led to environmental pollution and serious energy crises on a global scale. Natural gas, coal, and gasoline have more combustion and generate more pollution [1]. Different types of offshore platforms are constructed to transport natural gas and crude oil to the surface. They carry process equipment required for improving the production and moving it to onshore facilities [2, 3]. The penetration of renewable energy resources is a proven good solution for the current issues of diminished fossil fuel resources and rising electricity costs [4-6]. Solar energy has found extensive consideration as it is a perfect energy resource. Using such energy resources has turned out to be imposing in different methods because of its advantages such as decreasing the greenhouse gas emissions, cost of electricity, and global warming through lessening fossil fuel consumption. Solar energy sources can produce thermal energy for industrial heat demands and electricity in solar plants [7, 8]. The floating PV-generated power results from the combination of PV plant technology and floating technology. This technology replaces the installation of Photovoltaic power plants over valuable land. The floating PV plant consists of a Pontoon or separate floats, mooring system, solar panels, cables, and accessories as explained in [9]. As a new generation technology, it can change the existing photovoltaic (PV) plants that are installed on top of farmland, woodland, and buildings. When it comes to the shortage of land-based countries, floating solar system installation cost is negligible with production profits of useful land. The floating solar system also provides environmental benefits like the prevention of evaporation of water. Due to the cooling effect of water on both the panels and the equipment, floating solar plants are expected to deliver higher power output than conventional solar installation, and hence the return on investment is higher. The floating solar systems are now a very important issue and form a global interest taking place in many countries and have many applications [9-14].

Most oil and gas majors are thinking about electricity these days. They're in the business of providing energy for mobility and cost reduction. Putting wind turbines on offshore platforms akin to offshore oil and gas platforms developed for the petroleum industry provides a means of exploiting high-quality offshore winds which can withstand dynamic load and tidal effect. It must be more consistent than onshore winds in waters too deep for today's bottom-fixed foundations. In this paper, a simplified model is provided to replace fossil fuel of Diesel and Gas generating units supplying offshore oil production field facilities at the Gulf of Suez area with a floating solar system installed on the seawater surface as a first solution, an offshore Wind system as a second solution and a mixed PV-Wind-Gas system as a final solution.

The existed network is simulated on ETAP software with all its components, replacement system models also simulated, load flow generated and the cost is calculated in all cases as a promising type of renewable energy source. The floating solar panels and offshore wind are simulated to be used for the first time in this area in Egypt as offshore renewable energy systems as this region is rich with solar energy and wind energy. Looking forward to being an innovative step forward and a guide for more utilization of this clean energy.

This article is organized as follows: Section II shows the resource and electrical load, Section III models the modeling and power flow analysis. Section IV shows the gotten results and discussion which is divided into the environmental and economic assessment and finally, section V concludes the conclusions of this article. The flow chart in Figure 1 indicates that the case study network is an offshore oil field of Gulf of Suez area which is simulated on ETAP, collecting cost data as actual payment at the field, calculate Levelized cost of energy, and an assessment for environmental impact, kWh cost, and power flow analysis is placed. A replacement hybrid system of floating solar system, offshore wind system, and gas generators with different combination of power-sharing to improve economic, environmental, and diesel oil fuel cost reduction.

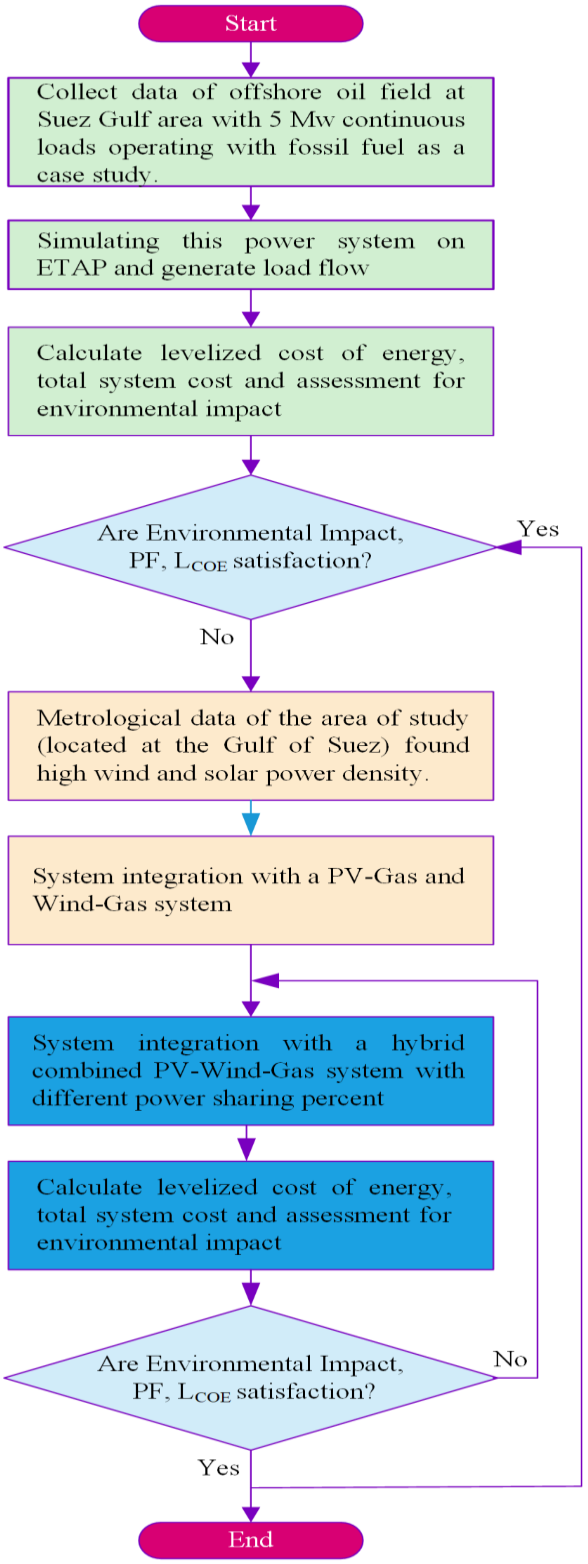

Fig. 1: Flow chart of organization and methodology

II. RESOURCE AND ELECTRICAL LOAD

A. *Area geographical nature*

The 22 years average monthly data of solar irradiation in the Gulf of Suez Egypt which is located at 27.82846 of latitude and 33.5337 of longitude are obtained from the National Aeronautics and Space Administration database. Wind speed is recorded by Egyptian wind Atlas, it is about 10 ms^{-1}. The concept behind this project is the fact that this offshore area is rich in solar energy and wind energy.

B. *Electric load demand*

This offshore oil field located in the Gulf of Suez area in Egypt needs existing continuous loads of about 5MW to supply oil production and process facilities according to the field actual load calculation.

III. MODELING AND POWER FLOW ANALYSIS

A. *Modeling and power flow of fossil fuel generating units*

The power generation system consists of nine generators (three Diesel units each 750 kW, three Gas units each 500 kW connected to Bus-1, and three Gas each 1MW connected to Bus-2) at normal operation all these units run in service except one Diesel engine (750kW) and one Gas engine (1MW) stay as a stand by for any failure in the running units also as a backup during routine maintenance. This power system is modeled on Electrical Transient Analyzer Program ETAP and Load flow analysis using ETAP software is accurate and gives reliable results. This paper makes effective use of ETAP to carry out load flow analysis of the traditional system. Fig. 2 shows the single line diagram of the traditional system after the network is modeled on ETAP. The generators are connected to two main buses main Bus-1 and the main Bus-2.

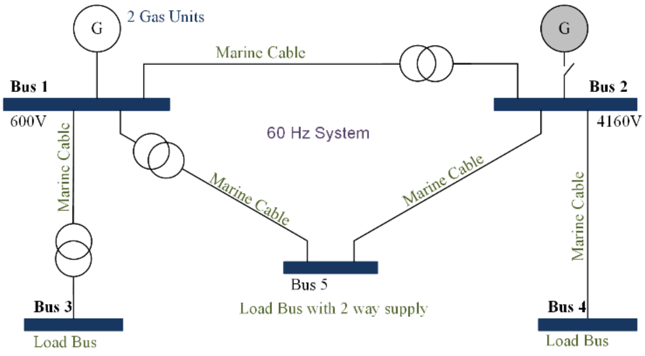

Fig. 2: Single line diagram for the traditional system

$$CRF = \frac{i(1+i)N}{(1+i)N-1} \tag{1}$$

$$L_{COE} = \frac{C*CRF+F_{O\&M}}{8760*C_f} + V_{O\&M} + F_{cos\,t} \tag{2}$$

CRF is the capital recovery factor, L_{COE} is the normalized cost of energy, *N* is the time life 25 yrs, *C* is the capital cost in \$/kW, C_f is the capacity factor, $F_{O\&M}$ is fixed operation and maintenance cost in \$/kW per yr, $V_{O\&M}$ is variable operation and maintenance cost in \$/kW and F_{cost} is fuel cost in \$ /kWh [15-16].

The active and reactive power flow is evaluated. According to the field actual load demand and continuous operation condition, kWh cost is calculated in all cases. The normalized cost of energy is calculated by equations (1) and (2). The cost of generators is recorded at field including capital cost, fuel, and running cost (Variable and fixed). Diesel G type CAT-3512 -750 kW, Gas G type CAT-399-500 kW, and Gas G type WAUKSHA-1000 kW are used. An average cost of production of electricity over the full life cycle of each generation technology accounting for construction, installation, operation, maintenance, decommissioning, recycling and disposal. Renewable sources, i.e. PV and wind may require backup and some replacement which has been included in the cost calculations.

The system cost is calculated depending on items price from manufacturers. All the prices are in dollars. For the generation system prices are recorded from the field as actual payment and RE prices depending on the selected brand type. The parameters of Diesel G - CAT-3512 are C of 666 \$/kW, $V_{o\&m}$ of 0.006 \$/kWh, $F_{o\&m}$ of 13.5 \$/kW, F_{cost} of 0.138 \$/kWh and C_f of 0.9. The parameters of Gas G - CAT-399 are C of 1000 \$/kW, $V_{o\&m}$ of 0.006 \$/kWh, $F_{o\&m}$ of 13.3 \$/kW, F_{cost} of 0,000 \$/kWh and C_f of 0.9. The parameters of gas G – WAUKSHA are C of 1000 \$/kW, $V_{o\&m}$ of 0.007 \$/kWh ,$F_{o\&m}$ of 10 \$/kW ,F_{cost} of 0,000 \$/kWh and C_f of 0.9. L_{COE} for Diesel Generator CAT-3512 equals 0.153 \$/kWh ,L_{COE} for Gas Generator CAT-399 equals 0.02 \$/kWh ,L_{COE} for two Gas Generator WUKSAH equals 0.018 \$/kWh ,total system cost equals 64,714,500 Dollars and kWh cost is 0.06 \$/kWh. Table I shows the fossil fuel operated system output data at all system buses, the active and reactive power generation, demand, and voltage magnitudes. This data is summarized from the ETAP load flow report which compared with actual field data found the same.

Table I: Generation output data of the traditional system

Bus number	**1**	**2**	**3**	**4**	**5**
Bus Type	G	G	Load	Load	Load
Voltage (kV)	0.600	4.160	4.160	4.160	4.160
Generated P (kW)	2.980	2.200	0	0	0
Generated Q (kVAR)	1.500	1.000	0	0	0
Demand P (kW)	1.000	1.630	0.500	0.645	1.050
Demand Q (kVAR)	0.500	0.800	0.280	0.350	0.520

Gulf of Suez has excellent hydrocarbon potential, with the Prospective sedimentary basin area measuring approximately 19,000 km^2, and it is considered as the most prolific oil province rift basin in Africa and the Middle East. This basin contains more than 80 oil fields, with reserves ranging from 1350 to less than 1 million bbl, The Egyptian Ministry of Oil and Mineral Resources has signed two production sharing agreements with Dutch Oil Company Shell for areas in the Red Sea for new oil exploration.

A recent discovery (GNN-4) with a production rate of 2,000 barrels per day (bbld^{-1}) of crude oil in the area of study is announced this year. The indications showed that there are about 70 million barrels of extractable crude oil reserves. All this assure that this area must be energy secured for current and future oil and gas operations.

To get a reliable result and compare the cost of different systems, selecting a 25 yr time life for the study as the Wind turbines are unlikely to last much longer than this because of the extreme loads they are subjected to throughout their lives also most Wind turbine manufacturers recommend that its lifetime extended to 25 yrs or longer. The selected PV manufacturer provides industry-leading 257 yrs warranty (5 yrs 100% warranty on workmanship & materials, 12 yrs at 90% rated performance, 25 yrs at 80% rated performance before it drops below this or require replacement.

B. *Modeling and power flow of PV- Gas system*

A simple model is designed as a replacement for fossil fuel-operated generators. The hybrid system energy consumption is calculated. Sizing PV system by five main points PV sizing, inverter sizing, battery storage units, and charger controller sizing Using sizing method explained in [17-19].

- Determine load demand

For 5MW continuous load, the daily load consumption is 120,000 \$/kWh. The annual load consumption is 43,800,000 kWh.

- Sizing of PV module

Table II shows the specification of the PV panel. This specification mentioned in this Table is used to calculate the necessary number of PV panels needed and to determine the number of series and parallel connections by selecting type Suniva ART245-60 Monocrystalline Solar Modules PV panel.

Table II: PV panel specifications

Max. power	240.00	W peak
The voltage at max. power	30.65	Volts
Current at max. power	7.82	A
Open circuit voltage	37.08	Volts
S.C current	8.33	A
Power tolerance	+1.5%	
Temperature	45±2	°C
Max. system voltage	1000	Volts

The required number of series PV, the required number of parallel PV, the total peak power, and the total current needed can be calculated by dividing the peak power by the DC- voltage of the system can be calculated by the following equations.

$$PV_s = \frac{V_{dc}}{V_{pv}} \tag{3}$$

$$PV_p = \frac{I_{dc}}{I_{pv}} \tag{4}$$

$$P = \frac{1.25\, E_d}{N * \eta} \tag{5}$$

$$I_{dc} = \frac{P}{V_{dc}} \tag{6}$$

$$PV_t = PV_p . PV_s \tag{7}$$

Where V_{dc} is system DC voltage, V_{pv} is panel voltage. PV_p is no. of parallel panels, P is the peak power, E_d is Daily load demand, N is no. of sun hours, I_{pv} is Rated PV current and η is the total efficiency. The tile angle and direction of the solar panels should be selected according to location and latitude angle. The panels' direction is south. The Panels angle is calculated by (3.1+ (28.36*0.760) = 25 deg).

- Inverter Sizing

The inverter power must be sufficient to handle the total amount of Watts required by the system. The inverter size should be 25-30% greater than the required watt of the loads as a safety margin. The Inverter size equals 6250 kW. The inverter rating is selected to be 500 kW matched with gas generator rating sized 13 EA Schneider 500 kW-600 Volt-XANTREX GT three-phase.

- Battery Sizing

Using a deep cycle battery type AGM US REL16-2V XC2-2V, 600 AH capacity to calculate the necessary needed number and the number of series and parallel connection.

$$Ns = \frac{V_{dc}}{V_B} \tag{8}$$

$$Np = \frac{N_{batteries}}{N_{days}} \tag{9}$$

The no. of series batteries is calculated by equation no. (8), the no. of parallel batteries is calculated by equation no. (9), the safe amount of energy storage is calculated by equation (10) by multiplication of the total power demand and the number of autonomy days divided by the maximum depth of discharge. The rated voltage of each battery *VB* (2V) to be used in the battery bank. The capacity of the battery bank needed in ampere-hours can be evaluated by dividing the safe energy storage required by the DC voltage of one of the batteries selected equation no. (10). The total number of batteries is obtained by dividing the capacity *C* of the battery bank in ampere-hours by the capacity of one of the batteries (C_b) selected in ampere-hours equation no. (11).

$$E_{safe} = \frac{E.D}{M_{dod}} \tag{10}$$

$$C = \frac{E_{safe}}{V_B} \tag{11}$$

$$N_{batteries} = \frac{C}{C_b} \tag{12}$$

$$N_{total} = N_s . N_p \tag{13}$$

Where, M_{dod} is the maximum depth of discharge, N_s is the number of series modules, N_p is the number of parallel modules, *E* is the required power demand, N_{days} is the no. of autonomy days, *C* is the battery bank storage capacity, C_b is the ampere-hour of one battery and E_{safe} is safe energy storage.

- . Solar charge controller sizing

It controls the flow of current. A good voltage regulator must be able to withstand the maximum current produced by the array as well as the maximum load current. Sizing of the voltage regulator can be obtained by multiplying the short circuit current I_{sc} by the No. of modules connected in parallel N_P by a safety factor F_{safe}. The result gives the rated current of the voltage regulator equation no. (14) The Nominal voltage is the same as battery and PV (62 V).

$$I = I_{sc} . N_p . F_{safe} \tag{14}$$

The solar charge controller rating equals 11,650kA. It is found that:

1. The number of panels equals 97,786 panels.
2. The number of inverters equals 13 inverters.
3. The number of batteries equals 34,658 batteries.
4. Solar charger rating equal 11,650A

Table III indicates the PV system cost and to be sure about system reliability, reliable lifetime, and prices, the solar system components are selected to be matched with system requirement, from strong manufacturers and replacement time to be considered in the cost calculations. The load flow analysis of the hybrid PV-Gas system is carried out by ETAP to carry out and compare the results with the traditional system. Fig. 3 shows the single line diagram of the hybrid PV-Gas system as a replacement to traditional generators.

In this paper, SUNIVA ART245-60 Monocrystalline Solar Modules PV panel, Deep cycle batteries type AGM US REL16-2V XC2 and Schneider Inverter 500 kW, 600 Volts Xantrex GT Series 3-Phase are used. From the manufacturer datasheet the expected battery and inverter lifetime will require one-time replacement during the selected lifetime So, the battery system and Inverters are to be replaced so its cost is doubled.

Using ETAP to simulate this network and generate load flow and analyze the result, found that the expected value of the balance of power at each bus is the same as actual data at the field but a voltage drops of 0.9 PU is noticed at Bus-2 and Bus-4. It can be seen that the expected values of active and reactive power flows are similar to the values obtained from the generator analysis. The deviations that exist are expected and can be avoided by many simple techniques.

The actual data of the electrical network is collected from the field. The system is modeled on ETAP software in the two cases. The first case depends on supplying loads from fossil fuel-operated generators and in the second case the Generators are replaced by PV power sources. The load flow is generated in the two cases found result data is the same as actual data, load demand is satisfied except voltage regulation is indicated at buses 2 & 4 that can be avoided by installing step-up transformer at Bus-1. The obtained power flow data of the hybrid PV-Gas system is the same as the traditional generators concerning load demand.

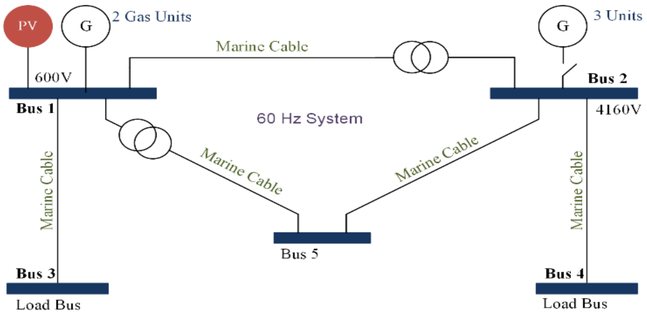

Fig. 3: Single line diagram of the hybrid PV-Gas system

Table III: PV-Gas system cost

Item	Cost
PV panel and MPPT	3,500,000 $
Inverter	1,000,000$
Battery and charger	10,000,000$
Cables and Accessories	1000,000$
Floats and Mooring system	1000,000$
Installation	3,500,000$
Fixed Maintenance cost	10,000,000$
Variable Maintenance cost	5,000,000$

Table IV: Generation output data of PV-Gas and Wind-Gas systems

Bus number	1	2	3	4	5
Type	G	Load	Load	Load	Load
Voltage (kV)	0.60	3.8	4.16	3.8	4.16
Generated P (kW)	4.00	0.0	0.0	0.0	0.0
Generated Q (kVAR)	2.50	0.0	0.0	0.0	0.0
Demand P (kW)	1.00	1.40	0.8	0.48	1.3
Demand Q (kVAR)	0.49	0.67	0.35	0.21	0.65

Table V: Wind-Gas system cost

Item	Cost ($)
Wind turbines	7,500,000$
Installation Cost	6,000,000$
Cables and Accessories	1,500,000$
Fixed Maintenance cost	5,000,000$
Variable Maintenance cost	2,500,000$

Floating PV is 5000 kW with C of 4,000 \$/kW, $V_{o\&m}$ of 0.01 \$/kWh, $F_{o\&m}$ of 80 \$/kW, F_{cost} of 0,000 \$/kWh and C_f of 0.5. One Gas G CAT-399 runs as a reference G for the system. The L_{COE} for a PV system of 0.104 \$/kWh, L_{COE} for 1 Gas G (0.5 MW) of 0.02 \$/kWh, Total system cost of 104,592,000 Dollars, and kWh cost is 0.095 \$/kWh· Table IV shows the PV-Gas and Wind-Gas systems output data at all system buses, the active and reactive power generation, demand, and voltage magnitudes. This data is summarized from the ETAP load flow report which compared with actual field data found the same.

C. *Modeling and power flow of Wind-Gas system*

Table V shows Wind-Gas system cost. To be sure about system reliability, reliable lifetime, and prices of wind turbine (EWT DW61-1MW – UK or SEATWITL S1 – Sweden) is selected for the system. The wind turbine is to have a backup power supply using gas generators. The size of generator that existed at the field is Gas (G type CAT-399-500 kW and Gas G type WAUKSHA-1000 kW) so, in case of low wind speed G 500 kW will run with the system and in case of turbine stop G 1000 kW will operate so 1 MW wind turbine operation matches with available G size also to reduce the capital cost of installation. Solar system component scaling is selected according to higher efficiency, Length of manufacturer's warranty, matching offshore installation, and comparing price with lifetime and rating.

A simple model is designed as a replacement for fossil fuel-operated generators. The system energy consumption is calculated. Keeping in mind that the Gulf of Suez area is rich in wind energy. The load flow analysis of the hybrid Wind-Gas system is carried out by ETAP to compare the results with other systems. Fig. 4 shows the single line diagram of the hybrid Wind-Gas system as a replacement to some traditional generators. Simulating this network on ETAP and generate load flow and analyze results found that the expected value of the balance of power at each bus is the same as actual data at the field but a voltage drop of 0.9 PU is noticed at Bus-2 and Bus-4. The expected values of active and reactive power flows are similar in magnitude to the values obtained from PV and Generators analysis. The deviations that exist are expected and can be avoided by many techniques. This wind turbine generates rated power at 16 ms^{-1} wind speed while the average wind speed at this area is 10 ms^{-1} so this wind farm can only supply 62% of total energy demand during the year and the generation can supply the other 38%.

Wind turbines is 5000 kW with C of 3,000 \$/kW, $V_{o\&m}$ of 0.002 \$/kW, $F_{o\&m}$ of 40 \$kW, F_{cost} of 0,000 \$/kWh and C_f of 0.62. One Gas G - CAT-399 runs as a reference G for the system. The L_{COE} for Wind system of 0.06 \$/kWh, L_{COE} for 1 Gas G 0.5 MW of 0.02 \$/kWh, L_{COE} for 5 backup Gas G 5 MW of 0.018 \$kWh, Total system cost of 54,355,800 Dollars and kWh cost is 0.045 \$/kWh.

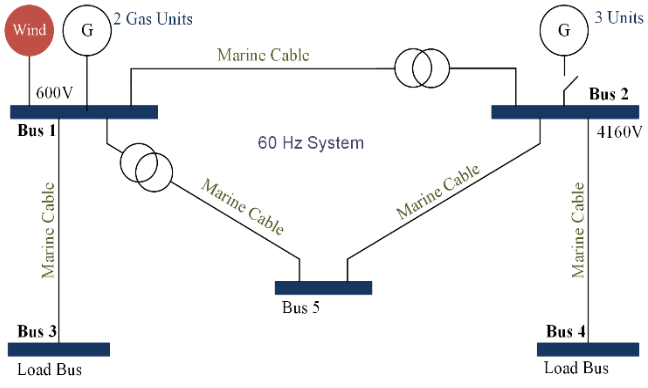

Fig.4. Single line diagram for Wind -Gas system

D. *Modeling and power flow of PV-Wind-Gas system case1*

A simulated model is used as a replacement for fossil fuel-operated generators. The system energy consumption is calculated. Keeping in mind that the Gulf of Suez area is rich in solar and wind energy. The load flow analysis of the hybrid Wind-PV-Gas system is carried out by ETAP to compare the results with the other systems. In this case, the total yearly energy demand of 43,800,000 kWh is achieved from three sources a floating PV system (replaces diesel generators (1.5MW), three wind turbines (each 1 MW) operating with one gas generator 500 kW and two Gas generators (each 1.5 MW) to supply the total loads.

- PV system

The same design method mentioned above to supply a Daily load of 1.5 MW, while PV daily energy output is 36,000 kWh. It is found that:

1. The number of panels: 29,336 panels.
2. The number of inverters: 4 inverters.
3. The number of batteries: 10,398 batteries.
4. The solar charger rating: 3,495 A.

- Wind system

This wind turbine generates rated power at 16 ms^{-1} wind speed while the average wind speed at this area is 10 ms^{-1} so this wind farm can only supply 62% of total loads energy demand during the year and the Gas Generators at Bus-1 can supply other 38% of loads. This system will be installed on Bus-1 to avoid voltage drop at Bus-2 so a reference generator at Bus-1 (Gas G 500 kW) will be running with the system. Table VI shows PV-Gas system cost and Table VII shows Wind-Gas system cost for combined PV-Wind-Gas system case1.

Table VI: PV system cost in PV-Wind-Gas system – Case 1

Item	Cost ($)
PV panels and MPPT	1,050,000$
Inverters	300,000$
Batteries and Charger	3,000,000$
Cables and Accessories	300,000$
Floats and Mooring system	300,000$
Installation	1,050,000$
Fixed Maintenance cost	3,000,000
Variable Maintenance cost	1,500,000$

Table VII: Wind system cost in PV-Wind-Gas system – Case 1

Item	Cost ($)
Wind turbines	3,750,000$
Installation Cost	3,000,000$
Cables and Accessories	900,000$
Fixed Maintenance Cost	3,000,000$
Variable Maintenance Cost	1,500,000$

- Two gas generators (each 1 MW)

The total cost of two Gas generators operating at Bus-2. The L_{COE} for a PV system of 0.104 $/kWh, L_{COE} of Wind system is 0.06 $/kWh, L_{COE} for Gas Generator CAT-399 is 0.02 $kWh, L_{COE} for Gas Generator WUKSAH is 0.018 $/kWh, Total system cost equals 56,764,800 Dollars and kWh cost is 0.051 $/kWh.

E. Modeling and power flow of PV-Wind-Gas system -case 2

The same design method as case-1 but with changing the percent of power-sharing between PV, Wind, and Gas generators. In this case, the daily energy demand of 43,800,000 kWh is satisfied from three sources a floating PV system (replaces diesel generators (0.5MW), two wind turbines (each 1MW), Gas Generators (three gas generator 500kW, two Gas generators (each 1 MW) to supply the total loads and another 1 Mw G as a backup during turbines stop.

while PV's daily energy output is 12,000 kWh/d. It is found that:

1. The number of panels: 9,779 panels.
2. The number of inverters: 2 inverters.
3. The number of batteries: 3,466 batteries.
4. Solar charger rating: 1,165 A.

Table VIII shows PV-Gas system cost and Table IX shows Wind-Gas system cost for combined PV-Wind-Gas system case-2.

Table VIII: PV system cost in PV-Wind-Gas system – Case 1

Item	Cost ($)
PV panels and MPPT	350,000$
Inverters	100,000$
Batteries and Charger	1,000,000$
Cables and Accessories	100,000$
Floats and Mooring system	100,000$
Installation	350,000$
Fixed Maintenance Cost	1,000,000
Variable Maintenance Cost	500,000$

Table IX: KWH Cost of different systems

System	Cost ($kWh^{-1})	Notes
Fossil-Fuel	0.06	Lower than PV
PV-Gas	0.095	highest Cost
Wind-Gas	0.045	Economic
PV-wind-Gas case-1	0.051	Lower than PV & G
PV-Wind-Gas case-2	0.039	Most Economic

- Wind system

The average daily energy output is 28,800 kWh. This wind turbine generates rated power at 16 ms^{-1} wind speed while the average wind speed at this area is 10 ms^{-1} so this wind farm can only supply 62% of total loads energy demand during the year and 1 MW G as a backup during turbines stop. This system will be installed on Bus-1 to avoid voltage drop at Bus-2 and three generators at Bus-1 (Gas G each 500 kW) will be running with the system. Table IX shows PV-Gas system cost and Table X shows Wind-Gas system cost for combined PV-Wind-Gas system case2.

Table X: Wind system cost in PV-Wind-Gas system – Case 2

Item	Cost ($)
Wind turbines	2,500,000$
Installation Cost	2,000,000$
Cables and Accessories	2,620,000$
Fixed Maintenance Cost	600,000$
Variable Maintenance Cost	6,120,000$

- Two gas generators (each 1 MW)

The daily energy output is 48,000 kWh. The total daily energy output from this combination is 124,800 kWh which is sufficient to supply 5 Mw daily loads. The L_{COE} for a PV system of 0.104 $/kWh, L_{COE} for Wind system of 0.06 $/kWh, L_{COE} for Gas Generator CAT-399 of 0.02 $/kWh, L_{COE} for Gas Generator WUKSAH of 0.018 $/kWh, Total system cost of 43,110,000 Dollars and kWh cost is 0.039 $/kWh.

Table X shows the generation output data of the buses of the PV-Gas and Wind-Gas systems. This data is summarized from ETAP load flow. Table XI shows the resulted kWh cost of different systems.

Table XI: Generation output data of PV-Wind-Gas system Cases 1 and 2

Bus number	1	2	3	4	5
Type	G	G	load	Load	load
Voltage (kV)	0.6	4.16	4.16	4.16	4.16
Generated P (kW)	2.98	2.2	0	0	0
Generated Q (kVAR)	1.5	1.0	0	0	0
Demand P (kW)	1	1.63	0.5	0.645	1.05
Demand Q (kVAR)	0.5	0.8	0.28	0.35	0.52

The output of solar energy and wind has strong uncertainty due to discontinuous availability of solar and wind energy but from the energy management point of view:-

1. The fossil fuel system has one diesel G and one g generator as standby during maintenance or any sudden failures.
2. PV-Gas system has battery storage that covers no sun-times.
3. Wind-Gas system has 5 MW of Gas generators as a backup during turbine stops.
4. PV-Wind-Gas case-1 with PV system has battery storage and Wind system has three gas generators each 500 kW as a backup
5. PV-Wind-Gas system case- 2 with PV system has battery storage and wind system has a 1 MW backup generator during turbine stops.

Gas generators can cover a backup for wind systems during no speed or cut-out speed (this cost is added) and the battery storage for no sun-times. In case-2 the battery storage as an energy buffer keeps the system stable during no sun. In no wind and high wind speed situations Gas generators can cover a backup. In the most economic, reliable, and high power quality Case-2, the diesel oil consumption is eliminated which means more money-saving and good environmental concern, the gas flared is utilized in the gas generator as an optimization to waste energy in the gas flare, reduced kWh cost, combine the advantages of floating PV and offshore wind as RE sources and improve system stability using energy storage and backup generator which guarantee power security. Table XII indicates the load flow analysis of the different systems using ETAP software, active and reactive power flow between buses where PF11 means power flow from a generation at Bus-1 to loads at Bus-1.

IV. RESULTS AND DISCUSSION

A. *Economic issues*

New PV and wind projects account for annual investments of billion dollars over the year. This can provide many economic benefits to reduce fuel cost, maintenance cost, reduce electricity bills, and can make some profits. According to the cost calculation in Table: XII, The PV-Wind-Gas system is more economic. It can save more money.

B. *Environmental issues*

As the solar system is installed on the seawater, the concern due to environmental impact is to be examined. The present floating solar power is similar to a ship. Therefore, environmental concern is minimal. Anchors are used to fixing solar panels and floating units. The fixing of the anchor is similar to a ship or boat. No disturbance or alternation is installed on the seabed. The power distribution cable floats on water in some places. However, because of compromise with the boat traveler, a section of the cable dips into the water to allow the boat to travel through. The cable after reaches the end, is installed the same way as the normal power distribution on lands. There is no particular concern. The battery storage, as an energy buffer, is also one of the key components of the development. There is a concern about the battery when they are near the end of life. The disposal of used batteries is a concern. It can be recycled to develop a new recyclable battery that will not impose the loading of waste batteries [20-25].

The major environmental concerns related to offshore wind developments are increased noise levels, risk of collisions, changes to benthic and pelagic habitats, alterations to food webs, and pollution from increased vessel traffic or release of contaminants from seabed sediments [26]. On the other hand, these offshore systems can provide many environmental benefits like prevention of water evaporation, prevent usage of valuable land, and increased output power and system efficiency. The Hybrid PV-Wind-Gas combines the advantages of the two renewable systems.

V. CONCLUSIONS

The proposed system is to develop offshore solar and wind turbine systems which are installed in sea conditions. The PV panels are supported by floating units. The wind turbines are fixed on a concert base installed on the seabed. A simplified model is simulated as a replacement to the traditional generating units supplying offshore oil field production facilities with these renewable energy sources (floating PV and Offshore wind turbines). The load flow analysis is carried out and the cost is calculated in all systems to find the most suitable answer to this energy problem and environmental concern.

The generator system cost is high due to high fuel (Diesel oil) consumption, bad environmental effects, and noise. The PV-Gas system cost the highest due to the energy storage device's high initial and replacement cost but it still promising according to Area and environmental benefits. The wind-Gas system cost is lower than fossil fuel system cost and promising according to Area and environmental benefits as the wind energy density is higher than solar energy so it is more economic than PV-Gas system and fossil fuel operated system. This replacement will save about 10 millions $ over 25 yrs lifetime.

The PV-Wind-Gas system in case-1 is considered economic and will save about 8 Million $ for 25 yr lifetime lower than the fossil-fuel system besides its environmental benefits. The PV-Wind-Gas system in case-2 is the most economic and will save about 21 Millions $ for 25 yr lifetime lower than a fossil-fuel system besides its environmental benefits also energy storage increase stability in this case and case 1. The gas generators will secure a backup power supply during wind turbine stops.

The PV-Wind-Gas system combines the advantages of floating PV and Offshore wind. It is a suitable answer for this energy problem, economic according to Table XI, the diesel oil consumption is eliminated which means more money-saving and good environmental concern, the gas flared is utilized in the gas generator as an optimization to waste energy in gas flare and low environmental impact.

This system is to be built in the New Territories of Egypt and is believed to be one of the first floating solar power systems and offshore Wind systems on the sea in this region. It is a good start for more applying new RE concepts like floating concentrated solar thermal and tidal power.

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Table XII: Different systems load flow summary

Power Flow	**S (MVAR) Generator**	**S (MVAR) PV-Gas**	**S (MVAR) Wind-Gas**	**S (MVAR) PV-Wind-Gas (case1)**	**S (MVAR) PV-Wind-Gas (case2)**
PF11	1.000 + j0.500	1.000 + j0.490	1.000 + j0.490	1.000 + j0.500	1.000 + j0.500
PF12	0.000 + j0.00	1.600 + j0.67	1.600 + j0.670	0.000 + j0.000	0.000 + j0.000
PF13	0.645 + j0.350	0.700 + j0.350	0.700 + j0.350	0.645 + j0.350	0.645 + j0.350
PF14	0.000 + j0.000	0.480 + j0.210	0.480 + j0.210	0.000 + j0.000	0.000 + j0.000
PF15	1.050 + j0.520	1.100 + j0.650	1.100 + j0.650	1.050 + j0.520	1.050 + j0.520
PF22	1.630 + j0.800	0.000 + j0.000	0.000 + j0.000	1.630 + j0.800	1.630 + j0.800
PF24	0.500 + j0.280	0.000 + j0.000	0.000 + j0.000	0.500 + j0.280	0.500 + j0.280

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