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PV, Wind and Fuel Cell Hybrid Optimization Generation for AL-Arish Site.

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***Abstract*—Thispaper, a site-matching technique to generate electricity by a hybrid system using renewable resources on the site, especially wind energy and solar energy is applied.**

The monthly averaged wind speed at 50 m. above the surface of the earth for 10 years and monthly averaged insolation incident on a horizontal surface for 22 years is collected [1].

A new matching technique is used to select the optimum wind turbine for AL-Arish wind energy capability, similarly the optimum PV panel is selected based on capacity factor technique to match the site.

HOMER Software (Hybrid Optimization Model for Electric Renewable) [2] was employed like tool of sizing and optimization. This software contains a certain component count of energy and evaluates the suitable options while being based upon the cost and the availability of the energy resources.

A combination of wind turbine and PV module along with fuel cell which is a completely renewable and un-pollutant source was introduced to the program to select the optimum combination.

***Keywords*—Site-Matching, Wind, TSI, PV, Capacity Factor, Fuel Cell, Optimization.**

I. INTRODUCTION

Generation of electric energy at a specific site using renewable energies depends upon many factors, including: mean wind speed, speed characteristics of wind turbine, hub height for wind generators and short circuit current, open circuit voltage, current and voltage for PV maximum power generation.

A matching technique called turbine selection index (TSI) is used, According to this concept, there is a unique TSI curve for every site fromwhich speed parameters of aturbine that will optimally match a site can be obtained[3,5,6].

For the photovoltaic panels, a probabilistic approach is used to calculate the capacity factor for various panels to select the optimum panels for the site which have the maximum capacity factor [8].

II. OPTIMUM WIND TURBINE MODEL

The average electrical power output of a wind turbine generator system is [4]

$$Pe,av=\int P_e * f(v)dv \qquad (1)$$

Where f (v) is a probability density function of wind speed

$$P_{e,av} = \int_{VC}^{Vr}(a+bv^k)f(v)dv + \int_{Vr}^{Vf} P_{er} * f(v)dv \qquad (2)$$

$$P_{e,av} = Per\left(\frac{e^{-Vc^k} - e^{-Vr^k}}{Vc^k - Vr^k} - e^{-Vf^k}\right) \qquad (3)$$

Normalizing the $P_{e,av}$ equation we get:

$$PN= \frac{Pe,av}{0.5\eta\rho AC3} = \left(\frac{Vr}{C}\right) * CF \qquad (4)$$

$$C.F= \left(\frac{e^{-(Vc/C)^k} - e^{-(\frac{Vr}{C})^k}}{(Vc/C)^k - (\frac{Vr}{C})^k} - e^{-Vf^k}\right) \qquad (5)$$

$$TPI=\frac{PN*C.F}{PN,Max*C.FMax} \qquad (6)$$

For AL-Arish Weibull parameter C= 4.56, Weibull parameter K=2.39 [2] and the monthly averaged wind speed at 50 m. above theSurface of the earth [1] are represented in Table I.

Table I
Monthly Average Wind Speed at Al-Arish At 50m

Month	Jan	Feb	Mar	April	May	Jun
Speed	5.6	5.8	5.8	5.3	5.1	5.2
Jul	Aug	Sep	Oct	Nov	Dec	Ann.
5.2	5.1	5.0	5.0	4.7	5.4	

Fig. 1 shows that the best operating point lies between the point of maximum normalized power, which is 0.87 and the point of maximum capacity factor, which is 2.1.

To reach this point the product of the previous two curves (normalized power and capacity factor) using turbine selection index technique (TSI) [5-6]

Fig. 2 shows TSI curve, which lead to the optimum operating point corresponds to normalized rated speed = 1.3.

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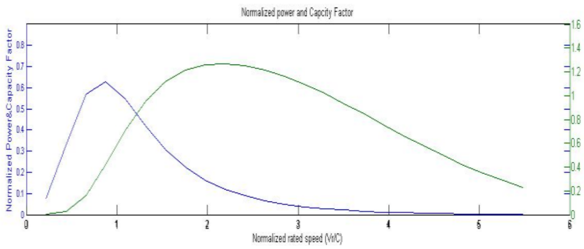

Fig. 1 .Normalized Power and Capacity Factor Curves

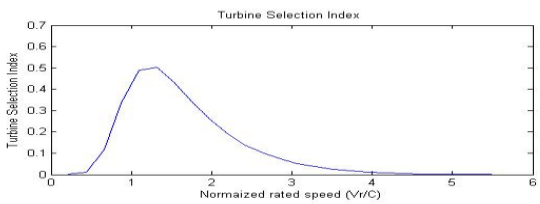

Fig. 2. Turbine Selection Index Curve For AL-Arish

Therefore, to that the optimum turbine mode parameters for AL-Arish:

a) Cut –in speed=1.6m/s.
b) Rated –speed =6m/s.
c) Cut-out speed= 10.3 m/s.
d) Rated power= 8.3 KW.
e) Average power=3.5 KW.
f) Capacity factor= 0.42.
g) Output energy= 30.7 MW.hr.

A number of turbines in Homer's library were tested using previous technique, and the turbine with the highest TSI was BWC Excel-R wind turbine [7].

III. Optimum Photo-Voltaic (PV) Model

The optimum photovoltaic module is selected according to the capacity factor, due to the stochastic nature of the solar radiation the capacity factor is calculated through three steps [8].

1. Calculation of irradiance probability density function.
2. Calculation of PV average output power.
3. Calculation of capacity factor.

The monthly averaged insolation data shown in Table II are fitted using Matlab code by three probability density functions (PDF): Lognormal, Beta and Weibull.

Table II
Monthly Averaged Insolation Incident on Horizontal Surface (Kwh/M2/Day)

Month	Jan	Feb	Mar	April	May	Jun
Insolation Level	3.2	4	5.4	6.6	7.6	8.2
Jul	Aug	Sep	Oct	Nov	Dec	Ann.
7.8	7.3	6.3	4.9	3.6	5.9	

Then the three PDF is tested using Kolmogorov-Smimov goodness of fit (KS), identifying that Lognormal and Weibull make a good fit for the insolation data; Weibull distribution was selected to represent the PDF of the insolation level as shown in Fig. 3.

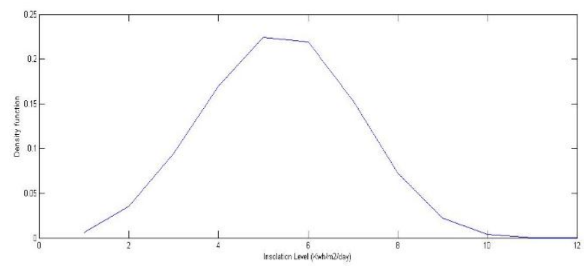

Fig. 3. PDF of the Insolation Level

After that the average power of the modules is calculated where the output power of the module is given by:

$$P(S) = V(S) * I(S) \qquad (7)$$

Where S is the insolation level
The average power is given by

$$Pa = \int P(S) * f(S).dS \quad (8)$$

Finally the capacity factor of the modules is calculated where the capacity factor is the ratio between the average power and the rated power

$$CF = \frac{1}{Pr} \int P(S) * f(S) . dS \qquad (9)$$

The capacity factor for various photovoltaic modules was calculated to select the module with maximum in table (III)

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Table III
Capacity Factor for Various PV Panels

Module	C.F	Module	C.F
Helioss 6T	0.42	KD140SX-UFBS	0.421
CHSM 6610P-250	0.435	Mono X LG250S1C-G2	0.435
EP125M/72-190	0.406	SW 130 poly R6A	0.31
ET-P660245B	0.417	SW-S85P	0.403
Sanyo HIT-N225A01	0.396	Trina 230, TSM-PAO5	0.419
Sharp ND-240QCJ	0.421		

Two module has the highest capacity factor (CHSM 6610P-250 & Mono X LG250S1C-G2) equal 0.435.

For Max. Power from PV panels the solar angle should be as follows [9]:

1- In winter angle= 36.
2- In spring/autumn = 59.
3- In summer= 82.

IV. Simulation Using Homer Software

After the pre-feasibility studies the selection of proper sizing of equipment is mainly based upon the weather data and maximum capacity of components.

The unit sizing of the hybrid system plays an important role in both the reliability and economy of the system [10]

The hybrid system after the pre-feasibility study consists of the following components as shown in Figure (4):

1. BWC Excel-R wind turbine.
2. CHSM 6610P-250 photovoltaic panel.
3. Converter.
4. Electrolyzer.
5. Fuel Cell.
6. Hydrogen Tank.
7. Load.

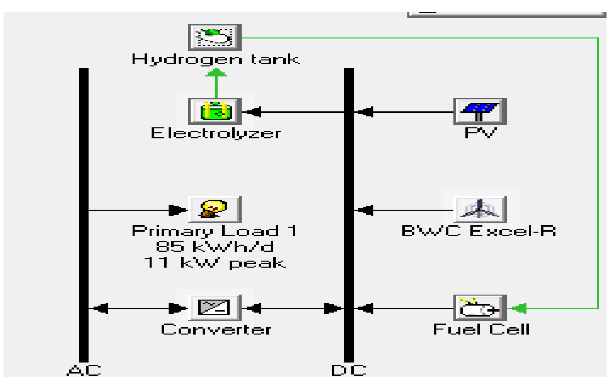

Fig.4. PV, Wind and Fuel Cell Hybrid Generation.

A. *Wind Turbine*

In this simulation, Bergey Wind Power's BWC Excel-R model is considered. It has a rated capacity of 7.5 kW and provides 48 V dc as output. Its initial cost is $28500 and its replacement at $24500 [7]. Annual operation and maintenance cost is $200. Its life time is estimated at 20 years.

B. *Photovoltaic Cell*

CHSM 6610P-250 photovoltaic panels are considered in the scheme, with initial and replacement cost $265, with rated power 25watt, its life time is estimated at 20 years [11].

Cost may be reduced to $250 based on recent of PV modules' price [12].

C. *Converter*

For a one kW converter, the installation and annual maintenance costs are taken as $1000 and $10.

D. *Electrolyzer*

In this method, electricity is used to split water into hydrogen and oxygen [13] with initial and replacement cost $2000 and $1800 respectively, for 1KW size and operation and annual maintenance cost $30.

E. *Fuel Cell*

Hydrogen as an energy carrier must be stored to overcome daily and seasonal discrepancies between energy source availability and demand. Hydrogen storage has an economic advantage over lead- acid batteries for long-term storage [14], with initial and replacement cost $1300 and $1200 respectively, for 1Kg size and operation and annual maintenance cost $10.

F. *Hydrogen storage*

Hydrogen as an energy carrier must be stored to overcome daily and seasonal discrepancies between energy source availability and demand. Hydrogen storage has an economic advantage over lead- acid batteries for long-term storage [15], with initial and replacement cost $1300 and $1200 respectively, for 1Kg size and operation and annual maintenance cost $10.

G. *Load Data*

The annual peak load is 11 KW with energy consumption of 85 KWh/day, and the daily profile of the load is shown in Fig.5.

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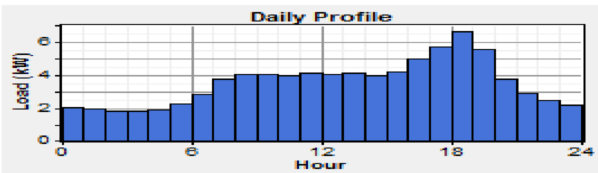

Fig.5. Daily Load Profile

V. CONCLUSION

Simulating the operation of the PV-wind-fuel cell system in AL-Arish using Homer's software and the results are shown in Table IV.

Table IV
Optimization Result for Al-Arish.

				PV (kW)	XLR	FC (kW)	Conv. (kW)	Elec. (kW)	H2 Tank (kg)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	FC (hrs)
				40.00	2	6	10	10	10	$ 158,000	6,675	$ 243,332	0.619	1.00	0.02	3,922

The system architecture is as follows: 40 KW PV, 2 BWC wind turbine, 6 KW Fuel cell, 10 KW Converter (Inverter & Rectifier), 10 KW Electrolyzer and 10 Kg hydrogen tank.

The system initial cost is $158,000, operating cost is $6,675 per year and Cost of energy is $0.619/Kwh.

In addition, the renewable fraction is 1 as the electrical energy is produced from renewable- non pollutant sources.

Furthermore, the fuel cell operates 3,922 hours per year.

Where the electrical production of the system is shown in Fig.6 and the capacity shortage is 2 %.

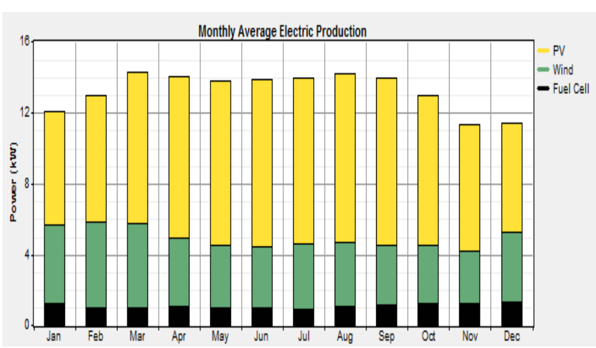

Fig.6. Monthly Average Electric Production.

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