A Novel Method of Optimization and Matching Generation of Photovoltaic Modules and Wind Turbines Models using Matlab

Abdelrahman Atallah Z. Saleh, Loai S. Nasrat, Barakat M. Hasaneen, Ibrahim A.I Nassar

ABSTRACT—This paper presents the site matching with given data about the percentage of availability of renewable energy resources in the selected site to choose the optimum and the best suitable wind turbines and photovoltaic modules for this site in Egypt using different techniques such as capacity factor (CF) and turbine selection index (TSI), programs used (Matlab). The selected site is "Qena Al-Gadida" City, New Urban Communities Authority, Egypt.

Index Terms— Matlab, Simulations, Models, Generation, Matching, Wind, Turbines, Photovoltaic, Modules, TSI, Capacity factor, Method, Site, City.

1. INTRODUCTION

THE New Cities of Egypt represent a major effort to redistribute investment and population away from Cairo and the Delta in a brave attempt to use desert land, the biggest challenge is the provision of electricity and water facilities for new cities. With the growing energy demand and environmental awareness, wind power is being regarded as one of most important alternative energy resources [5,17], The beneficial characteristics of wind power include clean and inexhaustible fuel, local economic development, modular and scalable technology, energy price stability, and reduced reliance on imported fuels [3]. Photovoltaic (PV) generation involves the direct conversion of sunlight into electrical energy. In recent years it has proved to be a cost-effective method for generating electricity with minimum environmental impact. Due to the environmental and economic benefits PV generation is now being deployed worldwide as an embedded renewable energy source and extensive research is being performed about this [11]. The selected site is "Qena Al-Gadida" City, New Urban Communities Authority, Egypt.

- *Abdelrahman Atallah Z. Saleh, Department of Electrical Power and Machine, Faculty of Engineering, Alazhar University- Qena Al-Gadida City, New Urban Communities Authority- Qena, Egypt- abdelrahmanatallah2012@gmail.com*
- *Loai S. Nasrat, Department of Electrical Power and Machine, Faculty of Engineering, Aswan University- Aswan, Egypt.*
- *Barakat M. Hasaneen, Department of Electrical Power and Machine, Faculty of Engineering, Alazhar University- Cairo, Egypt.*
- *Ibrahim A.I Nassar, Department of Electrical Power and Machine, Faculty of Engineering, Alazhar University- Cairo, Egypt.*

2. OPTIMIZATION OF WIND TURBINES

Matching site data with wind turbine generator is an important problem. If the generator rated speed is chosen to be low, the site loses too much of the energy in the higher wind speed intervals. If the generator rated speed is too high, the turbine will seldom operate at low capacity and the capital cost will be high. So this paper introduces a novel method of matching the wind turbine generators to a specific site data using normalized powers and capacity factor curves termed the Turbine Selection Index. The new matching technique identifies optimum turbine speed parameters, such as rated speed, cut-in speed, cut-out speed, and rated power to maximize the energy production [3,5,6,9]. The new technique was applied on the selected city in Egypt "Qena Al-Gadida" to evaluate the validity of the method using MATLAB program.

Equations of Simulations of Wind turbines [4, 8]

$$p_{e,av} = \int_0^\infty p_e \, f(v)dv \qquad (1)$$

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

$$f(v) = \frac{k}{c} \cdot \left(\frac{v}{c}\right)^{k-1} \cdot \exp\left(-\left(\frac{v}{c}\right)^k\right) \qquad (2)$$

Using the model of p_e,

$$p_{e,av} = \int_{v_c}^{v_r} (a + bv^k)\, f(v)dv + \int_{v_r}^{v_f} p_{er} f(v)dv \qquad (3)$$

$$p_{e,av} = p_{er} \left\{ \frac{e^{-v_c^k} - e^{-v_r^k}}{v_r^k - v_c^k} - e^{-v_f^k} \right\} \qquad (4)$$

$$p_{e,av} = 0.5\, \eta_o\, \rho\, A\, v_r^3 \left\{ \frac{e^{-v_c^k} - e^{-v_r^k}}{v_r^k - v_c^k} - e^{-v_f^k} \right\} \qquad (5)$$

Normalizing the $p_{e,av}$ equation we will get:-

$$p_n = \frac{p_{e,av}}{0.5\,\eta_o\,\rho\,A\,c^3} = \left(\frac{v_r}{c}\right)^3 * CF \quad (6)$$

$$CF = \left\{\frac{e^{-\left(\frac{v_c}{c}\right)^k} - e^{-\left(\frac{v_r}{c}\right)^k}}{\left(\frac{v_r}{c}\right)^k - \left(\frac{v_c}{c}\right)^k} - e^{-\left(\frac{v_f}{c}\right)^k}\right\} \quad (7)$$

$$v_r = \text{normalized speed} * c \quad (8)$$

$$v_{cut-in} = \delta v_r \quad (9)$$

$$v_{cut-out} = \gamma v_r \quad (10)$$

$$p_{e,av} = p_{er} * CF \quad (11)$$

$$\text{Energy} = p_{e,av}(\text{time}) \quad (12)$$

$$TSI = \frac{p_n * CF}{p_{n,max} * CF_{max}} \quad (13)$$

3. RESULTS AND DISCUSSION OF WIND TURBINES

Table (1) represents the monthly averaged wind speed of Qena Al-Gadida city [1] and table (2) represents the weibull parameters [2]. Fig. (1) Shows Normalized power (Pn) and Capacity factor (CF) curves of Qena Al-Gadida where Pn(max) = 1.415 at normalized speed= 2.443 and CF(max)= 0.5893 at normalized speed= 0.733. Fig.(2) shows the Turbine Selection Index (TSI) curve where TSImax= 0.4928 at normalized speed= 1.222.Table (3) represents the simulation results of wind turbine parameters for Qena Al-Gadida .Fig. (3) Shows the Energy curve.

TABLE(1): MONTHLY AVERAGED WIND SPEED (M/S) OF QENA AL-GADIDA

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Wind Speed (m/s)	4.47	4.50	5.05	5.17	5.19	5.58	5.19	5.08	5.08	4.97	4.36	4.36	4.91

TABLE(2): WEIBULL PARAMETERS OF QENA AL-GADIDA

City	Weibull parameter (c)	Weibull parameter (k)
Qena Al-Gadida	4.0925	2.23

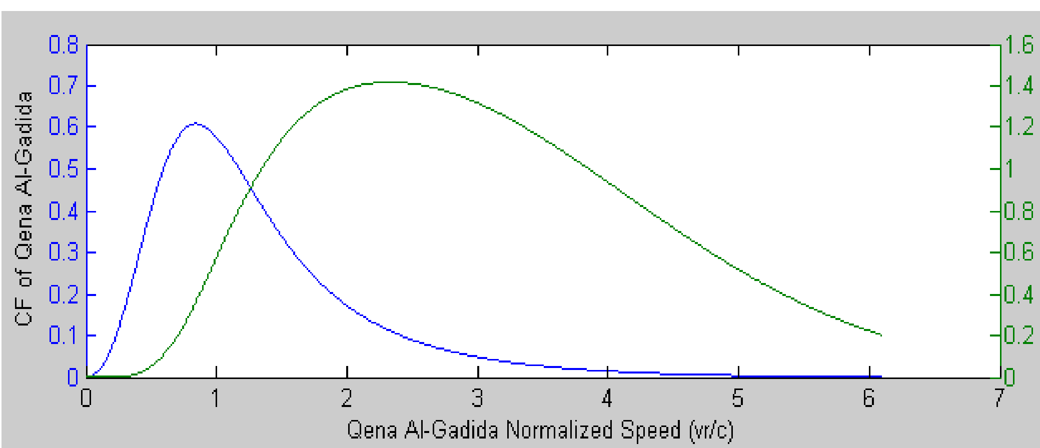

Fig. (1) Normalized power (Pn) and Capacity factor (CF) curves of Qena Al-Gadida

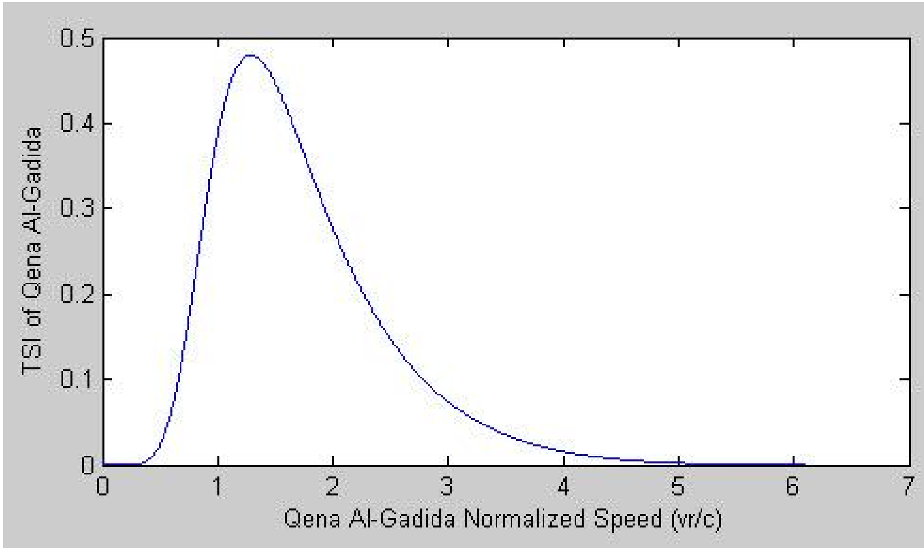

Fig. (2) Turbine Selection Index (TSI) curve of Qena Al-Gadida

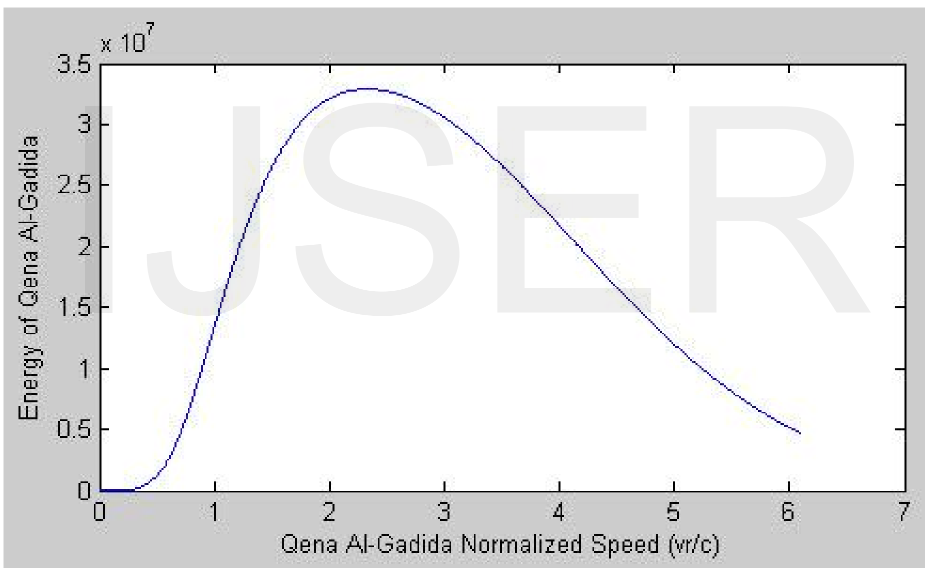

Fig. (3) Energy curve of Qena Al-Gadida

TABLE(3): THE SIMULATION RESULTS OF WIND TURBINE PARAMETERS FOR QENA AL-GADIDA

Normalized speed	Cut in speed m/s	Rated speed m/s	Cut out speed m/s	Rated power KW	Average power KW	Capacity factor	Normalized power	Output energy MW.hr
1.222	1.35	5.00	8.60	4.80	2.26	0.47	0.8657	19.80

A number of wind turbines were tested using previous technique as shown in table (4) and the turbine with the highest TSI was BWC Excel-R wind turbine [7,17].

TABLE (4): TURBINE SELECTION INDEX (TSI) FOR VARIOUS WIND TURBINES OF QENA AL-GADIDA

Turbine	Rated speed(m/s)	Cut-in speed (m/s)	Cut-out speed (m/s)	Rated Power	Capacity Factor	Normaized Average Power	TSI
BWC Excel-R	13	2	25	7.5	0.072	1.667	0.1526
BWC Excel-S	16	3	25	10	0.035	1.52	0.0632
BWC XL.1	13	4	22	1	0.0419	0.97	0.0385
Encron E33	13	3	26	330	0.0584	1.35	0.0881
Entegrity EW-15	16	5	25	50	0.0153	0.65	0.0084
Fuhrlinder 100	14	3	25	100	0.0487	1.4	0.0782
Fuhrlinder 250	21	3	25	250	0.0182	1.77	0.0416
Fuhrlinder 30	16	3	23	30	0.0351	1.51	0.0632
GE 1.5sl	12	4	25	1500	0.0514	0.93	0.0446
Northern power NW 100/19	13	4	25	100	0.0419	0.97	0.0385
PGE 11/35	15	4	25	35	0.0292	1.0394	0.0300
PGE 20/25	12	4	25	25	0.0514	0.93	0.0446
SW AIR X	11	4	18	0.4	0.0644	0.903	0.0528
SW Sky stream 3.7	11.5	3.5	25	1.8	0.0684	1.097	0.0749
SW Whisper 100	14.5	3.5	24	0.9	0.0383	1.231	0.0503
SW Whisper 200	13	3.5	24	1	0.0502	1.164	0.0604
SW Whisper 500	12.5	3.5	24	3	0.0554	1.142	0.0646
Vestas V82	13	4	25	1650	0.041	0.97	0.0385
WES 18	16	4	20	80	0.025	1.07	0.0269
WES 30	15	4	20	250	0.029	1.04	0.0300
WES 5 Tulipo	11	3	20	2.5	0.0883	1.239	0.1166

The BWC Excel-R turbine is rated at 7.5 KW at 13 m/s. The area is 38.465 m2. To compute the rated overall efficiency at the rating and standard conditions [8]:

At standard conditions, $\frac{\rho}{2} = 0.647$ (14)

$$\eta o = \frac{[\text{Rated power}]}{[\text{wind rated power}]} = \frac{7.5}{\frac{\rho}{2} * A * v_r^3} = \frac{7.5}{0.647 * 38.465 * 13^3 * 10^{-3}} = \frac{7.5}{54.67642044} = 0.137170648 \quad (15)$$

Excel program was used to calculate these equations for each turbine and to calculate the average values of "rotor diameter" and "efficiency" of all wind turbines as shown in table (5) to be used in Eqn (5). Also δ and γ for each turbine and the average values of them were calculated as shown in table (6) to be used in Eqn (9), (10).

TABLE (5): CALCULATION OF THE AVERAGE OF "ROTOR DIAMETER" AND "EFFICIENCY" OF WIND TURBINES OF QENA AL-GADIDA

Turbine	Rotor diameter(M)	Sweept area (M2)	Rated speed(m/s)	Rated Power(KW)	Wind Rated Power(KW)	Efficiency ηo
BWC Excel-R	7	38.465	13	7.5	54.67642044	0.137170648
BWC Excel-S	23	415.265	16	10	1100.49876	0.009086789
BWC XL.1	2.5	4.90625	13	1	6.974033219	0.14338905
Encron E33	33.4	875.7146	13	330	1244.7924	0.265104446
Entegrity EW-15	15	176.625	16	50	468.076032	0.106820253
Fuhrlinder 100	21	346.185	14	100	614.6057711	0.162705924
Fuhrlinder 250	29.5	683.14625	21	250	4093.321472	0.061075096
Fuhrlinder 30	13	132.665	16	30	351.5771085	0.085329788

GE 1.5sl	77	4654.265	12	1500	5203.542738	0.288265145
Northern power NW 100/19	19	283.385	13	100	402.8201587	0.248249741
PGE 11/35	11	94.985	15	35	207.4116206	0.168746572
PGE 20/25	20	314	12	25	351.057024	0.071213502
SW AIR X	1.15	1.0381625	11	0.4	0.894020904	0.447416831
SW Sky stream 3.7	3.7	10.74665	11.5	1.8	10.57476942	0.170216477
SW Whisper 100	2.1	3.46185	14.5	0.9	6.828361949	0.131803206
SW Whisper 200	2.7	5.72265	13	1	8.134512346	0.122932999
SW Whisper 500	4.5	15.89625	12.5	3	20.08764404	0.149345538
Vestas V82	82	5278.34	13	1650	7502.943898	0.21991368
WES 18	18	254.34	16	80	674.0294861	0.11868917
WES 30	30	706.5	15	250	1542.731063	0.16205028
WES 5 Tulipo	5	19.625	11	2.5	16.90020613	0.14792719
Average	20.02619048					0.162735825

Table (6): Calculation of δ and γ of wind turbines of Qena Al-Gadida

Turbine	Rated speed(m/s)	Cut-in speed (m/s)	Cut-out speed (m/s)	δ	γ
BWC Excel-R	13	2	25	0.153846154	1.923076923
BWC Excel-S	16	3	25	0.1875	1.5625
BWC XL.1	13	4	22	0.307692308	1.692307692
Encron E33	13	3	26	0.230769231	2
Entegrity EW-15	16	5	25	0.3125	1.5625
Fuhrlinder 100	14	3	25	0.214285714	1.785714286
Fuhrlinder 250	21	3	25	0.142857143	1.19047619
Fuhrlinder 30	16	3	23	0.1875	1.4375
GE 1.5sl	12	4	25	0.333333333	2.083333333
Northern power NW 100/19	13	4	25	0.307692308	1.923076923
PGE 11/35	15	4	25	0.266666667	1.666666667
PGE 20/25	12	4	25	0.333333333	2.083333333
SW AIR X	11	4	18	0.363636364	1.636363636
SW Sky stream 3.7	11.5	3.5	25	0.304347826	2.173913043
SW Whisper 100	14.5	3.5	24	0.24137931	1.655172414
SW Whisper 200	13	3.5	24	0.269230769	1.846153846
SW Whisper 500	12.5	3.5	24	0.28	1.92
Vestas V82	13	4	25	0.307692308	1.923076923
WES 18	16	4	20	0.25	1.25
WES 30	15	4	20	0.266666667	1.333333333
WES 5 Tulipo	11	3	20	0.272727273	1.818181818
Average				0.263507462	1.736508589

4. OPTIMIZATION OF PHOTOVOLTAIC MODULES

A methodology for the selection of the optimum photovoltaic module for a specific site is developed. The selection is based on the capacity factors (CF) of the available PV modules. The PV module with the highest capacity factor is the optimal and recommended PV module for the selected site, this is through three steps [10, 12, 14].

4.1. Fitting the irradiance data

To fit the irradiance data, three probability density functions were chosen: Beta, Weibull and Log-Normal. The three PDFs will be tested using Kolmogorov-Smimov tests goodness of fit (KS test) for the best fit.

4.2. Calculation the Average Output Power

The output power of the module is a product of the output voltage and the output current.

$$p(s) = v(s).i(s) \quad (16)$$

S – Value of insolation.

The average power output from a PV module is the power produced at each insolation level multiplied by the probability of the insolation experienced and integrated over all possible insolation spectrum. In the integral form, the equation is:

$$pa = \int p(s).f(s).ds \quad (17)$$

The function f(s) is the probability density function chosen.

4.3. Calculation the capacity Factors

Capacity factor can be defined as the ratio between average power output given by (17) and rated power of the considered module Pr:

$$cf = \frac{1}{pr}\int p(s).f(S).ds \quad (18)$$

5. RESULTS AND DISCUSSION OF PHOTOVOLTAIC MODULES

KS test identified that Lognormal and Weibull make a good fit for the insolation data, Weibull distribution was selected to represent the PDF of the insolation data. Table.(7) represents Monthly Averaged Insolation data (kWh/m2/day) of Qena Al-Gadida [1]. Fig. (4) shows Probability density Function (PDF) of the insolation data of Qena Al-Gadida.

TABLE (7): MONTHLY AVERAGED INSOLATION DATA (KWH/M2/DAY) OF QENA AL-GADIDA

Month	Insolation kwh/m2/day	PDF
Jan	3.87	0.1027
Feb	4.83	0.1905
Mar	5.96	0.2631
Apr	6.87	0.2338
May	7.20	0.2025
Jun	8.02	0.1068
Jul	7.75	0.1383
Aug	7.31	0.1904
Sep	6.34	0.2623
Oct	5.07	0.2119
Nov	3.98	0.112
Dec	3.47	0.0725
Annual average	5.89	0.2615

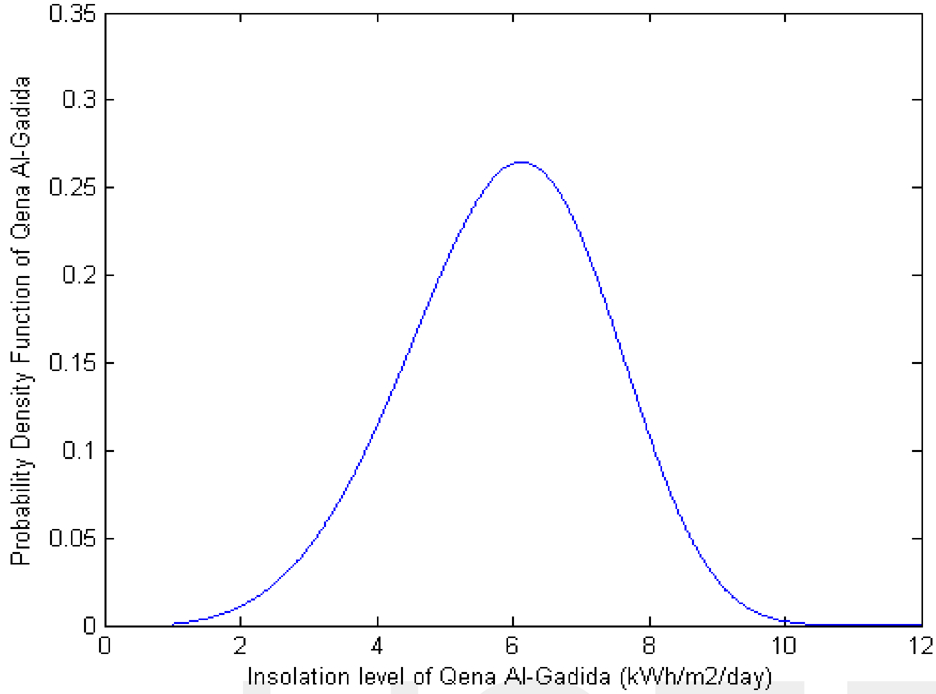

Fig. (4) PDF of the insolation data of Qena Al-Gadida

The capacity factors of various modules were calculated using Matlab Program for Qena Al-Gadida as shown in table (8). KD140SX- UFBS module was chosen that has the highest value of capacity factor [15, 16].

I-V and P-V characteristics of the pv module " KD140SX-UFBS" simulated using Matlab and represented in fig.5 and fig.6. The increasing of irradiation leads to the increasing of the open circuit voltage logarithmically and the increasing of the short circuit current linearly [11, 13].

TABLE (8): CAPACITY FACTORS OF VARIOUS PV MODULES FOR QENA AL-GADIDA

Number	Module	Rated Power	Voc	Isc	Vmp	Imp	Capital Cost ($)	CF
1	Helioss 6T	250	37.40	8.72	30.30	8.22	333	0.7072
2	CHSM 6610P-250	250	38.19	8.65	30.30	8.27	265	0.7159
3	EP125M / 72-190	190	44.83	5.749	36.11	5.325	233	0.7006
4	ETP660245B	245	37.27V	8.73A	30.14	8.13	258	0.7061
5	Sanyo HITN225A01	225	53	5.66	43.4	5.21	690	0.6910

6	KD140SX-UFBS	140	22.1	8.68	17.7	7.91	300	0.7170
7	Mono X LG250S1CG2	250	37.1	8.76	29.9	8.37	410	0.7155
8	Sharp ND-240QCJ	240	37.5	8.75	29.3	8.19	330	0.7084
9	SW 130 poly R6A	130	21.5	6.36	17.4	5.74	277	0.5395
10	SW-S85P	85	22	5.4	17.4	4.9	340	0.7013
11	Trina 230, TSM-PAO5	230	37	8.25	29.8	7.72	360	0.7066

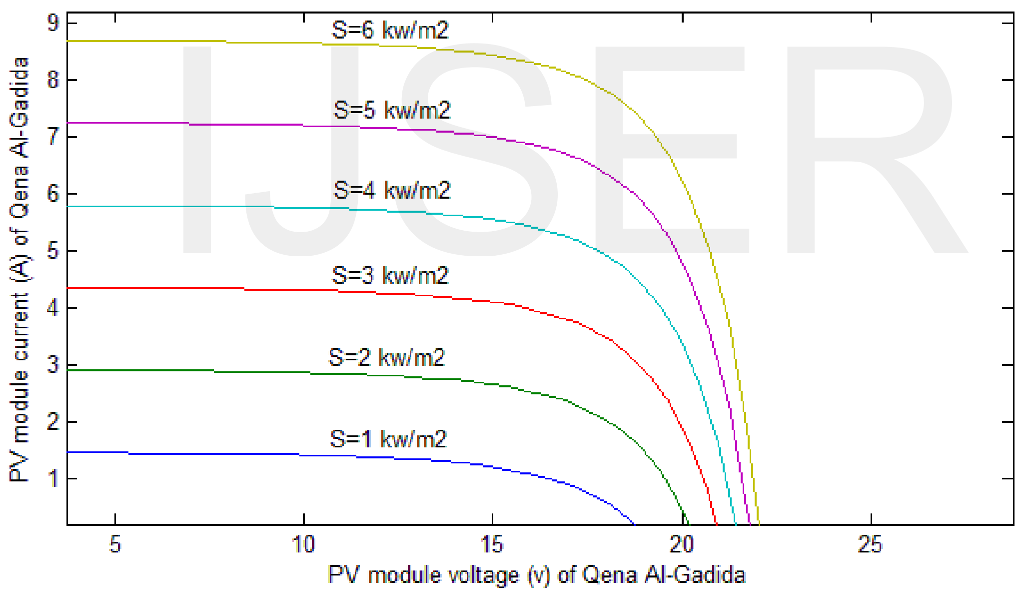

Fig.(5) I-V characteristics of Qena Al-Gadida module "KD140SX- UFBS" with various irradiances

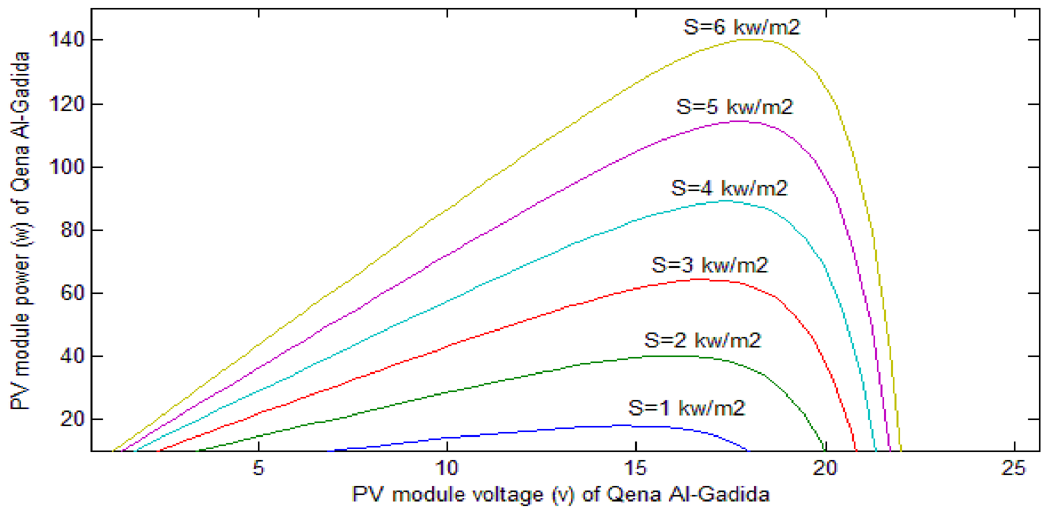

Fig.(6) P-V characteristics of Qena Al-Gadida module "KD140SX- UFBS" with various irradiances

6. CONCLUSION

The selection of proper and optimal system components is mainly based on the weather data and maximum capacity of components. This paper has presented a novel method of matching to generate electricity using renewable energy resources on the site, especially the wind energy and the solar energy. The new matching technique has used to select the optimum wind turbine for Qena Al-Gadida, the turbine with the highest TSI was BWC Excel-R wind turbine. Similarly, the optimum PV module is selected based on the capacity factor technique to match the site, the module that has the highest capacity factor was KD140SX- UFBS photovoltaic module.

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