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Optimizing the Combinations of Sites, Turbine Types and Cells Types of a Hybrid Power System for Remote Sites in Jordan

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Abstract: Based on the fact that many remote and isolated sites in Jordan are located far away from the national electric grid and cannot be connected to it in the near future or conventional generation is not practical to be built and keeping in mind that some of these sites enjoy highest yearly averages of both wind speed and solar radiation, the hybrid power system is considered as the practical solution for electrification these sites. The given study presents a preliminary analysis of hybrid wind/PV standalone power system in five preselected locations in Jordan. The Capacity Factor (CF) in each location for each turbine model has been calculated based on the monthly values of the Wiebul constants: scale parameter (C) and dimensionless shape parameter (K). The Cost of the Energy unit (COE) in each location for each wind turbine type and PV cell type has been calculated. The present work proposed an algorithm to select the proper wind turbine type and the proper PV cell type to the interested location. By means of the proposed algorithm, the suitable corresponding location can be specified to the investigated given wind turbine type or the PV cell type. The combination of location, wind turbine type and PV cell type that has a maximum CF and minimum COE is considered as the best one. A flowchart for the proposed algorithm has been presented. The analysis performed in this study will set guidelines to energy consultants or engineers in designing the standalone hybrid energy systems by considering wind speed, solar radiation and the current industry costs of various hybrid subsystem components in order to meet the load requirements on a bases of economical and technical constraints. The results are demonstrated on a virtual large scale load of 100 MW peak power with a load sharing between the wind energy (75%) and the PV energy (25%).

Key words: Wind energy, solar energy, capacity factor of wind turbines, cost of energy, renewable hybrid power systems, Weibul distribution

INTRODUCTION

Many remote and isolated sites in Jordan are located far away from the national electric grid and cannot be connected to it in the near future for that reason; hybrid power system is put forward to supply an off-grid power system in these sites. Jordan is one of the non-petroleum producing countries in Arab region and is strategically dependent on oil. The current fluctuating in energy prices has a direct impact on the country's national economy and puts its energy sector security at risk. Raising the share of renewable energy of Jordan's energy mix to 20% is an "achievable goal", knowing that the capacity of the under construction solar and wind energy projects is estimated at around 1350 MW. Jordan seeks to raise the contribution of local resources in the total energy mix from 4-39% by 2020 to ease the strain of the energy bill which constituted 18% of last year's gross domestic product. Consequently, a clear policy should be adopted for the forthcoming phases to secure energy supplies by diversifying the energy sources and using hybrid power systems. Many studies have been conducted to plan for installing off-grid hybrid power systems, some studies proposed an environmental decision-support system for selecting optimal sites for grid and off-grid-connected photovoltaic power plants (El-Tous, 2013). The country has a considerable potential for the solar and wind energy utilization for electricity generation (Gburcik*et al*., 2013). Therefore, it is necessary to rely much more on renewable energy sources to satisfy some of the steadily increasing energy demand. Jordan belongs to "sunny" countries. The annual average number of "sunny hours" is >7200 h. The data collected from formal organizations (Royal Scientific Society, National Centre for Research and Development and Ministry of Energy and Mineral Resources) indicates that there is many optimal sites in Jordan have a wind and solar potential at the same time. They enjoy highest yearly averages of both wind speed and solar radiation. It is interesting to know that it is rarely to locate a site that enjoys both high wind speed and high solar radiation. Normally, locations with high speed are poor of high solar radiation and vice versa (Hussein and Al-Masri, 2012). Studies and evaluations, regarding the wind potential estimation, show that 45 suitable sites have a capacity, considering a general efficiency of 33% of approximately 6500 MW. However, it is noteworthy that the nominal capacity of all power plants of the country is already 4000 MW. There are remote communities in Jordan and the world that is isolated from a utility grid and their electricity is supplied exclusively by diesel generators. Many other remote communities are connected to the power system via. unreliable and expensive transmission lines that may pass through rough terrains (Bhuiyan and Yazdani, 2010). The hybrid systems are getting more important for several reasons; the main one is its capability to secure the continuity of feeding the load with electric power in different operating conditions and its optimum utilization for available resources in remote areas. In addition, the economical factor plays an important role where the cost of some hybrid systems is far below than that of using a single type power generation system by Ani and Nzeako (2013). The hybridization of diesel generator source system with renewable energy sources was explored and demonstrated.

Solar sources are available during the day while the wind energy is 24 h a day. It should be noted that wind and solar energy sources are practically free after the installation of their infrastructure. An efficient management or control system can determine the power flow to the loads from various components of the hybrid system during the period of operation. Note that in a hybrid system, the individual power sources are operating like a team supporting each other in a highly reliable manner. It is obvious that when the energy is drawn from the solar subsystem, the other subsystems can be viewed as standby systems. The analysis revealed that the availability of open land would be an important constraint limiting the growth of solar photovoltaic and wind power plants. A minimum threshold value of 180, 200 W/m^2 for solar and wind power, respectively where used for identifying the land suitable for solar-wind energy exploitation (Sukhatme, 2012), it is noteworthy that the renewable energy market is rapidly expanding worldwide. This growth of the renewable energy industry has led to cost reduction. Cost is the first concern for the hybrid power plant owners (Zaman and Shakouri, 2010). In Jordan there is a need to accelerate efforts to produce energy from alternative sources of energy. To meet the country primary energy needs each year and the high cost of energy to supply electrical energy from the national grid, for the remote sites a special interest both for public and private sectors should be paid to use off-grid hybrid power systems. In order to encourage utilization of Renewable Energy (RE) sources and Energy Efficiency (EE) in different sectors of the economy, the government of Jordan introduced a new law in 2012. The new law was passed under the title “Renewable Energy and Energy Efficiency” No. 13 for the year 2012. A fair number of studies have been conducted on the subject of increasing diesel-based electric power generation with renewable energy resources which may be potentially available in many such remote sites (Infield *et al*., 1983; Nayar *et al*., 1989; Chambers and Mutale, 2006; Kini and Yaragatti, 2006; Stott and Mueller, 2006; Lopes and Almeida, 2006; Bhuiyan and Yazdani,2009). By Chambers and Mutale (2006), the economicdispatch problem in wind-diesel hybrid systems is investigated whereas (Kini and Yaragatti, 2006) deals with the modelling and performance of a wind-diesel hybrid system based on an electronically coupled squirrel-cage asynchronous generator. PV system also produce electricity during the times when it is most demanded on hot sunny days coinciding with regional peak electricity peak electricity consuming periods. Cost of electrical energy produced by PV technologies remains 267% higher than price of energy supplied by the grid but it is 36% cheaper than electrical energy produced by diesel generators, mean cost of electrical energy produced by diesel generators is around 0.4 US$/kWh. A hybrid system using wind-solar PV system and diesel generator as a backup system is expected to satisfy the load demands, minimize costs and maximize utilization of renewable sources. In order to minimize the cost of the wind-solar hybrid system and to provide best value for customer, entire system should be analyzed for subsystem costs besides the renewable potentiality of the site. There is a need for optimizing the cost of the hybrid systems based on the various operating and design parameters in this research attention has been paid to site renewable potentiality, type of wind turbine model, type of solar cell and size of both batteries and diesel power generation.

The study presents a technical-economical analysis of hybrid power system in a remote site (such as tourist zone, development zone and free zone which are generally are far from the national grid) located far away from the national electric grid and cannot be connected to it in the near future which operates 24 h a day and shows the importance of relying on renewable energy systems. In Jordan, there is a dearth in research related to optimization of off-grid hybrid power systems this study was carried out on a hypothetical off-grid hybrid power system. The system considered consists of wind turbines, photovoltaic cells, batteries and conventional diesel generator to feed a load of 100 MW peak load. The study is based on real data of wind speed and solar radiation obtained from official authorities. The main outcome was that the various available combinations of sites, wind turbine types and PV cells type are compared technically and economically using the proposed mathematical model, explained in the following sections to choose the optimal combination. For the right exploitation in renewable energy in Jordan there is a need to: firstly, works to view the main supportive tools of energy conservation and management, supportive tools for energy and public awareness, energy regulation and energy information programming. Secondly, researches for environmental decision-support systems for evaluating the carrying capacity of land areas in Jordan, thirdly, encourage studies to which this study is related that concerned with the best utilization of latest proper technologies and more efficient equipment as well as utilization of renewable system in these areas.

MATERIALS AND METHODS

Estimation of the energy cost and the capacity factor for PV system: PVs are durable and rarely require maintenance and can be dislocated easily. Currently, the most significant disadvantage of PV systems is the high initial cost compared to prices for competing, power-generating technologies. According to the improvements for cell efficiencies and manufacturing methods, a reduction in PV system cost is experienced, higher costs for conventional electricity-generating technologies help make PV and other renewable energy sources as a serious competitive alternative system that are more cost-effective.

The output power of the photovoltaic cell depends on the radiation, temperature cell and the temperature of the weather. The optimal photovoltaic cell for each site, according to technical and economical assessments based on which photovoltaic cell and site give the minimum number of photovoltaic panel and minimum cost of energy can be selected. The sun shines most of the year an average of about 7 h daily. The selection of suitable sites for solar energy farms in Jordan is based on a number of interrelated factors of geography, climate and land use. In this research, first step of analysis that should be carried out is a set of criteria aimed at guiding and facilitating the identification of the sites that are most suitable for location of ground-mounted photovoltaic plants. In other words, it assumed that a first phase of study in which a suitability index map of suitable zones to construct PV power plants or areas where PV plants are admitted is already conducted in advance. The total deserted area in Jordan is >90%. Most of the land is arid or semi-arid. Large amount of it is relatively flat and undeveloped. The energy deficit in deserted areas is relatively high which can be reduced by harnessing large amount of solar energy. But investment in terms of land, money and manpower is very high for such establishments thus in the present study a methodology has been suggested to arrive at the optimal site selection for PV power plants. Table 1 shows the annual averaged direct normal radiation in kWh/m^{2}day and temperature in the five sites (Mahmoud and Nabhan,1990). The output power of the photovoltaic cell (P_{out}) can be also calculated by the following Eq. 1:

Table 1: Annual averaged direct normal radiation and temperature

Location	Radiation kWh/m^2.day	T (C0)
Amman	6.02	25
Aqaba	6.81	28
D.Alla	6.17	26
Irbid	6.20	22
R.Monif	6.18	24

$$P_{out} = P_{pv} \times \left(\frac{G}{G_{ref}} \right) \times [1 + K_t(T_c - T_{amb})] \quad (1)$$

Where:

P_{PV} = Power of PV cell
G = Radiation
G_{ref} = Solar radiation at reference conditions (G_{ref} = 1000 W/m^2
K_t = Constant has the value of -3.7×10^{-3}
T_{amb} = Temperature of the weather
T_c = Temperature of the cell

The number of photovoltaic cells for each site can be estimated using the following Eq. 2:

$$\text{Number of PV cells} = (P_{rated})/(P_{out}) \quad (2)$$

P_{rated} = 25 MW which is equal 25% of load demand. There are several methods available for estimating the cost of solar energy. The Cost of solar Energy (COE) in $/kWh can be evaluated using the following simple equation:

$$COE = \frac{1}{7\times365}\left[\frac{i(1+i)}{(1+i)^Y -1}(C_{spi}+C_i)+C_{mc}\right] \quad (3)$$

Where:

i = Interest rate
Y = Project life time (20 years)
C_{spi} = Solar panels, inverter and the installation costs in US$/kW
C_{mc} = Maintenance, cleaning and labour costs in US$/kW
C_l = Land costs in US$/kW

According to the first phase of the analysis which is assumed to be done by formal organizations (Royal Scientific Society, National Centre for Research and Development and Ministry of Energy and Mineral Resources) in Jordan there are a number of regions with acceptable radiation and wind speed to generate electricity. The analysis in the given work has been performed on the following five sites in Jordan: Amman, Aqaba, Irbid, D. Alla and R. Monif. And the following six commercial types of photovoltaic cells: Canadian Solar 300, Canadian CS6 X, KD220GX-LFBS, KD250 X-LFB22, SW315 V2.5 and SW280 V 2.5. The load in each site for the solar system is assumed to be the same and have 25 MW as a peak value. The operating hours of the photovoltaic cell is seven hours per day. Using Eq. 1, the number of PV cells can be calculated. Then the required area also can be found. Table 2 shows P_{PV} given by specification of the PV cell, calculated area of each panel, number of PV cells to produce the desired power (25 MW) and the required total area for each of the six types of the PVs.

Table 3-5 show the Cost of Energy (COE) in US $/kWh for each type of PV in each site, land cost in US$/m^2. Calculations show that the P_{out} is the same for each site as the radiation almost is the same while the COE is differ because the price of land is differ from one site to other. From tables, SW315 V2.5 PV cells have minimum cost and lowest number of cells while R. Monief is the best site which has the minimum cost of energy. The land price was taken by the Hashemite Kingdome of Jordan Department of Lands and Survey.

For the wind power system: In Jordan a number of sites are being monitored by the Royal Scientific Society which is carrying out wind speed measurements of high accuracy. The results of these measurements are used in the analysis described here. The annual Weibull constants parameters (C, k) (Alghoul *et al*., 2007; Yang *et al*., 2009) in the five locations are shown in Table 6.

The analysis in the given work has been performed on the following five sites in Jordan: Amman, Aqaba, Irbid, D. Alla and R. Monif. And the following eight commercial types of wind turbine models: Aaer1, Aaer 2, Acciona1, Acciona 2, Gamesa, Bard, Xemc-Demand and Repower. The load in each site for the wind power system is assumed to be the same and have 75 MW as a peak value.

The manufactured specifications of wind turbine generator are taken from the website [http://en. wind-turbine-models.com/turbines/6-bard-vm].

The Capacity Factor (CF) for each turbine module can be calculated (Johnson, 2011; Mohahed and Nabhan 1990). Then the average output power of the wind turbine generator ($P_{e.av}$) can be determined. The yearly energy output of the wind turbine generator (E_{out}) can be estimated as follows:

$$E_{out} = CF \times P_{rated} \times 8760 \quad (4)$$

The cost analysis for wind power generation can be done using the simple following expression:

$$\text{Cost} = (\text{Investment costs} + \text{Labour costs}) \quad (5)$$

The Cost of Energy (COE) for each model in each site can be easily estimated (Amr *et al*., 1990; El-Tamaly *et al*., 1995; Shata and Hanitsch, 2006, 2008; Rehman *et al*., 2003; Dalabeeh, 2017). The interest rate (assumed to be 5%). The expected duration for the wind power project (assumed to be 20 years). Figure 1 shows the capacity factor for each manufacturer model in each site while Fig. 2 shows the Cost of Energy (COE) in $/kWh also for each manufacturer model in each site (Dalabeeh, 2017). Clearly, the most suitable Wind Turbine Generator (WTG) is XEMC and the best location is R.Monief in which COE has minimum and CF has a maximum value.

The method was applied to the sites at which Royal Scientific Society performs wind speed measurements and

Table 2: Area of each panel, number of PV panels and the total required area for each PV power plant

Type of PV	P_{pv} (W)	Area of each panel (m^2)	Number of PV panels	Required Area in (m^2)
Canadian solar 300	300	1.952	83333	163000
Canadian CS6X	305	1.952	81967	160000
KD220GX-LFBS	220	1.485	113640	169000
KD250GX-LFB22	250	1.485	100000	149000
SW315 V2.5	315	1.915	79365	152000
SW280 V2.5	280	1.609	89286	144000

Table 3: Cost of energy (COE) in US$/kWh for each type of PV in each site

Type of PV	COE in Amman (US cents)	COE in AqabaIn US cents	COE in D. AllaIn (US cents)	COE in IrbidIn	COE in R. Monif (US cents)
Canadian solar 300	14.815	13.030	13.140	13.480	12.920
Canadian CS6X	14.770	13.030	13.130	13.460	12.920
KD220GX-LFBS	17.220	13.050	13.170	13.510	12.940
KD250GX-LFB22	14.620	13.000	13.100	13.400	12.890
SW315 V2.5	14.660	13.000	13.110	13.420	12.900
SW280 V2.5	14.550	12.980	12.740	13.370	12.880

Table 4: Land cost (US$/$m^2$)

Location	Land cost (US$/$m^2$)
Amman	100
Aqaba	20
D. Alla	25
Irbid	40
R. Monif	15

Table 5: Total cost for the solar power plant in US$ and the cost of kWh in US$ in each location for each type of the PV cells

Variables	Total costs in Amman	Cost of kWh in Amman	Total cost in Aqaba	Cost of kWh in Aqaba	Total cost in D. Alla	Cost of kWh in D. Alla	T otal cost in Irbid	Cost of kWh in Irbid	Total cost in R. Monif	Cost of kWh in R. Monif
Canadian solar 300	118323527.0	0.189023	67560074	0.107928	50581171	0.080804	50581171	0.080804	50546520	0.080748
Canadian CS6X	116491816.7	0.186097	66560481	0.106331	49859898	0.079652	49859898	0.079652	49825815	0.079597
KD220GX-LFBS	128827315.3	0.205803	81669768	0.130468	65896936	0.105271	65896936	0.105271	65864747	0.105219
KD250GX-LFB22	114230357.3	0.182484	72733043	0.116192	58853396	0.094019	58853396	0.094019	58825070	0.093974
SW315 V2.5	116813870.5	0.186611	65722557	0.104992	48633995	0.077693	48633995	0.077693	48599121	0.077637
SW280 V2.5	104132656.9	0.166353	66063618	0.105537	53330629	0.085196	53330629	0.085196	53304643	0.085155

Table 6: Weibull constants (C, K) for the five locations at 10m height

Location	C	K
Amman	3.47	1.75
Aqaba	5.37	2.26
D. Alla	2.63	1.60
Irbid	3.49	2.14
R. Monif	7.03	2.45

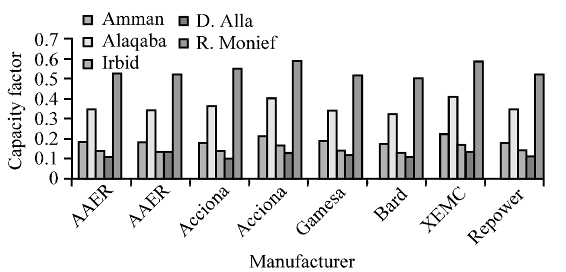

Fig. 1: Capacity factor for eight WTGs and five locations

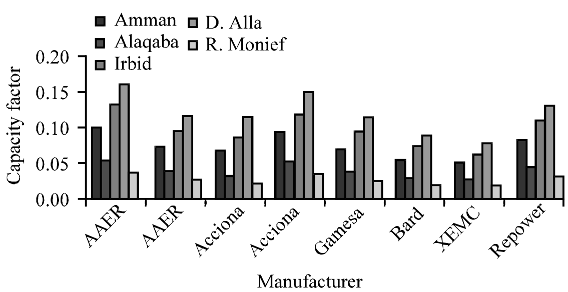

Fig. 2: The cost for each WTG and each location

the results indicate that some of these sites are well suited for cost efficient generation of electricity by wind energy. The results also show that a wind turbine which is designed to have a relatively low rated speed has a wider range of economical operation than a wind turbine with a higher rated speed for the sites investigated assuming that the maximum rated power for all wind turbines is held constant. The solar radiation and wind being intermittent sources of power, cannot meet the load demand all of the time, 24 h a day (Patel, 1999). The energy storage therefore is a desired feature to incorporate with renewable power units, particularly in stand-alone plants. It can significantly improve the load availability the key requirement for any power system.

RESULTS AND DISCUSSION

Optimal analysis for wind-PV system: In this study, a wind-solar hybrid power system with a diesel generator is analyzed for a standalone power generation system to supply energy to 100 MW load in five locations in Jordan. Cost is to be minimized to provide best value for the customer, so, the entire system analyzed for subsystem costs, a cost analysis is done to provide useful guidelines for large-scale wind-solar-diesel standalone hybrid power system. The analysis is based on the monthly out power of the system.

Study 2 shows how the solar power can be estimated and how the annual wind power can be calculated based on the annual Weibul constants C and K then to calculate the monthly wind power, the monthly Weibul constants are needed, Table 7 shows the monthly wind velocity for each site while the monthly Weibul constants are shown in Table 8 and 9.

$$\text{The power generated by the diesel generator} = \text{wind power} + \text{solar power} - \text{rated load power} \quad (6)$$

Figure 3-6 show the monthly (8760/12 h) output power of each turbine model in each site. Table 10 and 11 show the monthly PV and wind output power in R. Monief site. The PV output power almost constant and equal to P_{max} of the PV cells because of the high radiation in Jordan then the output power equal to 24.8 MW while the wind output power for XEMC, the best selected turbine model in R. Monief is shown in Fig. 7. A 50 MW diesel generator is used as backup system to supply the load in case of

Table 7: The monthly mean velocity in each site

Months	Amman	Aqaba	Irbid	R. Monief	D. Alla
Jan.	3.59	3.39	2.83	6.56	2.84
Feb.	3.42	3.60	3.03	6.67	2.37
Mar.	3.14	4.66	3.17	7.18	2.47
April.	3.36	5.49	2.94	6.17	2.87
May.	3.36	5.68	3.15	5.85	2.51
June.	3.63	6.26	3.75	6.49	2.04
July.	4.04	4.98	4.46	6.95	1.91
Aug.	3.35	5.49	3.92	6.22	1.61
Sep.	2.51	6.11	3.02	5.49	1.75
Oct.	2.02	4.38	3.08	4.83	2.22
Nov.	2.96	3.80	2.59	6.46	3.24
Dec.	2.80	3.44	2.57	6.14	3.00
Annual	3.14	4.77	3.13	6.26	2.40

Table 8: The monthly weibul (C) constants for each site

Month	Amman	Aqaba	Irbid	R. Monief	D. Alla
Jan.	3.24	3.81	3.13	7.39	2.90
Feb.	3.91	4.03	3.37	7.26	2.55
Mar.	3.79	5.24	3.56	8.10	2.66
April.	3.46	6.18	3.13	6.96	3.24
May.	3.79	6.39	3.59	6.60	2.83
June.	4.10	7.05	4.18	7.25	2.30
July.	4.50	5.62	4.97	7.71	2.16
Aug.	3.78	6.15	4.37	6.95	1.86
Sep.	2.80	6.85	3.91	6.17	1.97
Oct.	2.20	4.94	2.33	5.46	2.42
Nov.	3.15	4.27	2.87	7.29	3.56
Dec.	2.93	3.87	2.18	6.89	3.18
Annual	3.47	5.37	3.49	7.03	2.63

Table 9: The monthly Weibul (K) constant for each site

Month	Amman	Aqaba	Irbid	R. Monief	D. Alla
Jan.	1.27	1.81	1.51	1.89	1.05
Feb.	1.35	1.66	1.55	1.87	1.27
Mar.	1.31	1.82	1.72	2.32	1.28
April.	1.45	2.56	1.88	2.27	1.98
May.	2.03	2.66	2.25	2.37	2.13
June.	2.42	2.52	3.26	3.08	2.07
July.	2.39	2.48	3.36	3.62	1.96
Aug.	2.25	3.03	3.32	3.12	1.76
Sep.	1.65	2.96	2.36	2.75	1.77
Oct.	1.34	2.04	1.67	2.29	1.34
Nov.	1.20	1.80	1.49	2.10	1.41
Dec.	1.13	2.26	1.35	1.76	1.19
Annual	1.75	2.26	2.14	2.45	1.66

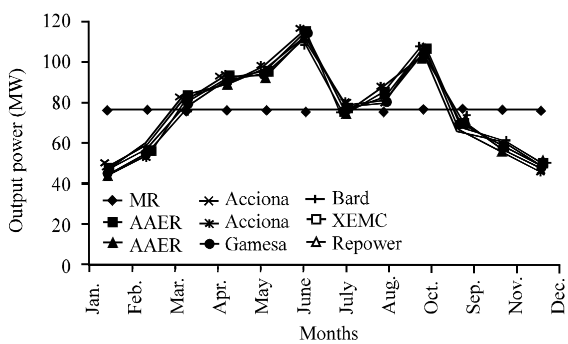

Fig. 3: The monthly output power in MW for each turbine model in Amman

insufficient power developed by w ind and PV. The study showed the importance of the addition of

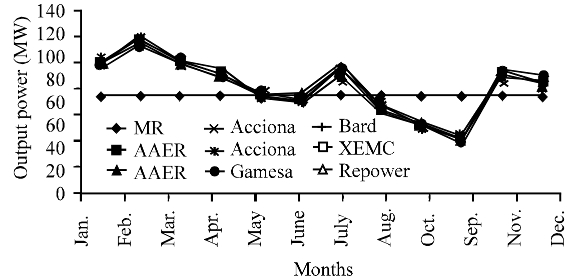

Fig. 4: The monthly output power in MW for each turbine model in Aqaba

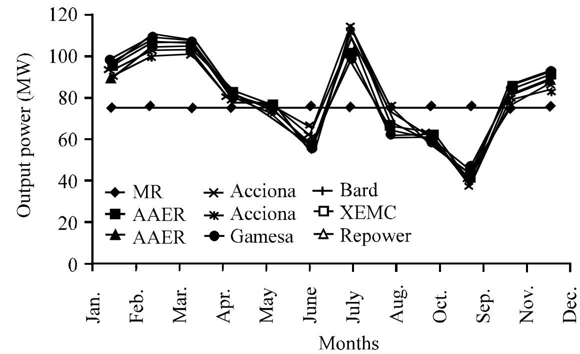

Fig. 5: The monthly output power in MW for each turbine model in Irbid

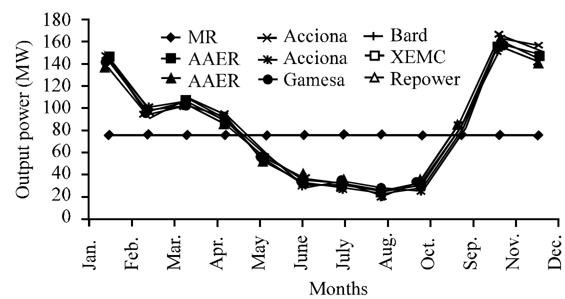

Fig. 6: The monthly output power in MW for each turbine model in D. Alla

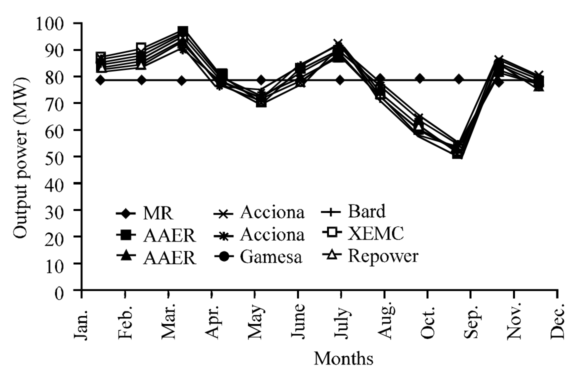

Fig. 7: The monthly output power in MW for each turbine model in R. Monief

Table 10: The monthly hybrid PV and wind out power in R. Monief site

Variables	Canadian solar 300 (MW)	XEMC wind turbine model (MW)	Total wind-solar power (MW)	Load rated power (MW)	Shortage in powerin(MW)
Jan.	24.8	77.22415	102.0242	100	2.02415
Feb.	24.8	78.95682	103.7568	100	3.75682
Mar.	24.8	85.24760	110.0476	100	10.0476
April.	24.8	73.71188	98.51188	100	-1.48812
May.	24.8	69.17392	93.97392	100	-6.02608
June.	24.8	77.30402	102.104	100	2.10402
July.	24.8	84.39188	109.1919	100	9.19188
Aug.	24.8	72.74867	97.54867	100	-2.45133
Sep.	24.8	61.28327	86.08327	100	-13.9167
Oct.	24.8	53.00607	77.80607	100	-22.1939
Nov.	24.8	77.03076	101.8308	100	1.83076
Dec.	24.8	72.39297	97.19297	100	-2.80703

Table 11: Shortage in the generated power for 7 h daily and the cost in US$/month in R.Monief site

Month	L/h	US$/h	US$/month
April	1488.12*0.4 = 595.248	595.248*0.68 = 404.7686	404.7686*7*30 = 85001.406
May	6026.08*0.4 = 2410.472	2410.472*0.68 = 1639.121	1639.121*7*30 = 344215.41
Aug.	2451.33*0.4 = 980.532	980.532*0.68 = 666.7618	666.7618*7*30 = 14019.978
Oct.	13916.7*0.4 = 5566.68	5566.68*0.68 = 3785.342	3785.342*7*30 = 794921.81
Sep.	22193.9*0.4 = 8877.56	8877.56*0.68 = 6036.741	6036.741*7*30 = 1267715.61
Dec.	2807.03*0.4 = 1122.812	1122.812*0.68 = 763.5122	763.5122*7*30 = 15437.562

a conventional diesel generator to the components of hybrid system not as an option but to ensure the continuous feeding of the electrical loads in some rare but critical condition especially for remote areas far from electrical grid.

The proposed system comprises primary renewable sources (wind/PV) which are supported by standby secondary conventional sources (diesel generator/batteries). Power converter is included in the system to connect between AC and DC links and the controller unit.

In this study, R. Monief is selected as it has the minimum Operating Energy Cost (COE) and the high power generated, maximum CF. In R. Monief April, May, August, October, September and December are the months in which there is a shortage in the generated power by wind and PV, the generated power <100 MW. Table 11 shows the shortage in generated power in these months. Taking into account that 0.28-0.4 L from diesel is needed to generate one kWh. The price of one litter of diesel is ~0.68 US$.

Close insight in Table 11, The maximum shortage in power is happened in September for the seven hours in which the PV system is operating (22193.9 kW) while in remain 17 h the maximum shortage in power is 48.993.9 MW. Based on this figure, depending on the needed level of reliability and the cost of energy interruption in the given study a 50 MW diesel generator is selected, if a high level of reliability is needed and the load is considered as an important load then a two 50 MW diesel generator may be selected (Fig. 8). From Table 11, the maximum excess generated power for a 7 h daily is happened in March month (10.0476 MW) this power can be transferred to dump load or any other load. When there is an excess in power generation from sun and wind with respect to load requirements the system charges a storage system. If the storage system is fully charged also, the excess power is transferred to dump load or to supply auxiliary loads such as streets lighting, water pumping, heating or refrigeration. This will improve the performance

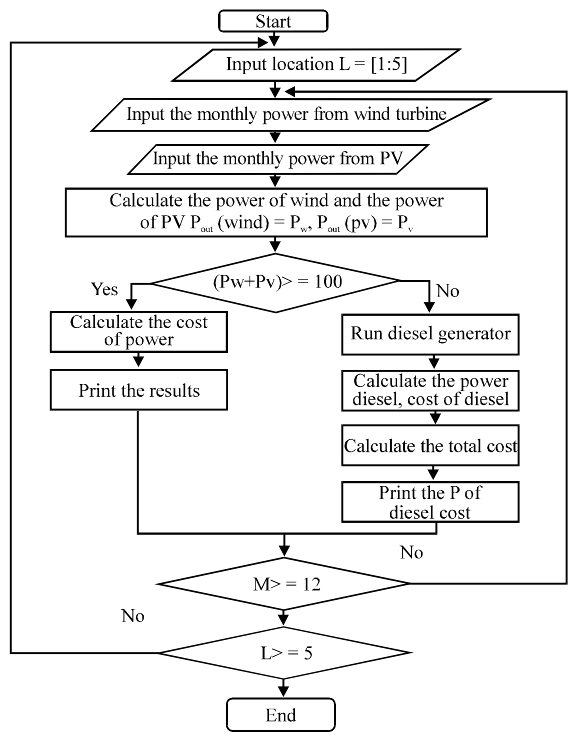

Fig. 8: Flow chart of the technical-economical analysis of a standalone hybrid wind solar system

of the hybrid system. Figure 8 shows the flow chart of the technical and economical analysis of hybrid standalone wind-solar diesel generator power system.

CONCLUSION

The generation of electricity utilized from wind and solar is feasible for isolated places far away from the national grid. A hybrid system using wind, solar and diesel generator as a backup system is expected to satisfy the load demands, minimize the costs and maximize the utilization of renewable sources. Selecting the best site and the proper system component (turbine and solar model) depend on several factors such as: wind speed and solar radiation (environmental constraints), turbine and solar cell rated data (technology characteristics), cost of kWh and the limit on primary energy consumption. To consider these factors and at the same time to optimize the system which means choosing the best site, the proper turbine and the solar cell models, the maximum Capacity Factor (CF) and the minimum Cost of Energy (COE) are used in the given research. The demonstrated results show the effectively of using this method in increasing the economical benefits while the technical and operational conditions meet the requirement of supplying the load, keeping in mind that the continuity of supplying kept not to be violated.

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