Prospects and Viability of Solar Energy in Khyber Pakhtunkhwa Pakistan

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***Abstract*— Pakistan is facing serious problems of energy shortage. Existing resources of energies such as thermal, fossil fuels, and coal are limited and expensive. Solar energy is the cleanest and an inexhaustible source of energy. The earth is receiving 18×10^{10} MW of power annually. This huge amount of power is more than the global requirement. If it is properly harnessed, it will solve the global energy issues forever. Pakistan being lying closer to the equator, which is in the Sun Belt, has a high potential of solar energy.**

This work shows solar mapping for Khyber Pakhtunkhwa(KPK) using Geospatial Toolkit and Hybrid Optimization Model for Electric Renewable (HOMER) to understand the energy generating capacity by solar Photovoltaic (PV) technology. This paper shows electrification analysis of some potential sites in the Karak district such as Shage Lawagher, Kamanger and Faqir Abad as a case study. For the electrification of these sites, load requirement, extension of distribution grid as well as installation of stand-alone solar power system is analyzed. The analysis takes into account a comparison of installation cost, running cost, and revenue generation. Based on the analysis, the viability of solar energy setup for the electrification of the above mentioned sites has been identified. After a detailed parametric analysis it is revealed that solar electrification is much better than grid system in mentioned targeted areas of KPK.

Keywords—solar energy; electrification analysis; renewable energy; green technologies; smart cities;

I. INTRODUCTION

Energy is the basic need of human being, the progress and prosperity of a country can be determined by the amount of energy it is using. In Pakistan major energy sources are coal, oil and gas which contribute 65% of the total supplied energy. A survey in 2008-09 has shown that energy shares in "%" by commercial generating plants were as mentioned in Table I. Pakistan is depending on the conventional sources of energy such as thermal, hydro and nuclear which are contributing 64%, 33% and 2.4% respectively [4].

There was no use of renewable energy before 2003 in Pakistan and then the government set the alternate energy development board (AEDB). Pakistan has high potential of solar energy and it is a great opportunity to take advantage of solar potential. The average solar radiation falling on the surface of earth is 200-250W/m^2/day. Sun shine hours in Pakistan are 1500-3000hrs/year, which can generate 1.9-2.3MWh/year. The AEDB has facilitated this technology to contribute 5% of power generation [3]. Pakistan is among those countries which have high potential of solar energy. It will be very economical to electrify the remote areas by solar photovoltaic (PV) system where the extension of distribution grid is not viable [4].

Due the poor economy and energy shortage Pakistan is facing serious problems of load shedding. Many peoples in Pakistan have no access to electricity. The problem of energy crises can be solved by finding indigenous sources of energy such as solar energy. Considering the geography of Pakistan it is suitable for solar energy generating technique such as photovoltaic [5].

For installing solar PV systems, different technologies such as monocrystalline, multicrystalline, and amorphous can be considered. Different factors that affect the efficiency of solar power systems are types of technology, ambient temperature and intensity of solar radiation [6].

Khyber Pakhtunkhwa (KPK) province of Pakistan is located in the North West part of Pakistan and it is one of the most well-known places on the terrain. KPK has an approximate area of 74,521km^2 and its total population is around 22 millions. It is located between latitude 34.000 North and longitude 71.000 East [7].

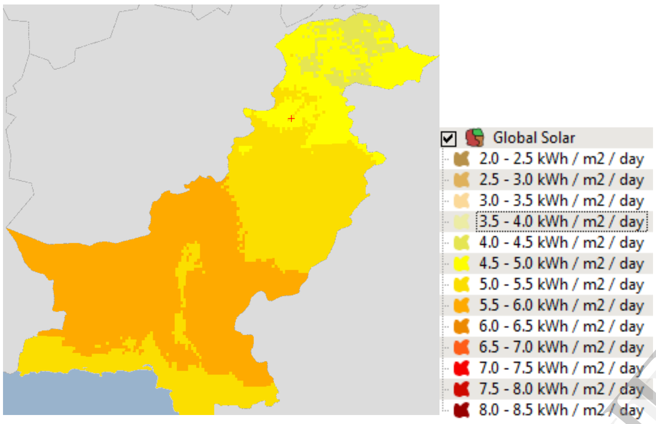
Arrangement of remaining paper is: Part II gives details about the potential of solar radiation and its generating capacity in Khyber Pakhtunkhwa. In Part III load curve have been plotted for the selected sites. Part IV and V provide analysis of cost for the electrification of selected sites by extension of distribution grid and installation of solar power system respectively.

TABLE I. COMPARISON OF ENERGY SOURCES IN PAKISTAN

	Comparison of Energy Sources by Various Generating Plants in Pakistan	
S. No.	***Energy Source***	***Total Generation Capacity (%)***
1.	Gas	50.3%
2.	Oil	29.8%
3.	Hydro power plants	11.1%
4.	Coal	7.6%
5.	Nuclear	1.2%

II. INTENSITY AND POWER GENERATION CAPACITY OF SOLAR RADIATIONS IN KPK

To find the potential of solar energy in various locations of KPK, the intensity of solar radiation have been identified by using Geospatial Toolkit. Fig. 1-(a) shows the intensity of solar radiation in Pakistan. The intensity of solar radiation is differentiated by colors as shown in Fig. 1-(b) in kWh/m^2/day. In KPK solar radiation varies as (4.0-5.5) kWh/m^2/day. To find the intensity of solar radiations, clearness index, power generation capacity by PV at specific latitude and longitude HOMER has been used. Fig. 2 shows output power for 1kW solar panel per year at 33.5800 N and 71.6670 E. Table II shows the clearness index and average solar radiation for a complete year.



(a) (b)

Fig. 1. Solar Radiations: (a) Intensity of solar radiations in KPK (Pakistan) (b) intensity of radiation by various colors

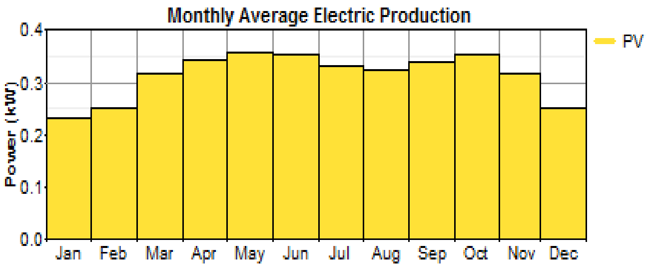


Fig. 2. Output power for 1kW solar panel per year

TABLE II. CLEARANCE INDEX AND SOLAR RADIATION PER YEAR

Monthly clearance index and solar radiation in KPK			
S. No.	***Month***	***Clearance Index***	***Average Radiations (kWh/m^2/day)***
1.	Jan	0.519	2.758
2.	Feb	0.508	3.358
3.	Mar	0.582	4.870
4.	Apr	0.597	5.992
5.	May	0.619	6.871
6.	Jun	0.623	7.172
7.	Jul	0.593	6.693
8.	Aug	0.578	6.014
9.	Sep	0.604	5.390
10.	Oct	0.658	4.685
11.	Nov	0.613	3.429
12.	Dec	0.547	2.681

III. CASE STUDY

The electrification of sites such as Shage Lawagher, Kamanger and Faqir Abad areas of KPK has been considered for a case study. The selected sites are different villages of district Karak, KPK. Theses villages have no access to modern day energy and they have similarity in typography. These areas have mountainous geography and scattered population. Most of the consumers are residential and their maximum demand is less than or equal to 1kilowatt (kW). The houses are usually “KACHA” hut type. Total number of homes in Shage Lawagher, Kamanger and Faqir Abad are 176,110, and 203 respectively and the distances of these sites from the distribution T-off are 7km, 6km, and10km respectively. In this case study, first the load requirements of these sites have been shown. The cost analysis has been carried out for the electrification of these sites by extension of distribution grid as well as by installation of stand-alone solar PV systems. These will be discussed in great detail in coming sections.

IV. LOAD REQUIREMENTS OF SELECTED SITES

To determine the load requirements of selected sites load curves for a single home (H) has been plotted for the month of June and January, which indicates the maximum and minimum kilowatts hour per day (kWh/day) respectively. Electrical components for a residential consumer and their ratings are given in Table III [1]. Fig. 3-(a) and Fig. 3-(b) shows load curves for a single home in the months of June and January respectively. Table IV shows Maximum Demand (MD), daily kWh/H, monthly kWh/H, and daily Load Factor (LF) for the month of June and January. To determine simultaneous maximum of selected sites Diversity Factor (DF) has been considered as 1.3 for residential consumers. Table V shows daily kWh, monthly kWh, sum of individual maximum demand (SoMD), and simultaneous maximum demand (SMD) for Shage Lawagher, Kamanger, and Faqir

Abad. In this work 1kWh is considered as a single unit of electricity.

TABLE III. ELECTRICAL COMPONENTS AND THEIR RATINGS

Residential Consumer's Electric Components Ratings (Domestic)		
S. No.	***Component's Name***	***Rating/Unit (Watts)***
1.	Energy Savers	25
2.	Pedestal Fan	67
3.	Ceiling Fan	55
4.	Water Pump	373

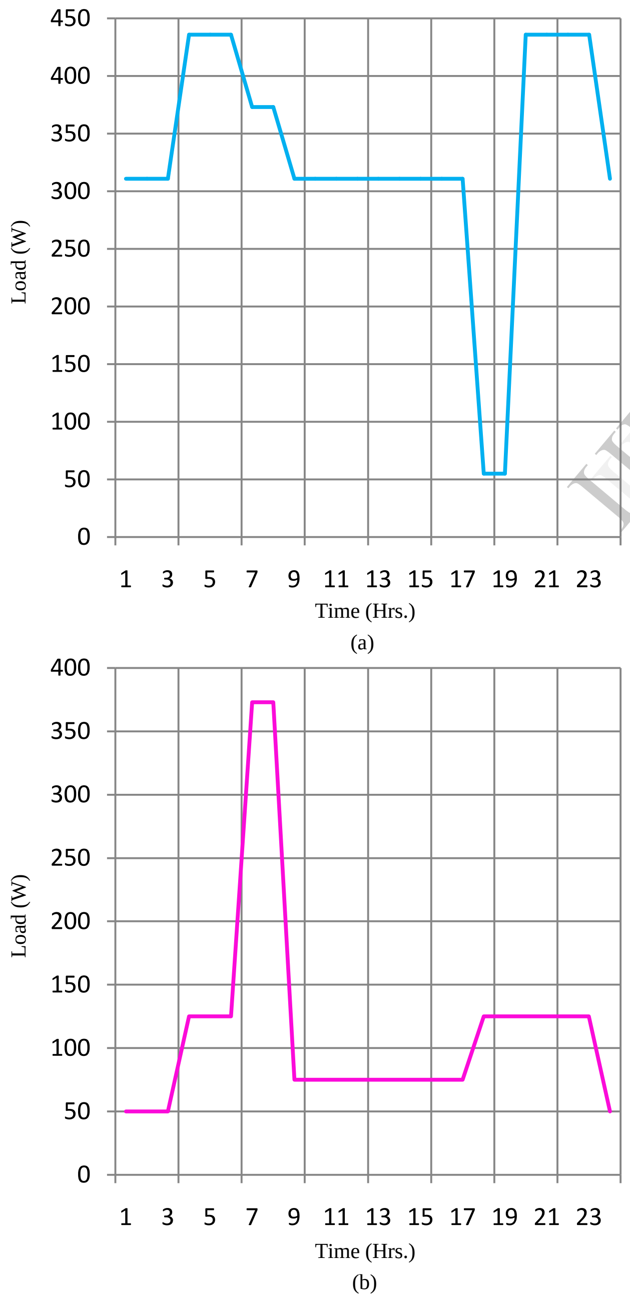


Fig. 3. Load curves of a single home in (a) June (b) January

TABLE IV. MAXIMUM DEMAND AND LOAD FACTOR PER HOME

Maximum Demand and Load Factor per Home for the Month of June & January					
S. No.	***Month***	***MD/day/ Home (W)***	***kWh/day/H***	***kWh/Mon /H***	***Daily LF***
1.	June	436	7.941	238	0.758
2.	January	373	2.746	85	0.306

TABLE V. COMPARISON OF VARIOUS SITES OF KPK

Comparison of Individual Maximum Demand and Simultaneous Maximum Demand						
Site Name.	***No. of Homes***	***Month***	***kWh /day***	***kWh /Month***	***SoMD (kW)***	***SMD (kW)***
Shage Lawagher	176	June	1397.61	41928.48	76.736	59.026
		Jan	483.296	14982.17	65.648	50.49
Kamanger	110	June	873.51	26205.3	47.96	36.89
		Jan	302.06	9363.8	41.03	31.56
Faqir Abad	203	June	1612.02	48360.69	88.508	68.08
		Jan	557.438	17280.57	75.719	58.245

V. ELECTRIFICATION ANALYSIS OF SELECTED SITES

For electrification of selected sites two options such as extension of distribution grid and installation of stand-alone solar PV system have been considered. The cost of installation and revenue generation is also discussed in great detail in coming sections.

A. Extension of Distribution Grid

The selected sites can be electrified by extending the distribution line from T-off. The major components that are required for extension of distribution grid are poles, conductors, distribution transformers, and insulators. As per specification of Water and Power Development Authority (WAPDA) Pakistan, the cost of distribution transformer (11/0.4kV) and required number of poles/span for 11kV as well as 0.4kV has been listed in Table VI. This cost includes cost of conductors, supports, insulators, and miscellaneous items in Pakistani Rupees (PKR). Electrification of selected sites have been analyzed on the basis of capital cost, running cost, and revenue generation.

TABLE VI. COST OF VARIOUS COMPONENTS AS PER SPECS OF WAPDA

S. No.	*Component's Name*	*Cost /unit in(PKR)*
1.	Distribution transformer 50kVA	33,0000
2.	Distribution transformer 25kVA	250,000
3.	11kV/pole/span	60,000
4.	0.4kV/pole/span	42,000

B. Capital Cost Calculations

Capital cost for extension of distribution grid for the electrification of sites can be divided into primary distribution, distribution transformer and secondary distribution. Primary distribution is the extension of distribution line from T-off to the distribution transformer. 11kV poles are required for primary distribution lines. According to the specification of WAPDA 15poles/km/span are used and cost/pole/span is 60,000PKR for primary distribution. Distribution transformers are used to step down the distribution voltage from 11kV to 0.4kV. The power factor of the distribution transformer depends upon load, where loads are mostly inductive. WAPDA Pakistan considered power factor 0.8 lagging; hence 50kVA and 25kVA transformers can take load of 40kW and 20kW respectively. The secondary distribution lines are used to distribute the electricity from the distribution transformer to the consumer premises. According to the specification of WAPDA, the number of poles required is 20poles/km and cost is 42,000PKR/pole/span for secondary distribution. Further detailed capital cost analysis of these sites is as given below.

i. Shage Lawagher

It is at a distance of 7km from distribution T-off and its maximum demand in June and January is 59.026kW and 50.49kW respectively as shown in Table V. To satisfy the load curves in Fig. 3(a-b), four distribution transformers of 25kVA are required. Length of secondary distribution line is half kilometer in four sides from distribution transformer. Poles required for primary and secondary distribution line are 105 and 160 respectively.

ii. Kamanger

It is at a distance of 6km from distribution T-off and its maximum demand in June and January is 36.89kW and 31.56kW respectively as shown in Table V. To satisfy the load curves in Fig. 3, two distribution transformers of 25kVA are required. Length of secondary distribution line is one kilometer in four sides from distribution transformer. Poles required for primary and secondary distribution lines are 90 and 160 respectively.

iii.Faqir Abad

It is at a distance of 10km from distribution T-off and its maximum demand in June and January is 68.08kW and 58.245kW respectively as shown in Table V. To satisfy the load curves in Fig. 3, total four distribution transformers of 25kVA are required. Length of secondary distribution line is 0.6km in four sides from distribution transformer. Poles required for primary and secondary distribution lines are 150 and 192 respectively. Table VII shows capital cost of primary distribution, secondary distribution, distribution transformer (DT) and total capital cost for the different sites in KPK.

TABLE VII. CAPITAL COST OF SELECTED SITES

Gross Expenses for installation of distributed grid					
Name of Site	***Site MD (kW)***	***Cost of 11kV Poles (PKR)***	***Cost of 0.4kV Poles (PKR)***	***Cost of 25kV DT (PKR)***	***Total Capital Cost (PKR)***
Shage Lawagher	59.026	630,000,0	672,000,0	100,000,0	140,200,00
Kamanger	36.89	540,000,0	672,000,0	500,000	126,200,00
Faqir Abad	68.08	900,0000	806,400,0	100,000,0	180,640,00

C. Revenue Calculations

In WAPDA Pakistan, revenue accumulation is based on the monthly charges called electricity bill/month. Electricity bill includes fixed charges and running charges. Consumers are charged on the basis of different types of tariff, residential consumers are charged according to their unit (1kWh) consumption as shown in the Table VIII [8].

TABLE VIII. TARIFF FOR RESIDENTIAL CONSUMERS

Residential Consumers Per Unit Charges (MD less than 5KW)		
S. No.	*Consumer kWh/month*	*PKR/kWh*
1.	Up to 50	3.00
For consumers exceeding 50kWh/Month		
2.	01-100	11.15
3.	101-300	15.50
4.	301-700	17.50
5.	Above 700	19.50

As shown in Table IV, the unit consumption per month are maximum in June, while they are minimum in the month of January. Units consumed per home in June and January is 225kWh/Mon/H and 74.1kWh/Mon/H respectively. As electricity bill per month has been calculated on the basis of charges for exceeding 50kWh/month. The revenue generation for selected sites on monthly basis for the months of June and January has been listed in Table IX.

TABLE IX. COMPARISON OF CONSUMED UNITS AND REVENUE GENERATION

Comparison of Consumed Units and Revenue Generation in Various Sites of KPK					
Site Name.	***No. of Homes***	***Month***	***kWh /Month /H***	***Electricity Bill /Month in (PKR)***	***Total site Revenue /month in (PKR)***
Shage Lawagher	176	June	238	3254	572704
		Jan	85	948	166848
Kamanger	110	June	238	3254	357940
		Jan	85	948	104280
Faqir Abad	203	June	238	3254	660562
		Jan	85	948	192444

VI. INSTALLATION OF SOLAR PHOTOVOLTAIC SYSTEM

To install a solar power system at any locality, the important parameters that can be considered are peak load demand, intensity of solar radiations, type and size of photovoltaic, ambient temperature, population density, types of consumers, size of batteries and inverters in case of AC load, charge controller, and efficiency of solar system. To install a solar power system the capacity of the system has been decided on the basis of simultaneous maximum demand. Simultaneous maximum demand has been calculated from the diversity factor, which is the ratio of sum of individual maximum demand to simultaneous maximum demand of the system. In this research work design of solar power system for 5kW load has been considered. To analyze electrification of selected sites by solar PV system, simultaneous maximum demands of selected sites for the month of June has been considered in segments of 5kW.

A. Design of Solar Power System for 5kW Load

For steady load of 5kW units consumption and ampere hours on daily basis are 120kWh and 2500Ah. Battery bank according to the load requirement will consist of 40 batteries each of 12 volts 250Ah. A solar panel of 12kWp will be required to produce 120kWh with 10 hours sun shine in June. To get 12kWp peak output power, 60 solar panels each of 200W are required. Each solar panel has open circuit voltage (V_{oc}) and short circuit current (I_{sc}) of 44volts and 5amps respectively. To connect these solar panels in 2 series connections and 30 parallel connections, 88volts and 150amps can be achieved. Charge controller of 160 amps and converter of 10kW are required. Table X shows capital cost analysis for the installation of 12kWp solar PV system to feed 5kW load for 24 hours.

TABLE X. COST OF SOLAR POWER SYSTEM INSTALLATION FOR 5KW LOAD

Cost of Various Accessories for Installing a Solar System				
S. No.	***Description of components***	***Capacity of Component***	***Cost/Unit (PKR)***	***Total Cost /Component in (PKR)***
1.	Solar Panel	12kWp	120PKR/W	1440000
2.	Charge Controller	160A	1250PKR/A	200000
3.	Inverter	10kW	35PKR/W	350000
4.	Wire + Structure	-	13PKR/W	156000
5.	Installation	-	-	100000
6.	Batteries	2500Ah	260PKR/Ah	650000
Grand Total				2896000

B. Capital Cost Calculation for Selected Sites

Capacity of solar PV system has been based on simultaneous maximum demand, greatest SMD occurs in the month of June for selected sites. 5kW solar PV systems required have been calculated by dividing SMD of site by 5. Table XI shows required number of 5kW solar PV systems and total capital cost for targeted sites of KPK.

TABLE XI. CAPITAL COST OF SOLAR SYSTEMS FOR SELECTED SITES

Capital Cost Analysis of a Solar PV System					
S. No.	***Name of Site***	***SMD of Site***	***Cost/ 5kW in (PKR)***	***No of 5kW Solar PV Systems***	***Total Capital Cost/Site in(PKR)***
1.	Shage Lawagher	59.026	2896000	12	34752000
2.	Kamanger	36.89	2896000	8	23168000
3.	Faqir Abad	68.08	2896000	14	40544000

C. Revenue Calculation

Revenue for the selected sites is calculated on the basis of fixed charges as well running charges. Running charges includes maintenance and operation charges for solar PV system [9]. Per unit cost for solar PV system is taken as 10PKR, which is less than per unit cost of grid extension. Table XII shows monthly electricity bill and total revenue generation per month per home for each site of KPK.

TABLE XII. REVENUE CALCULATION OF SELECTED SITES FOR SOLAR PV SYSTEM

Comparison of Consumed Units and Revenue Generation in Various Sites of KPK					
S. No.	***Site Name***	***Name of Month***	***kWh /Month /H***	***Electricity Bill /Month/H in (PKR)***	***Total Site Revenue /Month in (PKR)***
1.	Shage Lawagher	June	238	2380	418880
		Jan	85	850	149600
2.	Kamanger	June	238	2380	261800
		Jan	85	850	93500
3.	Faqir Abad	June	238	2380	483140
		Jan	85	850	172550

VII. CONCLUSION

Solar mapping shows that Khyber Pakhtunkhwa (KPK) has high potential of solar energy and installation of solar photovoltaic (PV) system can be a suitable and economical option for electrification of rural areas. Load curves for selected sites shows that maximum demand and kWh consumption per month is small. Electrification analysis shows that revenue generation from selected sites is very small as compared to the capital investment and running charges in case of grid extension. In case of stand-alone solar power system electrification is economical. Solar PV systems can supply electricity for 24 hours while in case of distribution grid consumers will face the problem of load shedding. Hence it can be concluded that installation of solar PV system is viable solution for electrification of selected sites in KPK, Pakistan.

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