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A FEASIBILITY STUDY: OFF-GRID PHOTOVOLTAIC SOLAR POWER SUPPLY TO THE REMOTE AREAS OF PAKISTAN

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Globally, electricity access in remote and rural areas has always been economically and technically challenging due to the long distances among the load centers and nearest power grid lines including substations; low load densities and challenging topography. Predominantly, diesel generators (DG) are used to meet the load demands for these areas due to their convenience and economic advantages. Nevertheless, solar PV systems are the most widely used and the fastest growing off-grid renewable energy technology (RET) deployed in these off-grid type power supply systems. This is due to the abundance of solar irradiance available in most parts of the world, and the rapidly decreasing cost of PV technologies. In this feasibility study, economic analysis of off-grid photovoltaic solar power supply system was performed for the remote areas of Pakistan. The average demand of each family in remote areas of Pakistan is around 100 watts/day (DC power supply). The analysis revealed that the total capital investment required to run the 100 watts DC system for a day is about PKR 10800 or USD 630 with the life of ~25 years. The payback period of this DC off-grid PV system is only 2.5 years which make it feasible for the remote and off-grid areas of Pakistan.

Keywords: off-grid power, PV energy, remote areas, payback period, solar radiation.

INTRODUCTION

The electricity demand is increasing day by day not only due to population increase but also due to invention of new tools for life comfort. Presently electricity is one of the basic rights of human being. In order to achieve the said right, it was planned that all the villages in Pakistan should be electrified till 2007. But due to financial and electricity production problems the goal "Electricity for all" was not achieved in time and only 76% villages were electrified out of 125000 villages (Mirjat *et al*., 2017; Yazdanie, 2010). It was assessed that still 30 million people are bound to live without electricity (Kamran, 2018). Which represent that such a huge population is living without necessities of life like electrical lightening and artificial temperature control. It was proposed that government should invest rupees sufficient budget on yearly basis to address such issues targeting alleviate of poverty (Raheem *et al*., 2016). On the other hand, areas with electricity supplies were also facing 6 to 12 hours of load shedding (Khalil and Zaidi, 2014) in urban as well as rural areas the demand-supply gap amounts to 5000 MW on average which reaches 7000 MW in the month of July when the energy demand is at peak and it was assumed that the said load shedding will become adverse if not addressed properly in time (Iqbal *et al*., 2018).

In the current scenario, if non electrified areas that are normally remote areas with low population density (Figure 1) were connected to power grid, the load shedding situation will become more adverse as well as cost of connecting such areas will be much high which can't be met due to financial constraints.

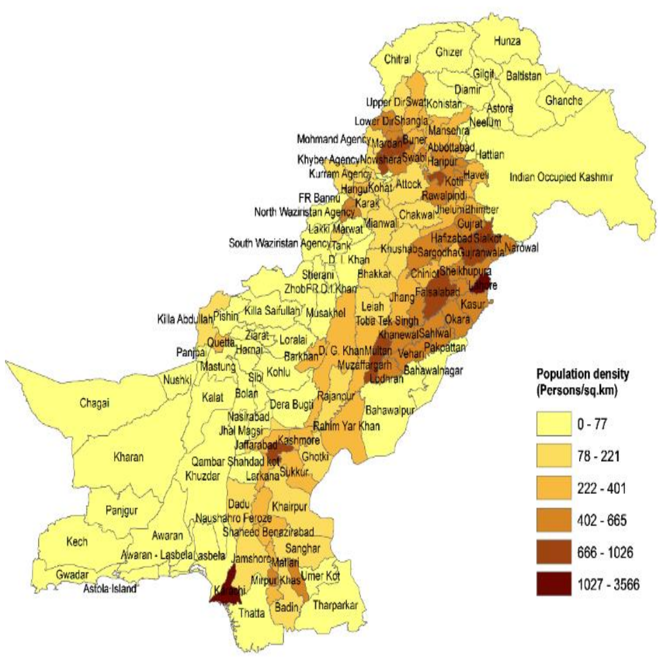

Figure 1. Districts wise population density of Pakistan.

So, renewable off grid means of electricity are the best solution for said areas. In this regard, it is observed that renewable energies based on mini grids can be placed in service faster due to small-scale infrastructure (Oladokun and Asemota, 2015; Rabetanetiarimanana *et al*., 2018). Comprising all facts, the aim of present study is to provide economical, rapid and reliable source electricity in remote areas in a more to fulfill their necessities. To achieve the goal, a feasibility study was designed and conducted to generate electricity from photovoltaic (PV) solar system for remote areas of Pakistan having low population density with high average solar radiation as shown in Figure 2.

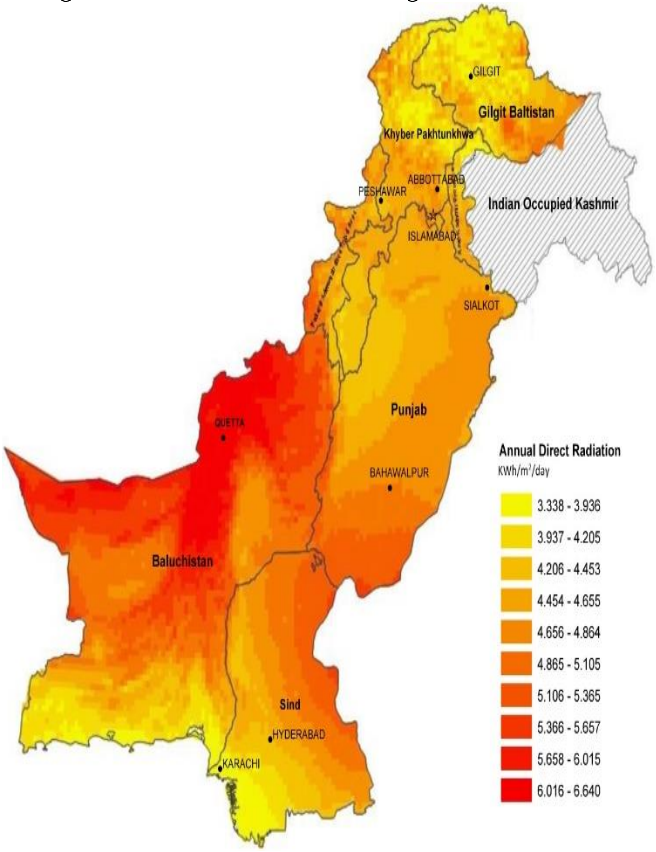

Figure 2. Average solar radiation intensity of Pakistan (PCRET, 2018).

MATERIALS AND METHODS

Materials shown in Figure 3 including PV panels, aluminum bars, charge controller, dry batteries, DC invertors, cables with connectors, LED lights and DC fans used in proposed off grid PV solar system are available in local markets of Pakistan. Figure 3 illustrate the flow line diagram and working of off grid PV system (Breyer and Gerlach, 2013).

Economic Analysis: The payback period of proposed off grid PV solar system was calculated using simple linear graph in M.S Excel Version 2016.

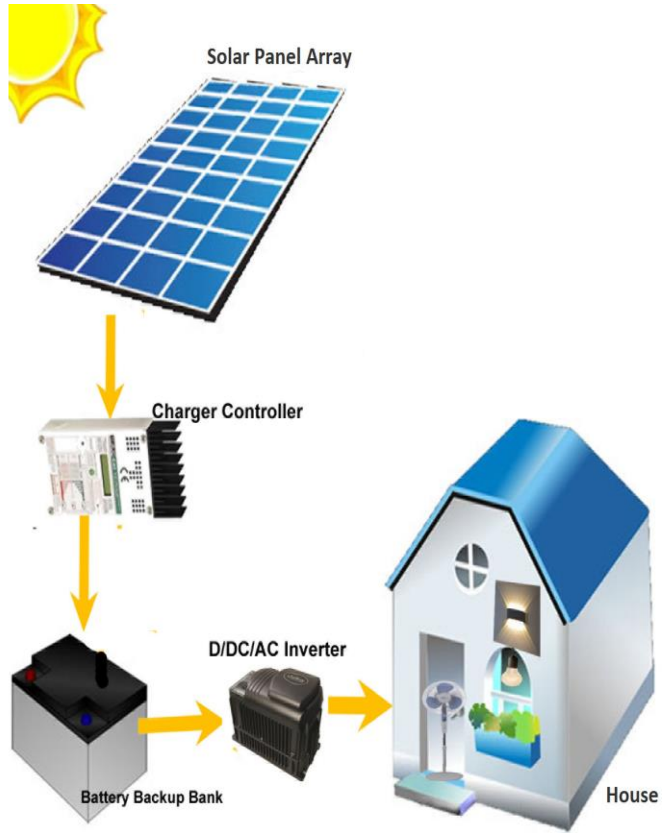

Figure 3. Schematic diagram of proposed off-grid solar photovoltaic system

RESULTS AND DISCUSSION

Operating and maintenance cost**:** Consideration of cost for battery replacement cost as well as the operation and maintenance of the system is extremely important for the accurate assessment of profit of the investment. In a research presented by Campoccia *et al*. (2009) the maintenance cost has been found in the range of 1% to 3% of the initial investment for a year. The present study is based on the assumption that the replacement of battery cost is 50% or almost 4% increase annually of the initial cost of battery (Jamal *et al*., 2017; Jamal *et al*., 2019).

Performance ratio (PV system losses)**:** As the losses from battery, cable length, type of material etc. are considered, the performance ration (PR) is taken between 75% to 90% for the PV systems as reported by Mani and Pillai (2010) and Peng *et al*. (2013).

Various studies have been conducted for the PR determination of PV systems and finding indicate the PR value to be 0.75 (Alsema and de Wild-Scholten, 2006), 0.84 for well planned PV systems (Jahn and Nasse, 2004) and 0.75 for roof top installations (Fthenakis *et al*., 2011). In the light of these findings and life cycle assessment (LCA) of the PV

Table 1. Cost estimation of material used in proposed 300 Watts off grid PV solar system to run 1 ceiling fan (25W), 1 portable pedestal fan (25W) and 4 LED lights (10W each = 40W).

Material	Function	Description	Quantity	Price (PKR)	Price (USD)
Mild steel stand	To fix 3 PV solar panels of 150W power	3 cm x 3 cm x 0.5 cm angle iron will be used to manufacture a 220 cm x 150 cm rectangular stand	1	4800	30
PV solar panel	To supply DC during sunshine hours	150 Watts and 12 Volts	3	20000	125
Charge controller	To take DC current from solar panels and supply it to the dry batteries	30 Amp. and 12 Volts	1	4800	30
*Dry battery	To store power during sunshine hours and continues supply during and after sunshine hours	100 Amp. And 12 Volts	1	25600	160
DC invertor	To take power from battery and supply to the electric appliances	to supply a stable voltage and current	1	12800	80
Electric cables with connectors	Conduit of current		1	4800	30
LED lights		10 Watts	4	2400	15
DC ceiling fan		25 Watts	1	8000	50
DC pedestal fan		25 Watts	1	8000	50
Power plugs, on-off switches and boards			10	1600	10
Labor charges and transportation	To install the off-grid PV system	-	-	8000	50
Total				108000	630

*Life span of dry battery is approximately 8 years and its average cost will be increased almost 30%. The reselling price of old dry battery is almost 10% of its original cost. Therefore, 30%-10% will be added after every 8 years.

systems, the value of PR is assumed to be 0.80 in the present work.

***Economic Analysis*:** Table 1 shows the total cost of off-grid ½ kW PV system, while Figure 4 shows the cost benefit ratio of PV system against existing alternative current (AC) system. The accumulative cost of AC system line intersects with off-grid PV system at 3rd year. It means the total cost of off-grid PV system will be recovered within 3 years and the pay-back period of off-grid solar system is only 3 years.

***Cost Estimation of AC system*:** Annual average power consumption of 1 ceiling fan and 1 pedestal fan (120 W each) = 120W x 2 fans x 20 hours/day x 30 days x 9 months = 1296000 Wh = 1296 kWh

Annual average power consumption of 4 energy savers (25W each) = 25W x 4 lights x 8 h/day x (30 days x 12 months) = 288000 Wh = 288 kWh

Total average annual power consumption by a house in remote areas of Pakistan = 1296 + 288 = 1584 kWh

Average price of one kWh in Pakistan = PKR 25 (USD 0.156)

Total annual cost of 1584 kWh = 1584 x 25 = 39600 (USD 247)

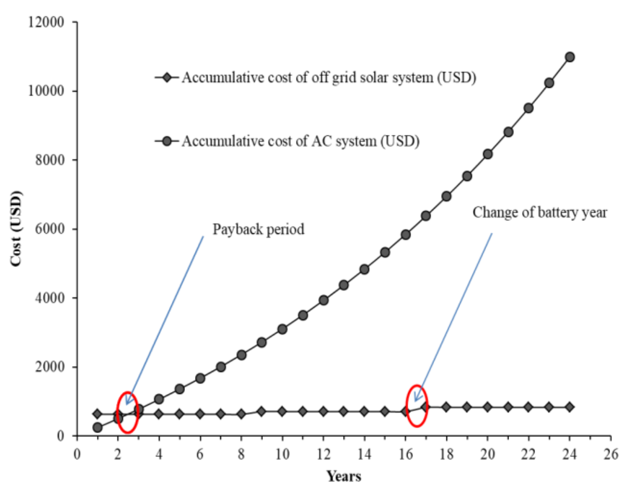

Figure 4. Cost benefit ratio of PV off-grid system on yearly basis

***Conclusion*:** The overall cost of electricity supply to the remote areas is very high due to less density of remote areas of Pakistan. Off-grid solar power supply to each house is the best possible solution in terms of economic and reliability of the power supply system. The payback period of off-grid solar system for remote areas of Pakistan is only 2.5 years which makes this proposed system adoptable. This system will also provide opportunities for the investors, NGO's and other funding agencies.

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