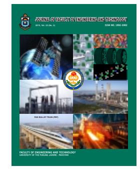
JFET 22(2) (2015) 61-68

Journal of Faculty of Engineering & Technology

journal homepage: www.pu.edu.pk/journals/index.php/jfet/index



MODELLING OF OPTIMIZED STAND-ALONE PV SYSTEM FOR BASIC DOMESTIC ENERGY USE IN PAKISTAN

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Abstract

Energy is a basic and vital for sustainable economic development of any developing country including Pakistan. A renewable energy solution for the energy crisis in a densely populated city of Lahore, Pakistan is presented in this article. PV system software is used to design a stand-alone PV system to tailor the basic energy demand for household requirements. Geographical and climatic study exposes that Pakistan has enormous potential of solar energy with average value of 5-6 kWh/m^2/day or 1800-2200 kWh/ m^2/annum. Accordingly, present research proved that this technology is a viable clean energy source. The modelled system has met the maximum demand using nominal space on roof top along with battery storage, leaving sufficient space for further expansion of the system to meet increase energy demand. As a result, the system has shown a promising sign and proves its feasibility for the region with energy loss consideration.

Keywords: PV System Pakistan, Energy crisis, Renewable energy Pakistan, Stand-alone, TMY, Solar power

1. Introduction

Energy is an important commodity for continued human development and economic growth. Availability of sufficient, affordable energy is vital key to eradicate poverty, improving human welfare and raising living standards worldwide [1]. Historically, fossil fuels are the main source of energy supply and contributed major part in fulfilling the human energy demands. Renewable energy sources have also been important for human from early times Renewable energy sources (biomass, solar, wind, geothermal and hydropower) are more environmentally friendly than other energy sources. The renewable energy sources have the potential to provide energy with zero or almost zero emission of air pollutants and greenhouse gases [2]

According to B.P energy outlook 2035, released in January 2014, world primary energy demand will increase by 41% from 2012 to 2035 with annual average growth rate of 1.5%.

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The major consumers will be residential and agriculture sectors in form of electricity [3]. Pakistan is an energy deficient country, where majority of population has no provision of basic energy facilities like electricity and gas. The primary energy consumption per capita was 5.70 MWh in 2010 and 5.60 MWh in 2011 where as in developed countries like U.K it was 37.40 MWh and 34.60 MWh for same period [4]. Pakistan largely depends on oil imports as main source of primary energy. In the recent years rapid increase in crude oil price has created concerns about expensive energy. The situation is even more worst as electricity crisis is going on since 2007 [5]. According to National Electric Power Regulatory Authority (NEPRA) 2014 report, under current policy and planning the electricity shortage crisis will continue till 2019 [6].

In order to reduce Pakistan dependence on oil imports and meets the energy requirements by utilizing available energy resources renewable energy is an alternate solution. Solar energy is available throughout the country with sufficient potential (5-6 kWh/m^2/day or 1800-2200 kWh/m^2/annum) for community energy requirement. This is the only resource in the country linked with no legal, political and social dispute [7, 8]. The solar energy map of Pakistan is shown in Figure 1.

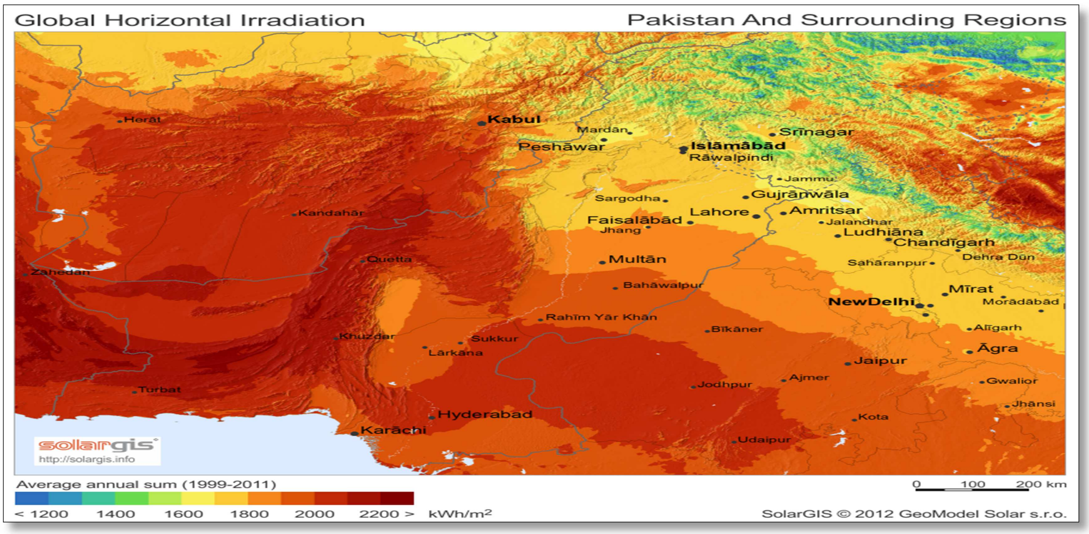

Figure 1: Solar energy map of Pakistan [9]

Photovoltaic (PV) system is the direct conversion of sunlight into electricity. PV devices are simple in design and require relatively less maintenance. A significant advantage of solar photovoltaic devices is that they can be used as stand-alone systems as well grid connected system. The size of a PV system ranges from microwatts to megawatts [10, 11]. The laboratory efficiencies of multi-junction cells and concentrating PV are reaching as high as 44% and panels available in market have efficiencies in range of 15%.[12] The price of PV panels decreased from about US$ 30/Watt about 30 years ago to less than US$ 1/Watt in 2013. In the global market share of thin film solar cell has increased in the last decade because of lower price. Currently, the Silicon based panels are dominant with market share of about 80% [13]. Solar PV generation capacity worldwide has increased sharply in last two years. In year 2013, more than 39 GW was added making worldwide total capacity of about 139 GW [14]. In International

Energy Agency (IEA) new policies scenario, PV share in electricity generation will increase to 950 TWh by 2035, which will increase from 0.4 % to 2.6% of total world electricity generation [15].

Many researchers have designed stand-alone PV system for different locations worldwide with different approach and programs. The work of M.Egido et al [16], K.Bataineh et al [17], A.Fragaki et al [18], R.Sridhar et al [19], and T.Khatib et al [20] is similar to current work.

2. Materials and Methods

1.1.

2.1. Climate Conditions for Modelling

In present research standalone PV system is modelled using Typical Meteorological Year (TMY) data. The TMY2 data is available in the PVsyst program for locations worldwide. TMY is suitable for long term prediction of system performance. The area selected for the analysis is Lahore as it is second largest city of Pakistan and its climatic condition represent for more than 60% population of country [21]. The TMY data is extracted for Lahore region and shown in table 1.

2.2. PV System Software

PVsyst is a photovoltaic design and simulation software used for full featured study and analysis of both grid connected and stand-alone system. It contains large databases of PV components (PV modules and inverters), location and meteorological information. The output data describes total energy production (kWh) on monthly basis, performance ratio (%) and specific energy (kWh/kWp) with the main energy gains and losses involved with the system. [22].

Table 1: TMY2 data for Lahore [23]

Monthly mean weather data for Lahore					
Month	G (W/m^2)	T_{max} (°C)	T_{min} (°C)	Wind speed (m/s)	RH (%)
January	119.80	18.13	7.45	1.62	75.07
February	164.91	20.65	9.66	2.22	66.84
March	205.83	26.18	14.50	2.60	59.91
April	231.83	32.39	19.85	2.84	46.21
May	254.84	37.21	24.45	2.97	39.33
June	264.77	38.21	27.55	3.40	48.70
July	229.90	35.08	27.55	3.04	68.24
August	230.88	33.83	27.29	2.66	75.16
September	226.77	33.35	24.80	2.22	75.11
October	174.81	30.97	20.04	1.73	68.15
November	137.76	25.58	12.97	1.55	72.50
December	115.71	20.42	7.88	1.55	79.14

2.3. Modelling of PV System

As mentioned in section 1, Pakistan is facing electricity shortage, a stand-alone solar PV system will be designed to meet domestic basic load of light, entertainment, and comfort to perform every day activities inside house. The present model is designed for the stand-alone PV system to meet the annual electrical energy requirement of a house hold with basic consideration of seasonal variation in operational hours of load. In summer season fans are used for comfort and in winter season an electric heater is sufficient to provide comfort. According to NEPRA report 2014, the monthly electricity consumption of basic domestic consumer is from 0-100kWh [6].

A typical house with kitchen and bathroom is considered for the present analysis. The quantity and capacity of electric appliances installed to fulfil the basic requirements of the house as shown in Table 2. The daily usage of each and every appliance is taken on average with variable usage for each month with respect to season and fed to the system. The load values of appliances (Fluorescent Lamp and TV) are taken from the System standard library and power consumption is from the available market products [24]. The average operational hours of each lamp is 10-12, TV 7-8 and each fan 7-14 hours. This difference is considered for seasonal variation in temperature and humidity ratio as shown in Table 2.

Table 2: Specification of electrical appliances

Description	**Quantity**	**Type**	**Capacity**
Fluorescent lamp	3	AC	18 W
TV	1	AC	90 W
Ceiling Fan 56''	1	AC	70 W
Pedestal fan 20''	1	AC	70 W
Heater	1	AC	1000 W

A typical roof size of $25m^2$ (author own observation) is considered for the installation of the solar PV system. The PVsyst contains a complete library of market available PV solar system components from leading manufacturers. The type of electrical designs for PV power systems used for homes is a fixed Si-poly Solar PV panel of 230Wp with 24V, 236Ah batteries, and (Maximum Power Point Tracking) MPPT converter as well. These specifications are according to market available equipment in India. Balance of System (BOS) equipment includes wiring systems and mounting systems used to integrate the solar modules with the structural and electrical systems of the house. The wiring systems include disconnects for the AC and DC sides of the inverter.

The slop of module set to zero in summer season (April to October) and 30° for winter season (November to March) as per NASA surface meteorology and solar energy data for Lahore [25].

3. Results and Discussion

3.1. Analysis of Roof-mounted Solar Panels

The solar PV system is designed to cater the 100% basic electrical energy requirement of the house hold with an average load of 2.5-3.5 kWh/day. To get the 100% solar fraction for setup of the system, it is found that the 4 solar panels with 4 batteries constitute an efficient system to meet the energy demand with minimum storage and other losses. The area occupied by the module is approximately 7m2 It lefts a lot of space on the roof for other activities and it can very well be utilized for future expansion to meet increased load requirement.

3.2. Overall Energy and Losses of the PV System

The design system meets the 100% of energy load for all the months and providing a surplus energy as shown in Figure 2. The system delivers seasonal requirement, one can effectively use the surplus energy for additional works or increased operational hours of appliances. The system is based on 33% of total energy by direct use and 67% with storage.

The maximum energy production is observed for the month of May and June with small decline observed in the month of July to October because of monsoon season. It further continues to decrease till January and then start peaking from the month February.

The maximum demand of energy is in summer with maximum load in the months of June, July, August, and September. As the fans are not used in winter the load of winter months are comparatively low, however the introduction of heater for the chilling months of December January and February is reflecting the increase in loads when compared with October and March as later are considered to be the months of moderate climate.

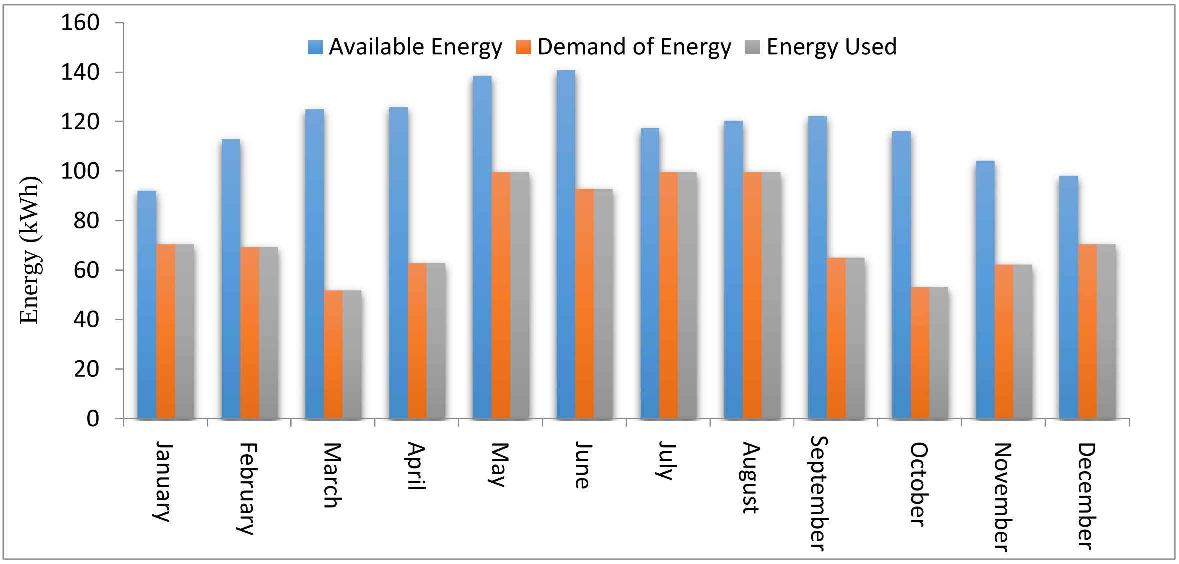

Figure 2: PV system energy availability and demand

The actual output efficiency of selected solar panels is 14.1%. The output energy available sown in figure 4 is after considering multiple annual losses. The major annual energy loss is unused energy, which due to less storage and usage compared to energy available and it is about 30.8% of total available. This loss can be overcome by increasing electricity usage. The losses of the stand-alone PV system are shown in figure 3.

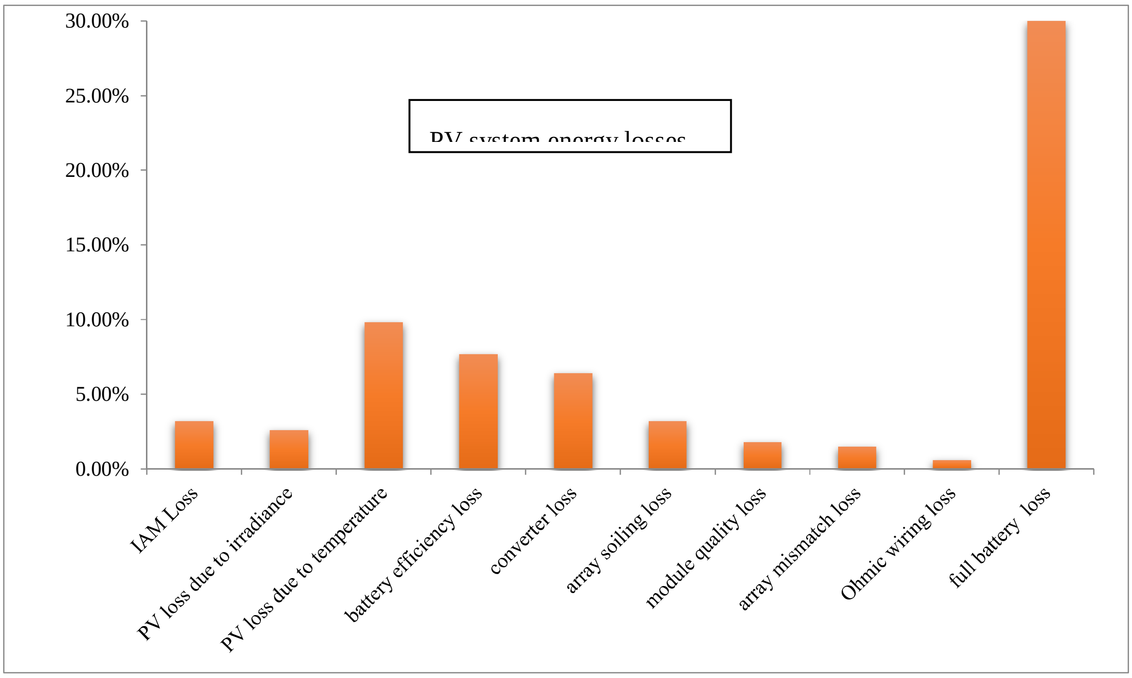

Figure 3: PV system energy losses

4. Conclusions

PVsyst software is used to design a stand-alone PV system to cater the need of energy for basic household requirements. The Lahore region was selected for the study as it represents general climate and major population of Pakistan. Geographical and climatic study reveals that Pakistan has immense potential of solar energy with average value of (5-6 kWh/m^2/day or 1800-2200 kWh/ m^2/annual). Overall, the system has shown a promising signs and proves its feasibility for the region with energy loss consideration.

Analysis of the results has shown the viability of the technology in the region. The system has achieved the 100% demand with in a typical space available at the roof top along with battery storage space, leaving ample amount of space to allow the expansion of the system to meet the future requirements.

It has been successfully able to compete with the peak load of the season with surplus energy. The unused surplus energy can effectively be used for other purposes based on the seasonal requirements. A further modification in the system will add up to the viability of the system, like introduction of single or double axis tracker over a fixed plane system will increase the efficiency of the system.

An economic analysis will be required to further consolidate the introduction of the technology in the region.

The change of collector slope with respect to seasonal and monthly variation can increase the output of the system.

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