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Cost and energy analysis of a grid-tie solar system synchronized with utility and fossil fuel generation with major Issues for the attenuation of solar power in Pakistan

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ABSTRACT

The entire world is facing severe energy crises. Gas, coal, biomass, oil, hydropower, wind, and solar power are the essential bases of energy for local and industrialized use. In the current work, four energy sources are synchronized in parallel to fulfil the energy demands: biogas (BG), the grid-tie solar system (GTSS), the water and power development authority (WAPDA) and diesel generators (DGs). This article describes a cost and energy analysis of the GTSS with two other energy resources and finds that the output of the GTSS is more efficient. At present, 406-kW solar panels are connected at the University of Lahore, Pakistan; this system consists of 19 on-grid inverters, each of which has a power capacity of 20 kVA, but this system is not working efficiently. Many solar systems in Pakistan also fail to produce the required output power, and Pakistan is currently facing a severe energy shortage. To overcome the energy shortfall, the results show that Pakistan should upgrade its energy system through solar thermal units. In this article, we compare the GTSS with two other energy sources and find that the GTSS is more economical and environmentally friendly. The billing cost comparison shows that solar energy has a lower unit cost than other energy resources and is a renewable source of energy with many advantages. If the installed GTSS continues to produce 60% of its total power, assuming 7 working hours per day, then the system will be able to return its capital cost in 6.9 years and save a total of $1,020,819.83. Our results are discussed considering the quality of the product, the required standard manpower for installation, the geographical location of the system and other parameters that affect the solar energy output.

1. Introduction

For the economic development of any nation, energy is a critical input (Gules et al., 2008). The progress and development of a nation depend on the energy available to its people (Agbossou et al., 2004). The energy requirement is gradually increasing because of growth in both industrial development and population. The increasing electric energy usage reduces the available resources and results in energy crises and inflation (Reddy and Yohan, 2015). Pakistan is also facing an annual energy shortage of approximately 5000 MW. More than 40,000 villages in Pakistan are not electrified. To overcome this crisis, alternate resources are required to produce energy (Bank, 2011; Nawaz et al., 2013). Compared to other resources, solar energy resources are plentiful. In addition, several regions of Pakistan, including Lahore, Bahawalpur, Quetta, Rajanpur, Multan and Faisalabad, receive the maximum radiation of approximately 6.8–8.3 kMJ/m^2 per year (Farooq, n.d.). The use of solar energy in these areas will produce a large amount of energy that can replace traditional electricity-generating sources (Force et al., 2003; Kanwar and Tabish, 2012).

The current article aims to examine the conditions required to improve the efficiency of a grid-tie solar system (GTSS). The main objective of this work is to calculate the cost and energy by comparing three sources the water and power development authority (WAPDA), the GTSS and diesel generators (DGs) to determine which energy source is best for electricity production as well as safe, environmentally friendly and economical. This work also explains how we can best overcome the energy shortage in Pakistan in the industrial sector and in the educational area, where load shading is currently a prominent issue.

Solar systems have many applications, the foremost of which are as follows:

(1) Off-grid solar systems (OGSSs) or stand-alone PV systems are

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independent systems that can work without a link to the main grid. Extra power generated by the solar system is stored in batteries. This type of system includes solar modules, battery power banks and off-grid inverters (IRENA, OFF-GRID Renewable Energy Systems: Status and Methodological Issues, 2015; Moradi et al., 2013).

(2) On-grid solar systems or GTSSs are commonly used in industry. In these systems, there is no battery bank for storage. Solar energy is the primary source and grid used. By net metering extra power can fed into the main grid. Current system is for daytime power generation and consumption only. For night-time consumption, we can save generated power in daytime using battery bank, which will ultimately increase the initial cost of the system. Therefore, for daytime there is no need for battery bank backup. With the system advisor model (SAM), Hadis Moradi shows that 97.7% of the utility bill is retained in the first year, and the net savings amount per year is $2525. The payback period of the system is 13.9 years (Moradi et al., 2013). Lashway analysed the cost, size and power of a grid-connected PV system. The results indicate that the owner of the house can save $647.68/yr., and the return on investment of the GTSS is eleven years. Gohul shows that the GTSS system provides a reliable provision to the main grid, and the cost analysis shows that the savings amount is $ 47.48/yr (Mojumdar et al., 2011; Lashway and Elsayed, 2014; Gohul et al., 2011).

(3) A hybrid solar system is a combination of an OGSS and a GTSS, where the main source of energy is solar, and the excess power is stored in a battery power bank; when the storage capacity is filled, extra power feds into the main grid through net metering. (Ingole and Rakhonde, 2015).

2. Grid-tie solar system

The off-grid PV solar system and GTSS are two major types of PV solar systems. Figs. 1 and 2 show the GTSS synchronized with the utility and fossil fuel generators. The grid-tie inverter and solar modules are arranged on the rooftop as shown. The installed solar panels have a power of 406 kW. A class of solar panels is used in which each panel has a power of 260 W. Each string has 23 modules connected in series. The specification of the module is shown in Table 1; polycrystalline solar modules are used because they are more efficient at high temperatures than mono-crystalline solar cells. The current system is installed in Lahore City, where the temperature can exceed 40 °C in summer (Sajjad et al., 2015).

2.1. Solar module specifications

The solar panel module in the present system is REC Peak Energy 260 W. REC is a leading global provider of solar energy solutions. REC is headquartered in Norway and listed on the Oslo Stock Exchange (ticker: RECSOL) (REC, n.d.). Sixty REC PE multi-crystalline solar cells (three strings of 20 solar cells) are connected with bypass diodes. With an anti-reflection surface treatment, 3.2 mm solar glass is used. The back sheet has a double layer of highly resistant polyester. The frame is made of anodized aluminium. The junction box contains a 4 mm^2 solar cable and a multi-contact MC4 (4 mm^2). The solar cell in the module has an efficiency of 16.1%; it means that solar cell converts 16.1% of available sun energy into electrical energy; solar cell efficiency totally depends upon its weight over power and volume over power ratio. the nominal operating temperature is 45.7 °C (± 2), and the operating temperature is −40 °C to 85 °C. An analysis of its mechanical data shows that the dimensions are 1665 × 991 × 38 mm, the area is 1.65 m^2, and single solar module has weight of 18 kg. All the modules are connected in series and parallel and spread all over the roof not on single point. All installation is done under security protocols and in any case if there's need to shift the whole system then whole setup can shift from one place to other one.

2.1.1. Grid-tie solar inverter fuel-saving controller specifications

The SMA fuel-saving controller is a major component in photovoltaic diesel hybrid solutions. The DG generally depends on the demand-based control of the photovoltaic system. The operating rate under ambient conditions is from -10 °C to 50 °C. The maximum operating altitude is 2000 m above mean sea level, and the humidity range is 5–95% (non-condensing).

3. Projected solar system

Before discussing the present system, we highlight the important principles for the effective use of solar systems. First, we check the installation location, environmental temperature and size of the roof available for the solar system. The quality of the solar panels and inverter should be high; we must also check the straightforwardness in the system to ensure integral storage and accurate monitoring, which are key considerations in making the system more efficient (Dincer and Meral, 2010; Chikate and Sewagram, 2015). A PV solar system depends on sunlight to produce electric energy. The power produced by solar modules depends on the angle and intensity of light. Generally, the angle should be 30-45° for maximum output; if the structure is fixed, an optimized angle should be used (Rehman et al., n.d.). For Lahore City, the latitude is 31° 32′ N, the longitude 74° 22′ E, and the tilt angle from the vertical is 58° 28′ (Town et al., n.d.). We install all equipment according to the manufacturers' specifications, and the cables are high-duty, aluminium-conductor, PVC class A, fire-retardant cables. The shadow and dust effects also decrease the output energy (Aribisala, 2013; Srinivasan et al., 2014). The dust factor is included in the power losses along with other reasons. A good solar system has an efficiency of approximately 60% with seven sunny hours. Solar system efficiency depend upon total installed capacity of solar verses total generation capacity, equally divided by solar hours in a day from sunrise to sunset. If one system installed in Pakistan has efficiency 60% it is not necessary that have same efficiency in other country, same system could has different system efficiency because of availability of sun in a day, its intensity, inverter efficiency, charge controller and solar cell's IV characteristics, shading, temperature and cable thickness (6 Factors

(a) (b)

Fig. 1. Grid-tie inverter and display of the diesel generator output at the University of Lahore.