Energy Conversion and Management 90 (2015) 458–465

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Preliminary assessment of a small-scale rooftop PV-grid tied in Norwegian climatic conditions

Muyiwa S. Adaramola *, Emil E.T. Vågnes

Department of Ecology and Natural Resource Management, Faculty of Environmental Science and Technology, Norwegian University of Life Sciences, Ås, Norway

ARTICLE INFO

Article history:
Received 12 August 2014
Accepted 16 November 2014
Available online 6 December 2014

Keywords:
PV system
Array yield
Energy output
Final yield
Performance ratio
Norway

ABSTRACT

This study presents the performance assessment of grid-connected PV system installed on the roof of a building. The results presented were based on data recorded from March 2013 to February 2014. The total annual energy output delivered to grid was found to be 1927.7 kW h, with an annual specific yield of 931.6 kW h and monthly average energy output of 160.6 kW h. Furthermore, the annual average daily array yield, final yield and reference yield of the PV were estimated as 2.73 kW h/kW$_p$, 2.55 kW h/kW$_p$ and 2.80 kW h/kW$_p$, respectively. In addition, the annual average daily PV module efficiency, system efficiency and inverter efficiency were 12.7%, 11.6% and 88.8%, respectively. The overall annual capacity factor, system losses and performance ratio were found to be 10.58%, 16.96% (with respect to reference yield) and 83.03%, respectively. The findings from this installation indicate that PV-connected system is technically feasible for electricity generation in Norway and could a play role in the future energy mix of the country.

1. Introduction

1.1. Background

Due to global decline in fossil fuel reserves and contribution of their emissions (during the extraction, production and utilization processes) to climate change, many countries are now examining their national energy policies with view of shifting toward low-carbon and renewable sources of energy. In addition, security of supply and fluctuations in crude-oil prices (which can be sensitive to internal and regional conflicts) can lead to economic vulnerability of oil importing countries. Furthermore, the oil exporting countries can use the price of these resources to settle political difference.

Electricity generation in Norway is currently dominated by hydropower. For instance, in 2012, electricity generation in Norway is 147.8 TW h, of which hydro power accounted for 96.7%, while wind power plants accounted for about 1% (1548 GW h) and thermal power plants accounted for 2.3% (3 358 GW h) [1]. As a result of various agreements and initiatives (with European Union and Swedish government, for examples), the government of Norway is committed to increase renewable energy resource share of Norwegian primary energy consumption to 67.5% and 10% renewable energy in transport by 2020 and become carbon free economic by 2050. In order to achieve these targets, development and investment in other renewable energy resources such as wind and solar energy, in addition to hydro power, are essential. Most recently, more attention has been placed on wind energy development due to favorable wind resource along the coastal and offshore regions of the country.

Due to improved technology and reduction in PV cost, solar energy is expected to play a significant role in the future global energy mix, both in the developed and developing countries. The global cumulative installed capacity of PV system increased rapidly from 1.4 GW in 2000 to about 102.2 GW in 2012 [2]. In 2012, the PV cumulative installed capacity per habitant in selected countries is shown in Table 1. This table shows that the cumulative installed capacity in Norway is merely 0.02 W$_p$/capita while that of Germany is 398 W$_p$/capita. It has been reported that if the current reduction of PV system costs can be sustained, grid-parity is possible in entire Europe in 2030 (central and southern regions between 2015 and 2020 and extended to northern region between 2020 and 2030) [3]. Also grid-parity is expected by 2017 in most regions in the USA [4] and in most regions of China by 2016 [4].

1.2. Solar resource in Ås, Norway

Norway with her location on the northern part of Europe is located in a region with low sunshine duration belt where the solar radiation is generally low. The main latitude and longitude of

* Corresponding author. Tel.: +47 6496 5793; fax: +47 6496 5801.
E-mail address: muyiwa.adaramola@nmbu.no (M.S. Adaramola).

http://dx.doi.org/10.1016/j.enconman.2014.11.028
0196-8904/

Norway is 62°N and 10°E. The major part of the country lies within the Tropic of Cancer and the Arctic Circle. The climatic condition of Norway varied from temperate climate along the coastal area to cold humid weather in the inland. The yearly sum of solar irradiation in Norway has been previously shown to be varied between 1.64 kW h/m^2/day and 2.5 kW h/m^2/day [5]. Due to generally low solar radiation, PV installations in Norway are dominated by domestic stand-alone systems which accounted for 9.250 MW out of total installed capacity of 9.95 MW in 2012 [6]. In 2013, the Norwegian Water Resources and Energy Directorate (NVE) approved a regulation that allows electricity customers that installed solar modules on their buildings' roof, or other homes or businesses that generate limited amount of power and can sometimes produce more power than they need, to feed the excess production to the local grid [7]. These customers are referred to as plus customers ('*plusskunder*' in Norway) in the NVE regulation. This regulation can be viewed as an incentive for installation of solar-PV in private households. The NVE hope that this regulation would encourage organization and individual to investment in PV system.

The daily monthly average global solar radiation on horizontal surface in Ås (latitude 59.65°N and longitude 10.76°E, and about 105 m above sea level), the location of the PV-grid installation used in this study, is presented in Fig. 1. The information presented in this figure was based on 10 years data (from January 2004 to December 2013). The global solar radiation was measured using Eppley Precision Pyranometer with maximum uncertainty of about 10%. The global solar irradiance data was recorded every 10 s, from which hourly, daily and monthly global solar irradiation data were obtained. It can be observed that monthly average of the global solar radiation varies between 0.710 MJ/m^2 (in December) and 19.8 MJ/m^2 (in June) with average annual mean of 9.02 MJ/m^2 (or about 2.5 kW h/m^2).

1.3. Focus of this study

Performance assessment of PV systems is the best way to determine the potential for PV power production in an area. There are many performance evaluation studies of PV modules installed outdoors across Europe [8–14] and globally [15–19]. However, apart from the work of Midtgard et al. [20], there is little information available (in open literature) on the actual operation and energy production from PV systems in Norway. The aim of this work is provide information on energy production from a small-scale PV-grid integrated system located in Norway. It is believed that the results presented in this study will provide useful information to policy makers and interested individual and organization about actual performance of grid-connected PV system in this country. The objectives of this study are therefore, to examine the technical viability of a solar PV as energy source in Norway and to estimate energy output from the PV system. In line with these objectives, the results obtained from field monitoring performance of a 2.07 kW photovoltaic grid-connected system installed at the Norwegian University of Life Sciences, Ås Norway (Ås is about 30 km south of Oslo) are presented in this present work. Even though, Norway is in temperate region with generally low solar irradiation, the initial findings from this installation indicate that PV-tied system can operate efficiently and the performance of the system is comparable with similar PV-tied systems installed in the northern Europe.

Table 1
Cumulative installed capacity of PV system per capita in 2012 [2].

Country	PV (W_p/capita)
Australia	105
Canada	22
China	6
Germany	398
Israel	31
Japan	55
Norway	0.02
Peru	0.5
South Africa	0.6
South Korea	22
USA	24

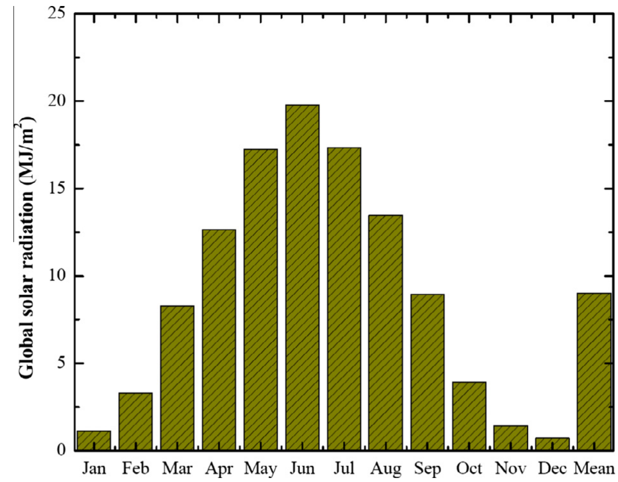

Fig. 1. The average daily monthly global solar irradiance on surface horizontal surface at Ås Norway.

2. PV systems

The PV energy system can be divided into three basics categories. These categories are: grid-connected system without storage facility, grid-connected system with storage facility (e.g., battery) and, off-grid PV system (mostly with battery). In an isolated or remote area with no grid access, the off-grid PV system with storage facility may only be reliable way for the habitants of these areas to have access to electricity. In addition, the off-grid system can facilitate grid extension to the remote area with relatively large scale mini-grid insolated system. The grid-connected system with storage facility can be a good option for areas with less reliable grid system.

However, in areas with good utility grid system, it is possible to reduce the storage cost by connecting them directly to the utility grid and this combined system is referred to as 'grid-connected PV system'. In this arrangement, when the PV produces more energy than needed, the surplus energy is fed into the grid and, energy is taken from the grid when it produces less energy than needed. This grid-connected can either be a small scale (mostly, rooftop and building integrated PV, in kW) or large scale (in megawatt size). Some of the advantages of rooftop PV-grid tied energy system include [21,22]: (i) it can reduce energy and capacity losses in the utility distribution network due it closeness to the load; (ii) upgrades to the transmission and distribution network can be avoided or delayed especially in the areas where the average daily output of the PV system corresponds with the utility's peak demand period, and (iii) it can be cost competitive. A typical PV-grid connected system consists of PV array, inverter and grid system.

3. Methods and materials

In the section, the description of the grid-tied PV system used in this study as well as data analysis methods were presented.