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Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland

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ABSTRACT

This paper presents results obtained from monitoring a 1.72 kW_p photovoltaic system installed on a flat roof of a 12 m high building in Dublin, Ireland (latitude 53.4°N and longitude 6.3°E). The system was monitored between November 2008 and October 2009 and all the electricity generated was fed into the low voltage supply to the building. Monthly average daily and annual performance parameters of the PV system evaluated include: final yield, reference yield, array yield, system losses, array capture losses, cell temperature losses, PV module efficiency, system efficiency, inverter efficiency, performance ratio and capacity factor. The maximum solar radiation, ambient temperature and PV module temperature recorded were 1241 W/m^2 in March, 29.5 °C and 46.9 °C in June respectively.

The annual total energy generated was 885.1 kW h/kW_p while the annual average daily final yield, reference yield and array yield were 2.41 kW h/kW_p/day, 2.85 kW h/kW_p/day and 2.62 kW h/kW_p/day respectively. The annual average daily PV module efficiency, system efficiency and inverter efficiency were 14.9%, 12.6% and 89.2% respectively while the annual average daily performance ratio and capacity factor were 81.5% and 10.1% respectively. The annual average daily system losses, capture losses and cell temperature losses were 0.23 h/day, 0.22 h/day and 0.00 h/day respectively.

Comparison of this system with other systems in different locations showed that the system had the highest annual average daily PV module efficiency, system efficiency and performance ratio of 14.9%, 12.6% and 81.5% respectively. The PV system's annual average daily final yield of 2.4 kW h/kW_p/day is higher than those reported in Germany, Poland and Northern Ireland. It is comparable to results from some parts of Spain but it is lower than the reported yields in most parts of Italy and Spain. Despite low insolation levels, high average wind speeds and low ambient temperature improve Ireland's suitability.

1. Introduction

Electricity generation in Ireland is largely based on exhaustible fossil fuels such as oil, gas and coal of which imports in 2008 accounted for 90% of all production. World reserves of these fossil fuels are fast diminishing which will inevitably lead to increased energy prices causing serious concerns for Ireland in terms of economic competitiveness and security of supply. It is therefore imperative that economic growth should be decoupled from the existing heavy dependence on fossil fuels. In order to reduce its dependence on fossil fuels, and to play its part in global warming mitigation, Ireland must develop viable renewable energy supply and efficiency policies which are sustainable in the long-term.

Electricity generation using photovoltaic (PV) systems is important, reliable and has the potential to play a significant role in CO_2 emissions mitigation [1]. It is widely accepted that PV will become one of the major future sources of electricity generation considering the potential for cost reduction of PV systems and grid-parity expected in Southern and Northern Europe around 2020 [2]. Global PV electricity generating technology has sustained an impressive annual growth rate compared with other renewable energy generating technologies. Total global installed capacity of grid connected solar PV was 3.5 GW_p, 5.1 GW_p, 7.5 GW_p and 13 GW_p in 2005, 2006, 2007 and 2008 respectively [3]. Despite this impressive growth, Ireland still lags with virtually little or no installations. In 2008, the cumulative installed PV capacity in Ireland was 0.4 MW_p made up of 0.1 MW_p and 0.3 MW_p of grid-connected and off-grid capacity respectively. The installed photovoltaic power per inhabitant in Ireland was 0.09 W_p/inhabitant while the EU 27 average was 19.2 W_p/inhabitant [4].

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Nomenclature

A_m	PV module area (m^2)
A_a	PV array area (m^2)
AC	alternating current (A)
CF	capacity factor (%)
DC	direct current (A)
E_{AC}	AC energy output (kW h)
$E_{DC,d}$	total daily total DC energy output (kW h)
$E_{AC,d}$	total daily total AC energy output (kW h)
$E_{AC,m}$	total monthly AC energy output (kW h)
$E_{AC,a}$	total annual AC energy output (kW h)
$\bar{E}_{AC,d}$	monthly average daily total AC output (kW h)
$\bar{E}_{DC,d}$	monthly average daily total DC output (kW h)
E_{ideal}	energy generated at rated power (kW h)
E_{real}	energy generated during operation (kW h)
G_{STC}	total solar radiation under standard test conditions (KW/m^2)
G_t	total in-plane solar radiation (W/m^2)
H_t	total in-plane solar insolation (kW h/m^2)
L_c	capture losses (h/day)
L_s	system losses (h/day)
L_T	cell temperature losses (h/day)
P_{AC}	AC power (kW)
P_{DC}	DC power (kW)
$P_{DC,STC}$	DC power under standard test conditions (kW)
$P_{PV,rated}$	PV rated power (kW_p)
PR	performance ratio (%)
Y_A	array yield (kW h/kW_p)
Y_F	final yield (kW h/kW_p)
Y_R	reference yield (kW h/kW_p)
η	efficiency (%)

Subscripts

deg	degradation
m	monthly
inv	inverter
PV	photovoltaic module
soil	soiling
sys	system
STC	standard test conditions
temp	temperature

In April 2008, the Irish Government announced a new micro and small scale electricity generation programme for Ireland. Fifty pilot trial micro-generation installations were due to be installed in 2009 with an average plant size of 1.25 kW_p [5]. This communiqué highlighted the Irish Government's desire to implement a micro-generation programme. In February 2009, the Irish Government announced the implementation of a feed-in-tariff of 19 € cents per kW h for electricity from micro-generation [6]. For such a programme to be successfully implemented, it is imperative that both field trials to provide information on the annual energy yield of typical installations and studies to determine the economics as well as environmental benefits of PV systems in Ireland be undertaken for informed policy implementation.

The aim of this paper is to present results obtained from field performance monitoring of a 1.72 kW roof mounted PV system in Dublin, Ireland. Data collected between November 2008 and October 2009 was analysed to evaluate the suitability of PV systems for installation in residential buildings in Ireland. The PV system is described while different performance evaluation parameters are presented based on collected data. The performance parameters calculated include: annual energy generated, array yield, final yield, reference yield, PV module, system efficiency, inverter efficiency, performance ratio, capacity factor, array capture losses, system losses and cell temperature losses. Results obtained give an indication of system performance and provide a basis for economic and environmental impact appraisal of PV generated electricity and inform policy formulation to promote uptake of the technology in Ireland. Performance data are compared with those obtained in other locations around Europe and the Middle East.

2. The PV system

The PV system was installed on the rooftop of the Focas Institute building, Dublin Institute of Technology, Ireland. It consisted of eight modules covering a total area of 10 m^2 with an installed capacity of 1.72 kW_p within the range of typical domestic installations. The Sanyo HIP-215NHE5 modules were each of 215 W_p capacity and comprised 72 solar cells made of thin mono-crystalline silicon wafer surrounded by ultra-thin amorphous silicon layers. The modules had an efficiency of 17.2% under standard test conditions and were connected in series. The unshaded modules were fixed, inclined at an angle of 53° equal to the latitude of Dublin, facing south at an azimuth angle of 0°. The roof was approximately 12 m high and the modules were mounted on metal frames that were 1 m high.

The PV modules were left uncleaned throughout the monitoring period to mimic operation in a domestic dwelling. A single phase Sunny Boy SB 1700 inverter was used to convert DC to AC which was fed directly into the building. The inverter had a rated maximum efficiency of 93.5% and maximum AC power of 1700 W. The solar irradiation sensor had an accuracy of ±8% and a resolution of 1 W/m^2. The PV module temperature sensor was a PT 100-M type with accuracy of ±0.5 °C while the ambient temperature sensor was a JUMO PT 100 U type with accuracy of ±0.5 °C. The ane-

Fig. 1. The PV system installation.