Solar 2 Lab Report

PV Design for the Wolfson Mechanical Engineering Façade

RENEWABLE
ENERGY
SYSTEMS
TECHNOLOGY

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Executive Summary

The PVSYS solar data analysis modeling software (version 4.36) was used to perform a solar site analysis and energy yield report for a grid-connected photovoltaic (PV) system. This analysis also includes a shading analysis for the Wolfson Mechanical Engineering Building stairwell facade located on the campus of Loughborough University located in the Leicestershire, UK. The geographical site and meteorological information was extrapolated from Birmingham, UK longitude 2.2°W, latitude 52.3°N, elevation 100 m, albedo of 0.20 and incident radiation at IAM 0.05.

The PV system array components selected include forty (40) BP585L Saturn semi-transparent mono-crystalline BiPV laminate solar modules to cover an area of 25.2 m^2 of the upper part of the southwardly-facing façade orientated azimuth -30° and 90° tilt with an array nominal power output of 3.4 kW_p. It is recommended the modules be fitted into a structural glazing system of the façade in four parallel strings of ten modules in series by using a carrier frame that can be bonded to the unit to enhance the façade's aesthetics.[1] To convert DC to AC power, two (2) SMA Sunny Boy SWR 2000 inverters with total nominal power rating of 3.6 kW AC and operating voltage of 125-500V were selected.

Overall performance metrics for the array include an annual energy production of 1245 kWh/year, at an energy cost of £1.45/kWh with a total system cost of £11,533, amounting to an annual cost of £1802/year. The performance ratio (PR) for this system is 51.5%, and an efficiency of 13.5% at standard test conditions (STC) for the PV array. This system affords a carbon emissions impact opportunity reduction of a 535.35 kg CO_2 per annum. A 50% grant was obtained from the UK Low Carbon Buildings Phase Two Organization for systems with an installed capacity of > 0.5 kW.[2] A 5% loan was secured over 20 years, a VAT of 15% imposed, 5%/year O&M considerations and 15% for balance of system (BOS) equipment i.e. wiring, ballasting supports, carrier frame, etc. are included in this estimate. Labor, planning transportation considerations were not included in this estimate.

'Window dressing' aesthetics aside, and although budgetary constraints were not a consideration, with performance being tantamount, overall this location is far from ideal. A better option would warrant a rooftop installation with perhaps an energy monitoring visualization installation of the measured data for demonstration, and to reveal further optimization opportunities for reduction in overall energy consumption of the building.

Contents

1 Introduction

The Wolfson Mechanical Engineering Building is located in the West Park on the campus of Loughborough University located in the Leicestershire province of the United Kingdom.

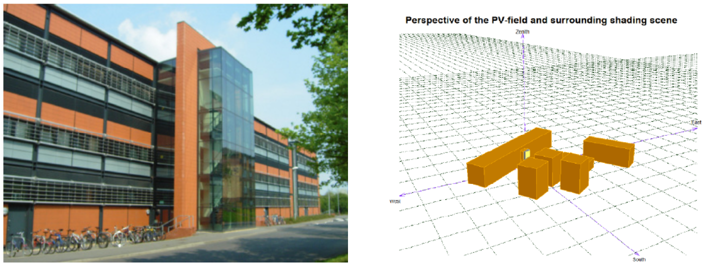


Figure 1. Wolfson Mechanical Engineering Building Façade & PV field-shading scene.

Reference Data

Location: Loughborough, Leicestershire, UK (extrapolated from Birmingham, UK)

Longitude: 2.2°W

Latitude: 52.3°N

Elevation: 100 m

Glossary

Notations	Convention
BiPV	Buliding Integrated Photovoltaic
BOS	Balance of System
IAM	Incident effect, ASHRAE parameter
kg CO_2	Equivalent ton of carbon dioxide
£/kWh	Price/kilowatt-hour
kWh	Kilowatt-hour
kWh/kW_p	Kilowatt-hour/Kilowatt-peak
PR	Performance Ratio
PV	Photovoltaic

2 PV System Design

For the two facades on the Wolfson Mechanical Engineering Building, a simulation was carried out, where performance results were collected, analyzed incorporating monthly and annual production, yield and performance ratios and losses. The system design and considerations investigated follow.

System Performance Analysis

Design options investigated

Standard BP584 PV modules were compared against the BP585L Saturn semi-transparent monocrystalline BIPV laminates covering an area of 25.2 m^2 of the upper part of the southwardly-facing façade orientated azimuth -30° and 90° tilt. The modules fitted into a structural glazing system.[1] of the façade in four parallel strings of ten modules in series. The only configuration option provided was to mount vertically on the glass stairwell façade of the building. Achieving a maximum energy yield (kWh/kW$_p$) by minimizing the impact of shading on the annual operation and performance is investigated. Originally, two facades were considered, but after determining the poor location of the site, predominantly due to the pervasive shading, this investigator opted out of sizing an array on the adjacent, western façade because it did not seem justifiable for overall annual power output. To convert DC to AC power, two (2) SMA Sunny Boy SWR 2000 inverters with total nominal power rating of 3.6 kW AC and operating voltage of 125-500V were selected. [See Table 1]

System energy outputs

Site evaluation based on an annual horizontal global irradiance of 922kWh/m^2 at STC for a 13.5% solar collector efficiency. After accounting for losses e.g. -22.9% global incident in collector plane, -24.1% near shading factor on global irradiation, and -4.4% IAM factor on global irradiation, etc., the available energy at the inverter yields 1245 kWh/year. Array nominal power output of 3.4 kW$_p$ was ascertained. Annual PR for this system returned 51.5%. Had the western façade been fitted with modules, although still far below nominal performance recommendations for a PV array, it's likely a 54% PR could have been achieved.

Seasonal effects on the energy yield

Although severely inhibited by shading throughout the day, the best opportunities for direct insolation occurred during the months of April through September, when the optimal window of operation was between the hours of 900 – 1600 hours. May produced the highest monthly effective global correction for IAM and shadings, with an 80.44 kWh/m^2 global incident radiation on the collector plane. All told, even though insolation opportunities were greatest during the warmer season months, due to the close proximity of adjacent structures, shading was more pervasive and energy yields lower during these warmer summer months, June, July and August. Collection losses due to shading amounted to 0.87 kWh/kWp/day over the year. Highest system efficiency achieved was 7.79% during March and September. [See Figure 2]

Positioning, inclination, orientation and shading considerations

Multiple simulations were run to influence inverter losses and influence the kWh/kW_p by sizing and placing the PV array in different location to reduce shading impacts. Placing the array near the top of the façade minimized shading losses. In adjusting the simulations, the PR varied from 0.54 to 0.50, albeit the cost per kWh generated would almost be similar. Under-powering the inverter aids in reducing the inverter losses. Largest losses influenced were Near Shading Factor on Global and Inverter Loss During Operation. Inverter losses amounted to -7.4%; this included during operation (efficiency) and due to power threshold losses. These considerations impacted the overall, annual efficiencies of the array 7.5% and system 6.69%. [See Table 2]

Other considerations

Soiling de-rating correction factor of 2% chosen due to the fact that the modules are in a 90˚ degree vertical position and in a geographical location where frequent rain is complementary to keeping dirt and debris minimal.

System Cost Considerations

Economic and environmental outcomes [3]

Overall performance metrics for the array include an annual energy production of 1245 kWh/year, at an energy cost of £1.45/kWh, with a total system cost of £11,533, amounting to annual cost of £1802/year. This system affords an opportunity for a 535.35 kg CO_2 reduction per annum. Had the western façade been fitted with modules, it's likely a nominal increase in kg CO_2 could have been achieved.

The UK Low Carbon Buildings Phase Two Organization for systems with an installed capacity of > 0.5 kW was taken advantage for a %50 grant toward the cost of the system.[2]

A 5% loan was secured over 20 years, a VAT of 15% imposed, 5%/year operations and maintenance (O&M) considerations and 15% for balance of system (BOS) equipment i.e. wiring, ballasting supports, carrier frame, etc. are included in this estimate. Labor, planning transportation considerations were not included in this estimate.

Table 1. PV Façade System Report Summary Simulation Parameters

PVSYST V4.36		07/05/09	Page 1/3

Wolfson ME Bldg Facade - Lboro University
PV Site Analysis & Cost-Itemization

Grid-Connected System: Simulation parameters

Project :		**Wolfson Mechanical Engineering Bldg Facade**		
Geographical Site	**Birmingham**		**Country**	**United Kingdom**
Situation	Latitude	52.3°N	Longitude	2.1°W
Time defined as	Legal Time	Time zone UT+0	Altitude	100 m
	Albedo	0.20		
Meteo data :		Birmingham , synthetic hourly data		
Simulation variant :		**Simulation variant_Wolfson_Project**		
	Simulation date	07/05/09 07h36		

Simulation parameters				
Collector Plane Orientation	Tilt	90°	Azimuth	-30°
Horizon	Free Horizon			
Near Shadings	No Shadings			
PV Array Characteristics				
PV module Si-mono	Model	**BP585L Saturn**		
	Manufacturer	BP Solar		
Number of PV modules	In series	6 modules	In parallel	6 strings
Total number of PV modules	Nb. modules	36	Unit Nom. Power	85 Wp
Array global power	Nominal (STC)	**3.1 kWp**	At operating cond.	2.74 kWp (50°C)
Array operating characteristics (50°C)	U mpp	99 V	I mpp	28 A
Total area	Module area	**22.7 m²**	Cell area	18.5 m²
PV Array loss factors				
Heat Loss Factor	ko (const)	29.0 W/m²K	kv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (800 W/m², Tamb=20°C, wind 1 m/s)			NOCT	45 °C
Wiring Ohmic Loss	Global array res.	0.0 mOhm	Loss Fraction	0.0 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.6 % at STC
Array Soiling Losses			Loss Fraction	5.0 %
Module Quality Loss			Loss Fraction	3.0 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1-bo (1/cos i - 1)	bo Parameter	0.05
System Parameter	System type	**Grid-Connected System**		
Inverter	Model	**PV-WR 1800**		
	Manufacturer	SMA		
Inverter Characteristics	Operating Voltage	80-130 V	Unit Nom. Power	1.8 kW AC
Inverter pack	Number of Inverter	2 units	Total Power	3.6 kW AC
User's needs :	Unlimited load (grid)			

Table 2. Seasonal and Annual Energy Production Data Main Results

PVSYST V4.36		07/05/09	Page 2/3

Wolfson ME Bldg Facade - Lboro University
PV Site Analysis & Cost-Itemization

Grid-Connected System: Main results

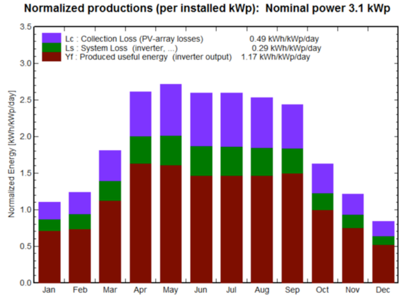
Project : **Wolfson Mechanical Engineering Bldg Facade**

Simulation variant : **Simulation variant_Wolfson_Project**

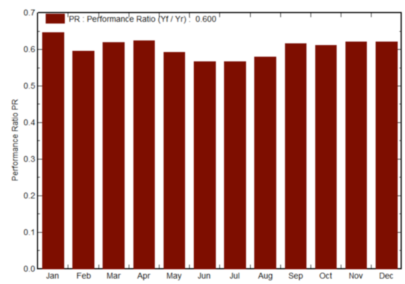
Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	90°	azimuth	-30°
PV modules	Model	BP585L Saturn	Pnom	85 Wp
PV Array	Nb. of modules	36	Pnom total	**3.1 kWp**
Inverter	Model	PV-WR 1800	Pnom	1.80 kW ac
Inverter pack	Nb. of units	2	Pnom total	**3.6 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**1304 kWh/year**	Specific	426 kWh/kWp/year
	Performance Ratio PR	60.0 %		
Investment	Global incl. taxes	2461 £	Specific	0.80 £/Wp
Yearly cost	Annuities (Loan 5.0%, 20 years)	197 £/yr	Running Cost	0 £/yr
Energy cost		**0.15 £/kWh**		

Normalized productions (per installed kWp): Nominal power 3.1 kWp



Performance Ratio PR



Simulation variant_Wolfson_Project

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	EOutInv kWh	EffArrR %	EffSysR %
January	20.0	3.40	34.21	33.21	82.6	67.7	10.66	8.72
February	33.0	3.60	34.65	33.41	80.5	63.1	10.25	8.04
March	63.0	5.70	56.18	53.94	132.2	106.4	10.38	8.36
April	105.0	8.00	78.46	75.06	184.4	149.8	10.37	8.42
May	136.0	11.20	84.19	79.77	191.4	152.8	10.03	8.00
June	138.0	14.10	77.88	73.55	172.1	135.0	9.75	7.65
July	139.0	16.00	80.44	75.99	176.6	139.4	9.69	7.65
August	120.0	15.90	78.39	74.64	175.2	139.0	9.86	7.82
September	81.0	13.70	73.06	70.29	168.8	137.7	10.19	8.32
October	47.0	10.40	50.50	48.57	116.3	94.6	10.16	8.26
November	25.0	6.70	36.47	35.39	85.6	69.3	10.36	8.38
December	15.0	4.60	26.00	25.20	61.0	49.4	10.35	8.38
Year	922.0	9.48	710.44	679.02	1626.6	1304.2	10.10	8.10

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	EOutInv	Available Energy at Inverter Output
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

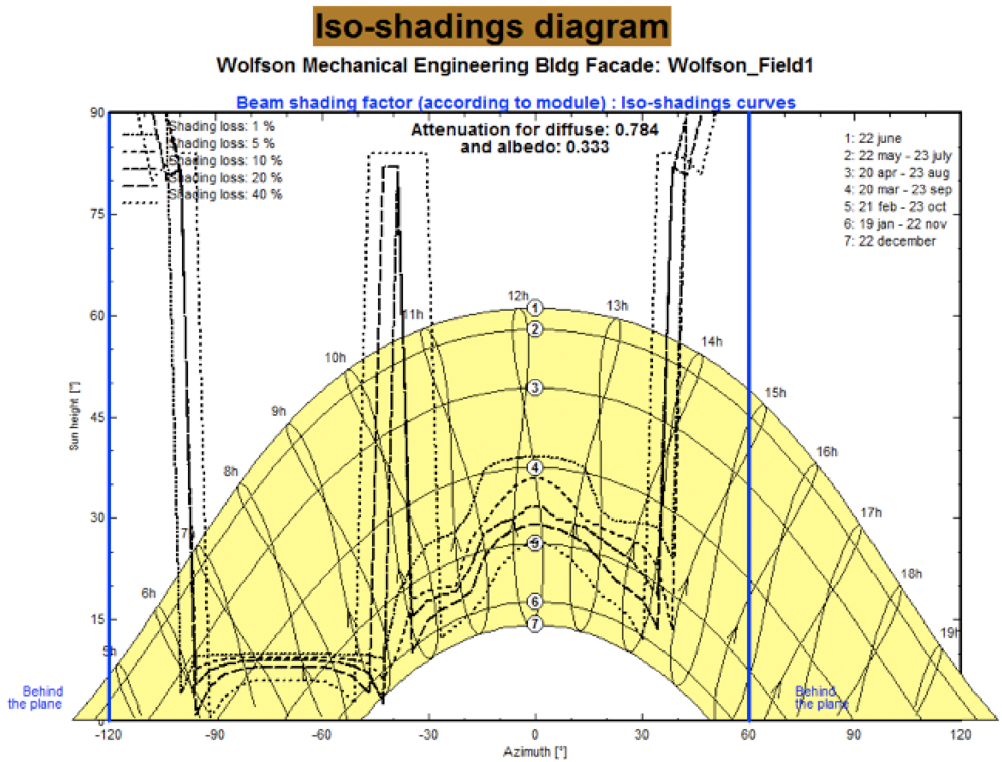


Figure 2. Iso-shading showing beam shading

3 Conclusions and Analysis

A discussion on the performance criteria for improving system performance of a grid-tied system follows.

System design comparison versus ideal system

The global incident radiation is the single most important factor for determining if generation of solar energy is feasible. As an example, an extreme effect of shading, say having 50% of one cell shaded on a mono-crystalline PV module can result in a 50% loss of module power[4]

When the proposed vertical array is hampered by a poor site location, due to the impact of shading from adjacent structures, a better option for a PV array might be the rooftop, by adding bypass diodes, or by reconfiguring the array with shorter strings in series, and blocking diodes in modules in parallel. Essentially, if shading is unavoidable, orientation of the modules is critical.

The only benefit for a larger system would only be a slight kg CO_2 reduction, since the location of this west facing façade has a great deal to be desired due to the impact of pervasive shading from adjacent structures. Although a great deal of on-grid PV systems tend to be optimized for summer months, in the case of this system on the Wolfson Mechanical Engineering Building, this installation ended up being an exercise in futility. Due to the prevalence of high, imposing structures, a better option would be a roof-top installation.

Looking at the ideal system analyzed in Task 1, with a PR of 74.2% and energy generation of 818 kWh/year, compared with the PR of 51.5% and energy generation of 1245 kWh/year of the Loughborough site, the latter warrants a focused and discerning look to see where opportunities lay for improvement.

The overall impression of this researcher is losses should be cut on any attempts to install a system at this location, that is, unless the adjacent structures are demolished to allow better insolation opportunities. Interestingly though, both systems produced their highest energy generation in the month of April; 112.4 kWh for the Task 1 system, and 153.1 kWh for the Loughborough array. Similarly, the lowest energy generation for both configurations occurred during the month of December, 18.5 kWh and 4.24 kWh for Task 1 and Loughborough, respectively.

Recommendations and PV system material considerations

Selecting appropriate PV modules for a given site is complicated and requires careful consideration of many variables for harnessing the incident solar radiation and converting it into electricity. PV systems are usually designed to meet a specific load and rarely consistent in configuration and component usage.

PV module selection

Mismatched or dissimilar modules in a series configuration can lower the short circuit current and drive a module into reverse bias, consuming power. In the case of a parallel configuration, the worst cell will be driven beyond its open circuit voltage and consume power. Mitigating power consumption is as simple as installing modules with similar performance characteristics in similar string configurations. The key practical criteria for selecting the correct PV module follow:

- Size
- Voltage
- Availability
- Warranty
- Mounting characteristics
- Cost per watt

Balance of systems (BOS) [4]

When considering a location for a PV system, the site location can drive the BOS configuration. Basic options mounting options which can be fastened to the ground, roofs, poles, or building façades include:

- Fixed
- Tilt Adjustable
- Tracking
- Building Integrated

In the case of a grid-tied inverter, ideal features include:

- High-efficiency
- Reliability
- Cascadability – series or parallel expansion capability
- AC/DC disconnects
- Ground fault protection

Wiring, disconnects and mounting brackets are also part of the BOS.

Minimizing losses

An inverter converts (DC) electricity to alternating current (AC) electricity, and if selected correctly presents one of the best opportunities for minimizing array losses. Mismatched or dissimilar modules can also have an adverse affect in power production, as well as how they are mounted in proximity to the inverter to minimize voltage drops i.e. loss of voltage due to a wire's resistance. And of course, site location where maximum peak solar hours can be achieved is ideal and where shading is minimal.

Other practical factors to consider: [5]

- Understanding your solar resource i.e. orientation
- Loads – time of use
- Local climate characteristics
- Distance from power conditioning equipment e.g. voltage drop considerations in wiring
- Mounting
- Accessibility for maintenance
- Safety i.e. grounding, etc.
- Human factors – vandalism, theft protection, aesthetics
- Establishing access to capital costs reduction or grants programs

BiPV pros [1]

- Lighting - BIPV advantageous, semi-translucent
- Load - weigh less than traditional PV modules
- Aesthetically pleasing – manufactured in different colors, can be tailored to increase energy output for time of day/season
- Cooling opportunity
- Recognized by Underwriters Lab for fire & electrical safety
- Unframed laminate - flexibly designed to fit with current building design, utilizing less framework material

4 References

[1] PowerGlaz® BIPV Modules web site. [Online] [Cited: May 4, 2009] http://www.powerglaz.co.uk/index.php?option=com_content&view=article&id=45&Itemid=55

[2] UK "Low Carbon Buildings Programme - Phase 2" (LCBP2) web site. [Online] [Cited: May 4, 2009.] http://www.lowcarbonbuildingsphase2.org.uk/index.jsp

[3] Solarbuzz Solar Module Retail Price Environment web site. [Online] [Cited: May 4, 2009.] http://www.solarbuzz.com/Moduleprices.htm

[4] [Citation – Study Notes for PV Design and Installation, Sutton, Kris. Solar Energy International, Lecture notes handout for PV Design and Installation. May 2004]

[5] Messenger, Roger A. Photovoltaic Systems Engineering, 2nd Edition, s.l, CRC Press, 2004.