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A Methodical Approach to Evaluating the Technical and Economic Feasibility of an Industrial Photovoltaic Project

Don Isiko[1], Zahir Dehouche[1] and Severin Baumann[2]

[1]School of Engineering and Design, Brunel University, Uxbridge, UB8 3PH, United Kingdom
2 Dept. of Research and Development, TRUMPF Maschinen AG, Ruessenstrasse 8, 6340 Baar, Switzerland

Abstract

In this paper a systematic approach to assessing the technical and economic feasibility of installing a photovoltaic system at an industrial site in Baar, Switzerland is developed. A 336kWp photovoltaic system is designed with the aid of CAD software followed by static and transient system performance analyses for an entire year of operation using simulation software RETScreen and TRNSYS respectively. A test system was constructed to determine the characteristic curves of a single photovoltaic module operating at simulated irradiances in above room temperature conditions; in addition to another test rig for assessing the effects of low temperatures on cell performance. Experimental results bear largely suitable agreement with simulated characteristic curves. A financial analysis is carried out using RETScreen and the installation of the proposed system is found to be a technically and economically favourable option.

Keywords: Integrated Renewable Energy, Solar Panels, Simulation, Legal Factors, Costs

I. INTRODUCTION

Enter the building integrated photovoltaic (BIPV) market. Traditionally only done for gain in the form of corporate image, buildings with integrated PV are becoming increasingly commonplace; driven by an increasing awareness of the available benefits. In America for example, aggressive campaigns involving BIPV installations were made by the U.S. Department of Energy in order to meet its own energy efficiency goals, part of a government that owns more than half a million facilities (Eiffert et al 2009). Europe has also seen exceptional market growth in recent years, stemming mostly from France, Italy and Germany; but with significant future prospects in the other Alpine states. However this fast growing industry is still in its early stages and as such no standard method for the complete design and evaluation of a photovoltaic project has been explored until now. A standard approach is required that encompasses both the technical, legal and financial project parameters, is experimentally supported and can also be theoretically applied to anywhere at reasonable cost within a reasonable time frame.

An industrial complex owned by laser and medical manufacturing company TRUMPF GmbH located in *Baar, Switzerland* is being considered for a commercial photovoltaic project. The roofs of the old and new buildings in addition to the old building car park have been designated as suitable for project development and were the basis for the conception of the following approach:

Step 1. Site Survey and Legislative Analysis

Step 2. CAD-aided System Sizing

Step 3. Simulation Analysis

Step 4. Experimental Validation

Step 5. Financial Analysis

In the following chapter a photovoltaic system is designed with the aid of Siemens NX CAD software and a thorough analysis of relevant legislation is carried out. Chapter III covers the static and transient analyses of the designed system with TRNSYS and RETScreen while chapter IV highlights the key results in experimental validation. Chapter V summarizes the financial aspects of the proposed project and in chapter VI conclusions and areas for further consideration can be found.

II. TECHNICAL DESIGN

Before any form of assessment can be carried out, there needs to be a photovoltaic system with which to assess. Following steps 1 and 2 of our approach a 1431 high performance module system is proposed for TRUMPF's industrial complex (fig. 1).

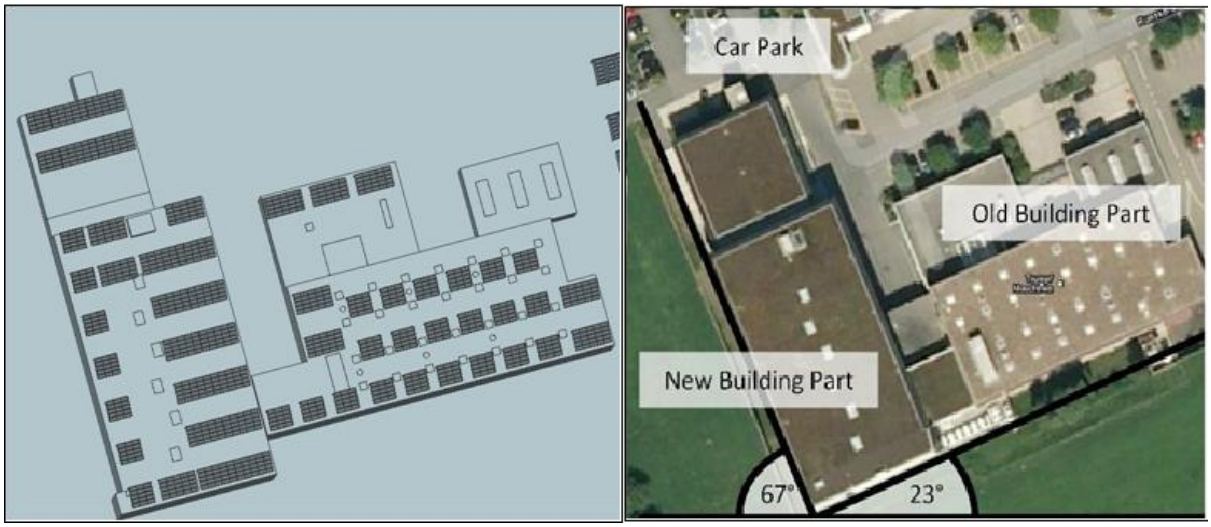

Figure 1. North Pole oriented satellite view of TRUMPF's industrial complex (courtesy of Google Maps) (Right) and CAD recreation of complex with the proposed system (left)

Of the modules that satisfied selection criteria in the areas of efficiency, dimensions, power output, durability and cost the HIT Power S 235Wp module is selected based upon its advantages in cost, performance and size. Standard panel mount configurations are cost effective to use while day lighting windows, ventilation components and car parking space should not be affected by the installation; since various additional costs would arise from needing to resize and reinstall affected building services in order to maintain the quality of the work environment. The effects of shading should also be addressed as this has a significant impact upon both system costs and performance.

A direct-grid transformerless central inverter configuration is selected for this system on the basis of cost effectiveness and reliability in comparison to alternatives; this has proven to be a popular option in European commercial solar PV Installations (Worden et al 2009). A direct grid connected system in which all of the generated energy is not used but exported to the grid is favoured purely because it financially speaking is significantly more beneficial

than exporting only surplus energy. This nicely follows on into the legislative infrastructure in Switzerland. Despite the leaps and bounds photovoltaic technology has made over the last decade the technology remains uncompetitive with fossil fuel sources of energy. Switzerland is one of over 70 countries to have introduced the now popular feed-in-tariff incentive system; where producers of electrical energy from renewable sources are offered a fixed rate to export this energy to the national grid. Beyond this, state and local level policies have been introduced to financially support projects and consolidate the project approval process for PV in particular. The adoption rate for PV in Switzerland was far higher than first anticipated with thousands of projects now on a waiting list estimated to have an equivalent installed capacity of over 450MW. This provides evidence of the effectiveness and importance of incentive policies to providing a competitive edge to current photovoltaic technology (Weibel 2011).

III. SIMULATION ANALYSIS

The performance of the proposed system is simulated at an hourly (TRNSYS) and monthly (RETScreen) resolution for an entire year of operation using the most recent local weather data. The ability to carry out a transient analysis is generally more useful than a static analysis as it minimizes the number of generalizations and provides a higher resolution description of how a given system will perform over a period of time. The following tables and figures are the key results obtained upon simulation. Table I indicates that there was good agreement between TRNSYS and RETScreen while fig. 3 illustrates potential annual energy savings of 12.2%. The PV system output shown in figure 4 possesses an even distribution when compared to the horizontal incident irradiation. This agrees well with incident irradiation data from low latitude climates as high latitude solar projects are commonly installed with inclined panels to emulate equatorial or low latitude yield conditions; with a higher consistency in annual performance. Using TRNSYS module characteristics were also simulated; the logic being that if TRNSYS is capable of accurately predicting actual module behaviour then its system modelling capabilities would have grounds upon which to claim reliability with supportive experimental validation.

Table 1. Summary of Simulated Annual System Performance

	TRNSYS	RETScreen
Predicted Energy Yield (MWh)	385	376

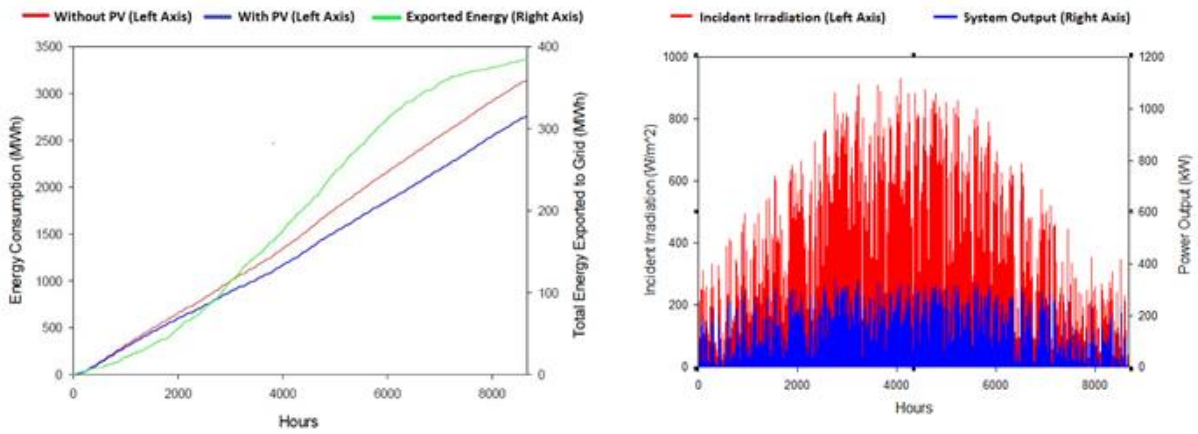

Fig 2. Cumulative energy consumption and exports over one year (left) and hourly horizontal incident irradiation and system output over one year

IV. EXPERIMENTAL VALIDATION

In order for the performance predictions to hold any weight there needs to be some proof of TRNSYS's ability to predict system behaviour. Characterisation of a monocrystalline solar module with similar characteristics to HIT's Power S 235 was carried out at operating conditions representative of a particular month of the year in Baar, Switzerland (fig. 4d). Due to the low winter temperatures in Switzerland a refrigerated cool-box (fig. 4c) was constructed to accurately regulate the temperature of a monocrystalline solar cell that was characterised to investigate low temperature performance; this was required because the facilities for regulating the modules temperature below ambient conditions were unavailable. A self-contained test rig that was capable of operating both experiments was designed with the help of Siemens NX CAD software (fig. 4a and b) and constructed.

Fig 4. a) Rig CAD model b) Complete Rig c) cool-box d) Rig In operation

Fig. 5a and b are example comparisons of simulated and experimental current-voltage and power-voltage characteristic curves at operating conditions representative of a typical day in November and June in Baar. Overall there is an indication of strong agreement between experiment and simulation results, with the difference between simulated and observed maximum module power output falling below 5%. This in turn gives strength to the credibility of TRNSYS and its simulation of an entire PV system operating for one year.

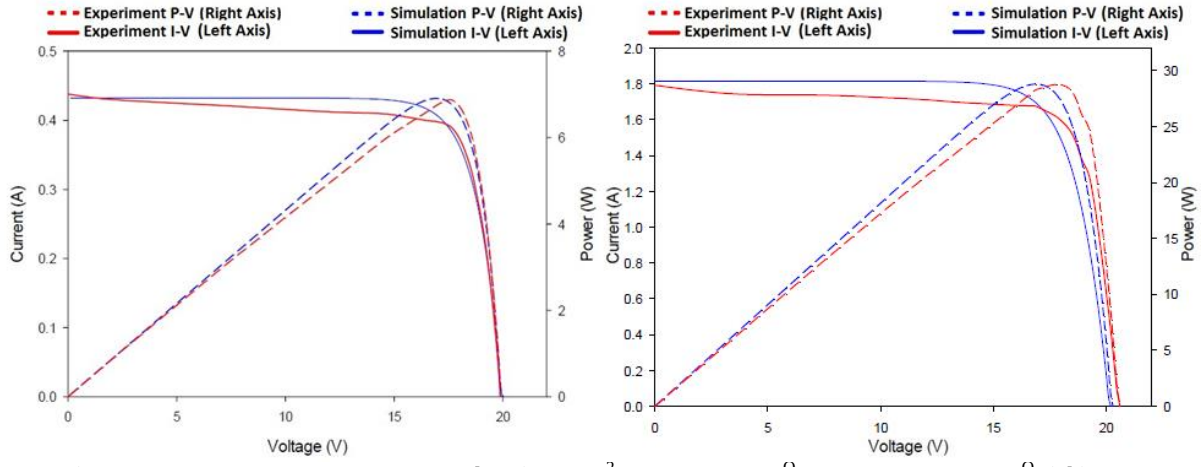

Fig 5. a) Experiment vs. TRNSYS in November (71W/m^2, $T_{CELL\ DESIGN}$: 8^{O}C, $T_{CELL\ ACTUAL}$: 21.5^{O}C) b) Experiment vs. TRNSYS in June (295W/m^2, $T_{CELL\ DESIGN}$: 26^{O}C, $T_{CELL\ ACTUAL}$: 26^{O}C)

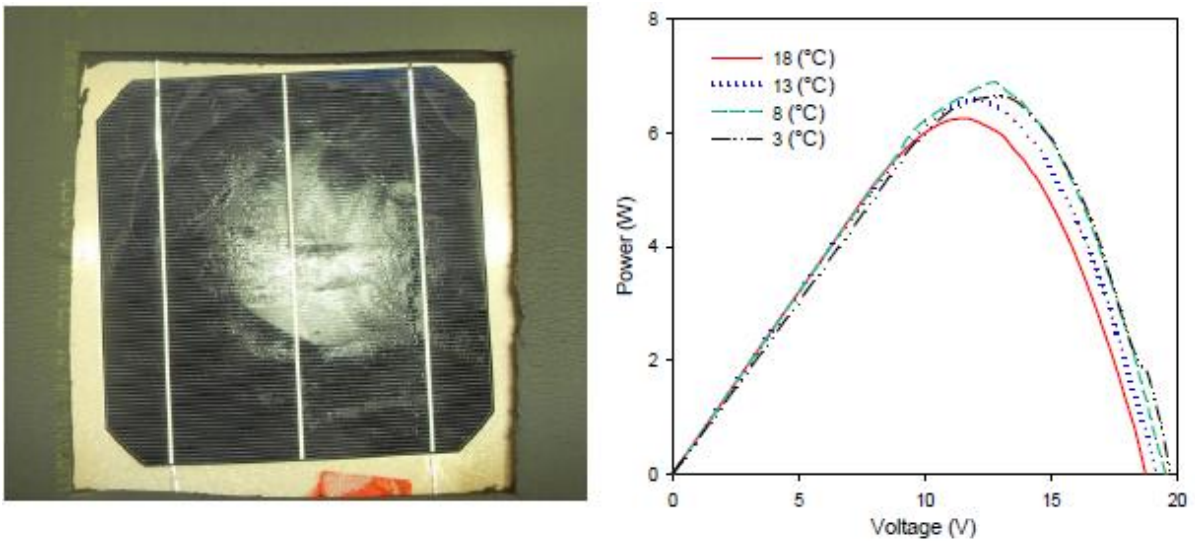

Fig 6. a) Frost formation over the monocrystalline cell. b) PV characteristics for an equivalent 32 cell module at different temperatures (71W/m^2)

Table 2. Comparison of P_{MAX} coefficient of module and monocrystalline cell

	Experimental	Manufacturer	Typical
Power Temperature Coefficient (Module)	-0.37%/^{o}C	-0.38%/^{o}C	-0.5%/^{o}C
Power Temperature Coefficient (Cell)	-1.04%/^{o}C	-0.42%/^{o}C	-0.5%/^{o}C

Although the previous comparisons at the higher end of the temperature range proved to be reasonably accurate, investigating the low temperature performance of the system was an important task as a non-trivial portion of a year in Baar has temperatures below 10 ^{o}C and although less common also below 0^{o}C. As the power output of photovoltaic systems are temperature dependant the coefficient corresponding to this was compared over a range of cell temperatures from -3 ^{o}C to 53 ^{o}C for the module and a monocrystalline cell of similar performance. Table 2 summarises the results and shows clearly that the cell has a significantly higher power temperature coefficient than the module. This is most likely due to the difference in mechanics between individual cells and modules. However what is consistent is that both the module and cell efficiency increases as the temperature decreases, meaning a higher energy per unit of irradiation would be achieved which in turn agrees with common theory.

At the lower temperature range however other factors such as condensation and frost formation came into play (fig 6. a and b) and affected the power output of the cell. Due to the limitations of equipment and time this could not have been investigated further to look at the impact on entire modules; however the trend of impacts were generally adverse, an example can be seen in fig 6b where at 3^{o}C the Peak output decreases instead of increasing. The results of the low temperature investigation indicate a trend that agrees with theory but despite this there is a clear need for resources to investigate this in more depth and with a wider scope.

V. FINANCIAL ANALYSIS

Having a technically feasible project is a large part but not all of the battle, as there needs to be grounds upon which financing of the project can be justified to investors. Table II summarizes the results of analysis into decision influencing parameters. The Net Present Value and Benefit Cost Ratio are the most useful indicators. BCR values above one indicate that going through with the project would be a wise decision while positive NPV values imply it would be more prudent to invest in the project than not to as it would add financial value to stakeholders.

Table 2. Financial viability parameters obtained from RETScreen

Simple Payback	7.2 Years
Equity Payback	9.1 Years
Net Present Value (NPV)	£545,334
Annual Life Cycle Savings	£55,519/yr
Benefit-Cost Ratio (BCR)	1.84

VI. CONCLUSION AND FURTHER WORK

The aim of this paper was to explore whether there was scope to develop an industry accepted procedure for comprehensive photovoltaic project planning by developing said procedure and testing its reliability in-field. Given the strong experimental agreement and indication of a financially viable project upon comprehensive analysis of financial factors, it can be said with some confidence that the method developed thus far gives support to the possibility of a low cost, purpose built, reliable and readily usable industry standard with which future potential projects could be assessed. This is the first attempt at consolidating the design, legal and financial aspects of photovoltaic project planning. For such a standard to become common industry practice would require collaboration between relevant bodies such as TRNSYS and RETScreen with CAD or Building Information Modelling (BIM) specialists as the BIPV market matures.

For post-project completion, stratified assessment criteria which industrial or commercial PV projects can be ranked with are worth exploring. The recommended areas are financial viability (System cost per kWp), Accuracy of predicted performance, Component Quality (with a heavy weighting on the power electronics and modules reliability) and the duration of a given project from conception to completion. These criteria are unambiguous, they will foster competition within the concerned industries if mandatory assessment is widely endorsed and also serve as an indicator to clients of where their photovoltaic investment stands relative to others.

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