Optimising commercial rooftop PV


Credit Syzygy Renewables

System design | Despite the decline of subsidies in the UK, well designed commercial PV systems still offer potentially attractive financial benefits to businesses. Kirsty Berry and Andrew Hancock of Syzygy Renewables detail some of the key considerations in designing and executing a commercial solar system that will deliver maximum return on investment

Gunwharf Quays, Portsmouth, UK. Rooftop PV offers substantial benefits to businesses, but only if designed correctly

There is often a misconception that the process that takes place between deciding to adopt solar PV to generate power for on-site consumption and having a wonderful installation pumping away on the roof is a very simple one. There are a range of things to consider when investing capital to ensure that your money is well spent, and you have a fit-for-purpose, well-specified system that will stand the test of time. It is easy to get it wrong and spend too much money on a poorly specified system

Furthermore, the market and financial metrics for projects have both changed dramatically over the past seven years. The reduction in feed-in tariffs means there is less margin available to contractors, and high levels of exported energy will hurt any financial appraisal; the combination of these two alone mean that procuring the right installation to achieve your financial objectives and to ensure it is built to last, is arguably more difficult now than it was in 2010.

There are many questions to consider the answers to which will impact the size and design of a system, and they need to be considered together. What is the right size system? What are my objectives? Which of these is the main driver? Am I simply trying to generate as many kilowatt-hours from my roof space? How can I maximise the financial return (savings) for my money? Is my roof suitable? How much electricity are we using and when are we using it? What are my plans for reducing my consumption? Am I about to move my business onto LED lighting and reduce my load by 30%? What is the best hardware? What warranty should I expect from my contractor? What sort of maintenance regime can I expect? How will this affect the design?

This article aims to provide some useful pointers and provide a framework for you to use when you are considering making the decision to generate your own energy, in the process reducing your grid costs, providing your business with a long-term hedge for a substantial element of your power costs and of course reducing the business's carbon footprint.

Building – physical constraints

Connection point

Every PV project that is connected to a building that has a grid supply must have a connection agreement from the distribution network operator (DNO).

It is generally sensible to try and minimise the amount of energy a system will spill to the grid. The value of a unit of energy used on site is significantly higher than the amount you will receive from the energy suppliers for energy you sell to them. Systems that export a lot of energy will show longer paybacks – this is something to get right when sizing the system.

Identify the best point of connection within the building. This will often be at the main distribution board, however in very large buildings, getting to the distribution board can require long cable runs and add significant cost. Ideally your board will have been designed with future unidentified uses in mind and have a spare breaker, and incoming cabling that can take the capacity you wish to have installed. Hopefully you will have an electrical schematic for your building.

East/West facing system on flat roof

South facing system on flat roof

Flat-to-roof system on South/East/West pitches

Upstanding South Facing system on East/West pitches

Examples of typical rooftop array configurations, clockwise from top left (a) east/west-facing system on flat roof, (b) south-facing system on flat roof, (c) upstanding south-facing system on east/west pitches, (d) flat-to-roof system on south/east/west pitches

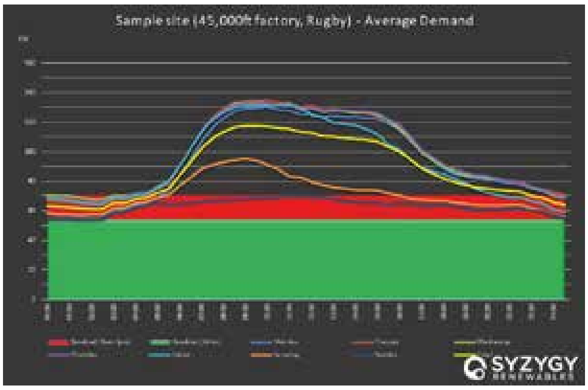

Figure 2. Average 24-hour load profile for an actual occupier, annual consumption 750,000kWh per annum

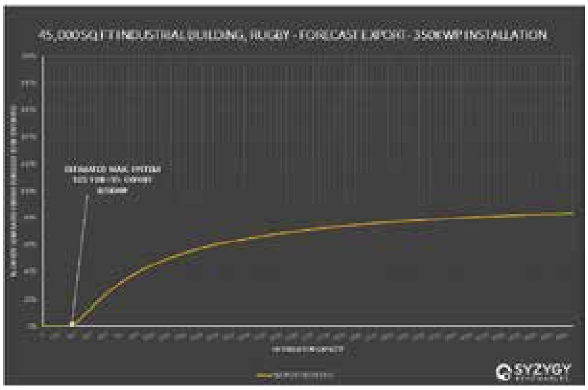

Figure 3. Effect of solar PV generated energy on existing consumption and forecast exported levels

Commercial buildings will have an incoming grid electricity connection point, a 'supply MPAN', provided by the local DNO. The supply should be suitable for the building's load requirements, and will have a DNO-agreed capacity, which reflects the maximum load draw in kVA (KW), or MVA (MW), the supply can provide. The supply will also be constrained by the size of the cables, and fuses between the MPAN, and the DNO's supply transformer. It is therefore important to consider both the supply fuse sizes and the agreed kVA capacity.

Roof area – things to consider

Roof type: The design of your roof will have a material impact on the range of framing and fixing options that would be considered. Most industrial buildings have either a 'trapezoidal' or a 'standing seam' roof sheet, both of which can generally be fixed to. Standing seam roofs can be clamped on to, thereby avoiding additional penetrations. Many office buildings have flat roofs with membrane or asphalt surfaces; in most instances a 'ballasted' system would be specified.

Rooflights: Avoid covering rooflights if possible. Not only do they provide natural light and help reduce lighting costs, they are also a weak point of the roof. A safety and access margin of 500mm should be maintained around skylights.

Structural loading: What load can the roof suppor. In the example we explore below, the building has 0.25kN/m of available load which is plenty for most designs of loading tolerances. Flat-to-roof installations tend to impose a spread load of 0.15kN/m2 and ballasted systems can impose significantly more than this, and generally not less than 20kN/m2.

Shading: Trees, vegetation and all manner of structures can cause shading, and unless space is at a premium, the areas that will shade should be avoided. Where this is difficult, the inverter selection, and possibly string design will need to factor this in. String design can certainly limit the impact of shading, however we would recommend looking at module level optimising, and some inverter manufacturers can cater specifically for this.

Module orientation: There is not a 'one size fits all' solution for how PV installations are designed. The physical constraints outlined in this article will impact the range of solutions available; however there are several suitable solutions to choose from. Modules can often be orientated (within design limitations) to optimise kWh/kWp on any surface material, orientation or pitch. There are specific dual-orientated east-west, and single orientated ballasted, or penetrative framing systems for flat roofs. There are also 'flat-to-roof', and 'upstanding pitched' penetrative framing systems for pitched roofs. The choice of framing design is dependent on structure and loading tolerances, roof material, space, positioning, layout, orientation, pitch, and the necessary choice to achieve an optimised design for maximum self-consumption.

East-west: This is often the most efficient use of space if high output is the requirement, sacrificing efficiency in return for a greater quantum of generation, with typical power curves flattened throughout each day. East-west oriented modules perform better at lower pitches, however pitches less than 5° are likely to need more regular cleaning because dust settles and the water run off angle means they are less effective at 'self-cleaning'. We would recommend 10° where possible. East-west PV systems provide a more even spread of power throughout each day compared to a south-facing system, but require a greater m^2 coverage for the same total kWh. An east-west design can be the optimal solution where the building's electricity demand is fairly flat and evenly distributed through each day. East-west systems are often used on large industrial roofs to maximise capacity. This can be a cheaper way to install (less framing and greater economies of scale), however outputs on a like-for-like basis could be as much as 15% lower than a south-facing installation on the same building – the right choice will be driven by the original objective. In many cases pitching modules facing south on an 'east-west' pitched roof whilst more expensive will deliver a better financial performance and improve payback periods.

South facing: Modules orientated south optimise kWh/kWp output at around 35-40° pitch, with typical power curves peaking at midday. This orientation can be utilised to provide power where the building's electricity demand is greatest for example between 10-3pm. As the pitch of the panels increases (if on a flat roof) more space is required to allow for the shading between rows.

Existing usage

System sizing is primarily driven by the existing and future energy consumption within the building. Most medium and large commercial buildings will have a smart meter from which half-hourly data can be exported. This data should assessed to get an understanding of how much and importantly, when, electricity is being consumed.

Worked example

The charts below use actual data from a project Syzygy Renewables recently advised on. It is a 45,000 square foot industrial building near Rugby, with the potential to install up to 350kWp on the roof adopting an 'east-west' design.

Figure 2 shows the current daily load profile; note the weekend reduction in consumption, falling to a steady baseload of between 60kW and 70kW. Bearing in mind the weekends represent 28% of the year, sizing a system to meet weekday peaks will most likely export significant amounts at weekends (which will have an impact on paybacks).

The grid connection for this project allows the generator to export the full 350kW. If the grid connection was restricted or even prohibited export, the system should be sized at a DC level to operate within the baseload (the amount of demand that is constant throughout the day/week). Figure 3 shows a way to approach calculating the correct size for an installation. If the grid connection prohibits export, the system should be sized to sit within the baseload; in this example the AC rating (Net Declared Capacity) of the system should not exceed 80kW, which means the DC rating (aggregate capacity of the modules) should not exceed c.100kWp. If, however, the project has a grid connection agreement that allows export there is less pressure to keep the size within the baseload paramaters, and sizing to allow up to a theoretical 10% export is a sensible approach – in this instance. This is where 'Export Analysis' is a good idea to understand how much a range of system sizes would export.

Figure 3 shows that the system should not exceed 100kWp if export is restricted, whereas the system would export approximately 5% at 175kWp. Further on, this article briefly explores battery storage, which provides building owners and occupiers with the ability to deploy significantly greater renewable energy capacity without spilling to the grid.

Examples of the factors to be considered in a financial appraisal

Forecast system output (use a reliable database)	Maintenance budget
Construction costs (EPC contractor – fully inclusive fixed price contract)	Full replacement of inverters in line with warranty (we would recommend procuring a 10-year warranty)
Structural survey costs	RPI forecast over 25 years (3.5% is the Bank of England's latest published 25-year forecast)
Grid connection costs (if any)	Today's delivered daytime energy cost per kWh and energy cost increases over 25 years (we would not recommend applying more than 6%; the compounding effect will over inflate potential returns/reduce payback periods if this is over estimated.
Planning cost (likely to be permitted development, however to qualify for feed-in tariffs confirmation from the local authority will be required)	Business rates

	System parameters	System capacity (kW)	Module orientation and pitch	Energy consumed on site	Forecast output, kWh (year 1)	Project cost	Payback (years)	Percentage demand from PV (%)
1	Maximum capacity and generation	350	East-west/10º	75%	295,000	Highest	11.1	30
2	Optimise efficiency	207	South facing/15º	90%	195,000	↓	9.0	23
3	East-west facing (5% max. export)	200	East-west/10º	95%	170,000	↓	9.4	21
4	South facing (5% max. export	175	South facing/15º	95%	165,000	↓	9.0	21
5	East-west facing (no export allowed)	114	East-west/10º	100%	95,000	↓	9.6	13
6	South facing (no export allowed)	105	South facing/15º	100%	100,000	Lowest	9.0	13

Table 2. Six different scenarios put into an appraisal model to understand the financial benefits

Feasibility

We now understand what could be installed using the available space. We have also looked at the energy usage to identify the forecast level of export for any given system size. The next step is to undertake a financial appraisal for a range of scenarios.

This is where running a sensitivity analysis applying a range of scenarios will help identify the right system size and layout approach for specific requirements. A typical 'weigh up' is between whether the objective is to reduce the carbon emissions associated with occupation (i.e. generate as much energy as possible from the available space regardless of levels of export) or to maximise savings and minimise payback period, the latter being most prevalent.

The reason why increased levels of export tends to hurt the financial returns for a project are because the 'value' of an exported unit of energy is c.5 pence (export tariff), whereas the replacement value (saving) achieved when the energy is consumed on site is the delivered daytime cost of a unit of electricity, which is often more than twice this level. The appraisal will need to consider some of the factors shown in Table 1.

An appraisal will enable you to identify the right system size, and put a budget together for the project. Consideration should now be given to the more detailed specification and what is required from the chosen contractor.

Table 2 shows the 'top line' outputs from a sensitivity analysis of six potential solutions. In this instance, the client decided against the largest system (350kWp) because the forecast export of 25% would have added over two years to the payback. The client chose to pursue option two, balancing a higher reduction in grid consumption whilst preserving a forecast payback of nine years.

Procurement

EPC contractors are continuing to experience severe pressure on margins, and whilst there are many excellent contractors out there, there are some that will sacrifice system optimisation for cost savings. The key to successfully procuring a system is in the work carried out before you tender: measure twice and cut once.

There is always a balance to be struck between capital costs and value in the long term. When specifying the equipment, it will be important to consider the design life of the project i.e. how old is the building? Is the project receiving subsidy or funding? What are the expected returns on investment? Ease of access for repairs or replacement and whether there is on-site support to monitor the performance are also considerations. (Most PV systems are remotely monitored, enabling any issues to be quickly identified and rectified but it may be necessary to examine equipment on site from time to time.) The insurance company for the building may also impose certain requirements, particularly in respect of fire safety.

The warranties offered with equipment should be assessed. In the fast-moving PV market, it may be decided that insurance-backed warranties are necessary. Choice of contractor and contract structure will also help ensure optimum performance for the system. What PV experience does your contractor have? What is the most appropriate form of contract to use in relation to the project size? What are the payment terms and are bonds or parent company guarantees appropriate? Consider tying the construction contractor into a maintenance contract for some period to help ensure the quality of build.

It will be important to consider performance expectations for the installation and possibly imposing penalties relating to any failure to generate as expected. Performance obligations may be based on the overall energy yield of the system (what output did your contractor forecast, what database did they use?), hours of operation (availability) or a combination of the two and this may be related to a measurement of the actual solar energy at the site. Within the specification it is important to define how the expected performance of your PV system is forecast; different software packages can produce vastly different predictions and even when using the same software, the results can vary greatly with different sets of climate data.

Often commercial projects take place on sites operating over long hours, possibly 24-7 and any constraints on the construction programme should also be set out clearly in the contract. The choice of point of connection is critical as at some point a shutdown may well be required to connect the system; the impacts of this need to be identified at an early stage in the design, and factored into the build programme.

Failing to consider these factors can result in the wrong contractor and poor equipment, for example smaller cable sizes, cheaper panels and inverters – do you know what you are buying? It will do you no harm to provide a very detailed specification that not only covers all of the obvious compliance and regulatory matters, but also ensures that cheaper equipment cannot be used, shading mitigation has been considered within the design, cable sizing is optimised, approved manufacturers have been used for certain elements such as datalogger, pyranometer, type of ballast, even UV resistant cable ties, demonstration of wind load calculations and structural sign off.

Ongoing operation

Ensuring that your PV system operates properly is key to maximising the return on investment. Although solar panels themselves should not require a lot of maintenance over their lifetime, it is essential to keep them clean and to carry out regular servicing on the installation. How often cleaning is required will vary hugely from site to site and is driven of course by the environment within which they are located. From time to time, there may be a requirement for a reactive maintenance visit to rectify technical faults. For a system above 100kW, it is probably sensible to procure the project with a two to five-year maintenance agreement.

On top of ensuring that access to the equipment is satisfactory, other design considerations can also decrease the need for cleaning. Higher-pitched panels (usually tilted by more than 5°) will better self-clean when it rains. Panels mounted on frames without wind deflectors could provide a welcome shelter to birds. We would always recommend wind deflectors are installed on 'pitched up' systems – these are simple matters to consider at the design stage, but expensive to rectify post construction if issues arise.

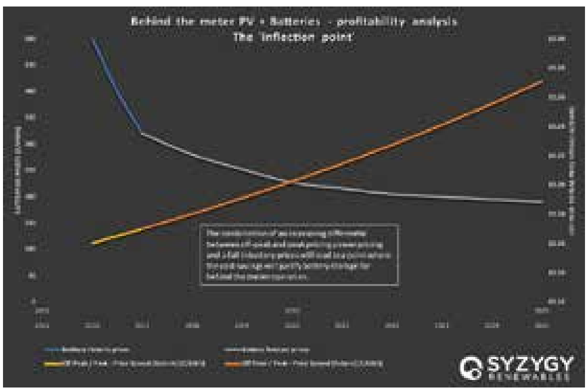

Figure 4. The inflection point after which rising energy prices and falling battery costs will combine to make behind-the-meter storage profitable

Another feature to consider in the planning stage of the project is the location of inverters. Once again, providing easy access to them would allow for easier fixing and inspections. However, care must be taken if inverters are installed outdoors, as they will then be exposed to dirt, rain, heat and could suffer more frequent breakdowns.

Finally, to ensure technical issues are picked up at the earliest stage, and therefore rectified quickly, installing a remote monitoring of the system is essential. A wide range of monitoring equipment exists, and can provide information at the plant level up to the panel level. The amount of detail needed depends on multiple factors such as the location, the size of the system or the type of equipment, and should be determined with a cost/benefit analysis in early stages of the project.

Battery storage

In recent years, the strong development of renewable energies and the decrease in lithium-ion battery prices have led to increased interest in stationary battery storage. In what the industry calls 'behind the meter' operation there are generally three reasons for using battery storage in a commercial setting:

- Back-up supply
- Reducing energy costs (cheap charge – use at peak times/absorb spill from embedded generation)
- Cost avoidance: avoiding costly capital expenditure on increasing the supply capacity to the site

To generate a financial return from a battery, it is likely that the first two approaches will not provide a reasonable payback on their own; therefore, providing the National Grid with a range of services in addition to the 'on site' strategy is a way to generate additional income (income stacking) to generate that financial return. For example, batteries in certain geographic locations can produce a 'stack' of revenues through the provision of grid services (such as frequency regulation or capacity market). There are companies, called Aggregators, who can manage your battery within a larger portfolio, who are providing the National Grid with a range of services.

As of today, the cost of batteries is still too high to show a short enough payback to the majority of behind-the-meter users. The cost of peak energy varies significantly from region to region. However, prices are decreasing fast, especially for Li-ion batteries, driven by the electric vehicle manufacturers, and we are close to the inflection point where energy prices, which are generally rising, and battery costs, which are falling, will combine to make behind-the-meter operation profitable in its own right – so keep watching. Figure 4 shows how the likely inflection point will be reached.

Authors

Andrew Hancock graduated from Reading University in 2007 with an MSc in renewable energy, technology and sustainability. Over the past 10 years he has worked for some of the leading UK solar installation companies, and has gained valuable experience in most areas of the solar business. Positions include installation and site management, to key design and technical management. Andrew joined Syzygy Renewables in July 2016 and works in the asset management team.

Kirsty Berry has a masters in engineering from Manchester University and Technische Universitat Berlin and a MSc in renewable systems technology from Loughborough University. Her career in renewables started at BP in 1998 after which she spent 17 years at Solarcentury where she was latterly head of health and safety. Other roles at Solarcentury include project management. She is now senior project manager at Syzygy Renewables.

The right design

In summary, solar PV is a fantastic technology that should deliver low cost energy for many years to come. The trick to getting it right is in the work undertaken before any construction takes place. Lower subsidies mean sizing correctly has never been more critical, as is understanding that the cheapest solution is not necessarily the best, that this is a long term investment and that it is therefore important the installation delivers what you expected it to, year in, year out.

There will be maintenance that needs to be undertaken, but the cost of this can be reduced through effective design. If you are not deeply technical, or have a good understanding of how to get the right technical and commercial solution, it is probably worth getting some independent advice. There is a cost attached to this, but a good consultant should pay this back through enhanced specification, helping you avoid over sizing, making sure it has been built correctly and that your warranty package is robust – protecting your investment into the future.