

Modelling PV electricity generation and calculating self-consumption within the Home Energy Model

A technical explanation of the methodology

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Background to the Home Energy Model

What is the Home Energy Model?

The [Home Energy Model \(HEM\)](#) is a calculation methodology designed to assess the energy performance of homes, which will replace the government's [Standard Assessment Procedure \(SAP\)](#).

Where can I find more information?

This document is part of a wider package of material relating to the Home Energy Model.

Home Energy Model technical documentation (e.g. this document)

What: This document is one of a suite of [technical documents](#), which explain the calculation methodology in detail. New documents will be added, and the content amended, when necessary to ensure documentation is sufficiently comprehensive. This will usually, but not always, occur alongside the release of a new version of HEM.

Audience: The technical documentation will be of interest to those who want to understand the detail of how the Home Energy Model works and how different technologies are treated.

The Home Energy Model consultation and government response

What: The [Home Energy Model consultation](#) introduces the overhaul to the SAP methodology and sought views on the approach taken by the new Home Energy Model. The [Home Energy Model consultation](#) summarises the feedback to the consultation and the actions taken subsequently in development, ahead of the initial release of HEM.

Audience: The Home Energy Model consultation will be of interest to those seeking a general introduction to HEM and its role in government policy on domestic energy performance.

The Home Energy Model reference code

What: The full Python source code for the Home Energy Model core engine has been published as a [Git repository](#). Note the reference code for official HEM wrappers is published separately.

Audience: The reference code will be of interest to those who want to understand how the model has been implemented in code, and those wishing to fully clarify their

understanding of the new methodology. It will also be of interest to any potential contributors to the Home Energy Model or those wishing to use it within their own projects.

Related content

Other relevant technical papers include:

- HEM-TP-03 External conditions (for description of the solar radiation data)
- HEM-TP-08 Solar gains and shading (for explanation of shading calculations)

To understand how this methodology has been implemented in computer code, please see:

src/core/energy_supply/pv.py

src/core/energy_supply/energy_supply.py (for calculation of instantaneous self-consumption and surplus available for battery and diverter)

src/core/energy_supply/elec_battery.py

src/core/heating_systems/storage_tank.py (for PV diverter)

Methodology

Photovoltaic (PV) systems generate electricity which can be used in the dwelling or exported to the grid. The amount of electricity generated will depend on the characteristics of the PV system and the solar radiation incident upon it. The latter of these is dependent on the location, orientation, and tilt of the array and any shading upon it, and the shading calculation is dependent on the array's height, width and base height (i.e., height of the lowest part of the array from the ground). More than one array can be specified with different characteristics, and the generation from all the arrays will be summed at each timestep.

The amount of the generated electricity that is used in the dwelling or exported to the grid is also dependent on the electricity demand within the dwelling and the extent to which this occurs at the same time as generation by the PV system.

1. PV generation

The energy output of a PV system is calculated using the hourly procedure ('Method 6') given in [BS EN 15316-4-3:2017](#).

For each time step, the electrical energy E_{out} delivered by the PV modules in kWh per m² is:

$$E_{out} = E_{sol} \cdot \frac{P_{pk}}{I_{ref}} \cdot f_{perf} \quad (1)$$

where

E_{sol} is the solar irradiation energy on the modules in the time step per m² (kWh/m²)

P_{pk} is the peak power of the PV system in kW/m² at standard test conditions¹ (irradiance of 1 kW/m², 25°C cell temperature, a solar spectrum corresponding to direct normal radiation with an air mass² of 1.5, that is, with a tilt angle of 37° and a solar zenith angle of 48.19°)

I_{ref} is the reference solar irradiation in kW/m² under standard test conditions (1 kW/m²)

f_{perf} is the system performance factor of the PV system (dimensionless)

¹ [PD IEC/TS 61836:2016](#) Solar photovoltaic energy systems - Terms, definitions and symbols

² National Renewable Energy Laboratory, 'Reference Air Mass 1.5 Spectra' at <https://www.nrel.gov/grid/solar-resource/spectra-am1.5.html>

1.1 Shading

The output of the PV system is limited by the incoming solar irradiance on the panels. The solar irradiance on the PV panel may be reduced by shading due to distant objects (e.g. neighbouring buildings) and/or nearby objects. The shading reduction factor is calculated as described in the shading sections of the technical paper HEM-TP-08 Solar gains and shading.

For further details see 6.2.4.7 *Calculation procedure* in [BS EN 15316-4-3:2017](#).

1.2 System performance factor

The system performance factors (f_{perf}) used are from a bespoke national annex as permitted in Section 6.2.2.7 of the BS EN standard. Re-arranging equation 1, f_{perf} is defined as:

$$f_{perf} = \frac{\text{Actual energy out}}{\text{solar energy efficiency at STC}} = \frac{E_{out}}{E_{sol} \frac{P_{pk}}{I_{ref}}} \quad (2)$$

The table below shows the default informative values provided in Table C.4 Annex C of the standard, and the updated values proposed for HEM, which are based on monitored performance data for UK systems.

According to research from the University of Sheffield's Sheffield Solar research group³, the median performance factor of domestic solar systems in the UK during the monitored period was 0.85. It was assumed that the median performance factor corresponds to the value for moderately ventilated modules. The other figures from Table C.4 were increased by the same proportion (0.85 / 0.8).

Table 1 – System performance factors

Type of ventilation of the photovoltaic modules	Informative value (Table C.4)	f_{perf} used in HEM
Unventilated modules	0.76	0.81
Moderately ventilated modules	0.80	0.85
Strongly or forced ventilated modules	0.82	0.87
Free-standing (not integrated)	n/a	0.87

³ J Taylor, J Leloux, L Hall, A Everard, J Briggs & A Buckley (September, 2015). '[Performance of Distributed PV in the UK: A Statistical Analysis of Over 7000 systems](#)', 31st European Photovoltaic Solar Energy Conference and Exhibition. Hamburg, Germany, 14-18 September 2015.

Section 6.2.4.7.2 of the BS EN standard states that if modules are not “integrated” (i.e. rear surface free) then the performance factor is equal to 1.0. This is assumed to mean that the PV system is not integrated (BIPV) or attached (BAPV). This appears to be an unrealistic value, given that cell temperatures would usually be higher than 25°C, and there are also other system losses such as inverter losses (see below). For these systems, a value of 0.87 is proposed as it is assumed that they will have similar performance to strongly or forced ventilated modules. In the Sheffield University study of domestic solar systems in the UK, very few PV installations exceeded 0.92, while 0.87 did occur frequently. In Germany, the Fraunhofer Institute found in 2012 that the best performing solar installations had a performance factor around 0.87: of the top 10 best performing of the 100 systems they studied, 8 out of 10 were also free-standing⁴.

Inverter efficiency adjustments

The system performance factors shown in Table 1 represent an overall efficiency factor, taking into account both panel and inverter efficiency. While panel efficiency is assumed to be constant, inverter efficiency varies significantly with power output - dropping sharply at low loads and ‘clipping’ at loads above its rated maximum. Different inverter types are also affected by partial shading to different extents.

To model these effects, the implicit inverter component is therefore firstly removed from the figures given in Table 1. These figures are then recalculated and applied explicitly to avoid double counting.

The tests used to derive the figures in Table 1 did not involve overshadowed panels, so no correction is needed to handle partial shading. To remove the impact of the fixed inverter efficiency embedded in the system performance factors, system performance factors are divided by 0.972 - representing the peak inverter operating efficiency. For details on how this value was derived, refer to *Annex A – Inverter efficiency*.

Inverter efficiency is then calculated at each timestep based on the panel power output and the inverter’s maximum input power, which is specified in the input data⁵. The equations used for this calculation, along with their derivation, are provided in *Annex A – Inverter efficiency*.

Next, a second factor is applied to account for efficiency losses specifically related to the partial overshadowing of the panels. This factor depends on the inverter type, which is a user-defined input. Currently, two types are recognised: *string inverter* and *optimised inverter* (also known as *micro inverter*)⁶. The equation used to calculate this factor and its derivation are provided in *Annex B – Impact of partial shading on inverter efficiency*.

⁴ Reich, N.H., Mueller, B., Armbruster, A., Van Sark, W.G., Kiefer, K. and Reise, C., 2012. [Performance ratio revisited: is PR> 90% realistic?](#). *Progress in Photovoltaics: Research and Applications*, 20(6), pp.717-726.

⁵ Inputs are required for maximum power on the input/panel side (DC) and on the output/mains side (AC). Both these maxima are required in the input file and are applied as limits in the calculation.

⁶ The terms ‘string’ and ‘optimised’ are used in the PV industry to refer to the electrical arrangement of the cells and inverter. Clear definitions of these will be needed in due course to give consistency of understanding.

Note that this shading-related efficiency reduction is separate to the reduction in output due to the lower level of incident radiation caused by overshadowing described in Section 1.1

1.3 Limitations

There are various further parameters which could influence system performance in a given timestep which are currently accounted for in HEM only in an implicit way via the annual performance factors listed in Table 1. Accounting for these parameters separately and calculating their effects in each timestep in future could result in a more accurate prediction of overall performance. Table 2 below lists some key parameters, and the impact on the accuracy of energy output predictions.

Table 2 – Parameters affecting system performance

Temperature co-efficient	The temperature coefficient of the maximum output power of PV modules is typically in the range $-0.3\% / ^\circ\text{C}$ to $-0.5\% / ^\circ\text{C}$ ⁷ . Modules with lower temperature coefficients will have better system performance factors. There are also separate temperature coefficients for open-circuit voltage and short-circuit current, which may need to be accounted for separately.
Normal Operating Cell Temperature (NOCT)	NOCT can vary from 45°C to 49°C ⁸ . Modules with lower NOCT will have better system performance factors.
Degradation rate	Degradation rates can vary from 0.1% to 1.1% per year ⁹ . Modules with lower degradation rates will produce more total energy over their lifetime.
Model specific inverter efficiencies	Inverter efficiencies vary from model to model, whereas in HEM only two generic inverter efficiency curves (one of each of the inverter types defined) are currently allowed for.

2. Use of generated electricity in the dwelling (“self-consumption”)

Since HEM has sub-hourly modelling, it can account for near real-time variations in PV supply and in electricity demand in the home. This improves the accuracy of predictions of self-

⁷ [Does Solar Panel Temperature Coefficient Matter? | Solar.com](#)

⁸ Muller, M., 2010. [Measuring and Modeling Nominal Operating Cell Temperature \(NOCT\)](#), ‘Conclusions and Continuing Work’. National Renewable Energy Laboratory.

⁹ Deline, C. et al., 2022. [PV Lifetime Project-2021 NREL Annual Report](#). National Renewable Energy Lab.

consumption, with closer matching of available PV power to the electrical demand in the home in each time step. Further explanation is given below.

2.1 Priority assumptions

Generated electricity is by default allocated in order of priority to:

1. Instantaneous demand from the dwelling
2. Battery storage
3. PV diverter
4. Grid export

Normally battery storage is preferable to prioritise over a PV diverter, since the financial value of stored electricity is typically around three times greater than the value of stored hot water¹⁰. However, some householders might wish to prioritise the PV diverter over battery storage, for example if they want hot water quickly. Therefore, an input option is included in HEM to prioritise a PV diverter over battery storage if desired.

Electricity demand within the home is assumed to be met from the following sources (in order of priority):

1. Self-generated electricity
2. Battery storage
3. Mains electricity (grid import)

2.2 Instantaneous self-consumption

Instantaneous electricity demand in a timestep is summed from various components of electricity used during that timestep by:

- Space heating/cooling and hot water systems (including electric showers)
- Ventilation systems
- Appliances, cooking, lighting etc.

Note that this does not include electricity used to charge a battery or to top-up thermal storage such as a hot water cylinder in response to surplus generation. This is handled later in the calculation.

The fraction of energy generated on site that is used instantaneously within the dwelling is commonly known as the self-consumption factor. The equation used to determine the self-consumption factor is based on a small field data sample¹¹ of UK dwellings which all had gas boilers. Four of these had hourly data which was used to derive the formula, while 15 had

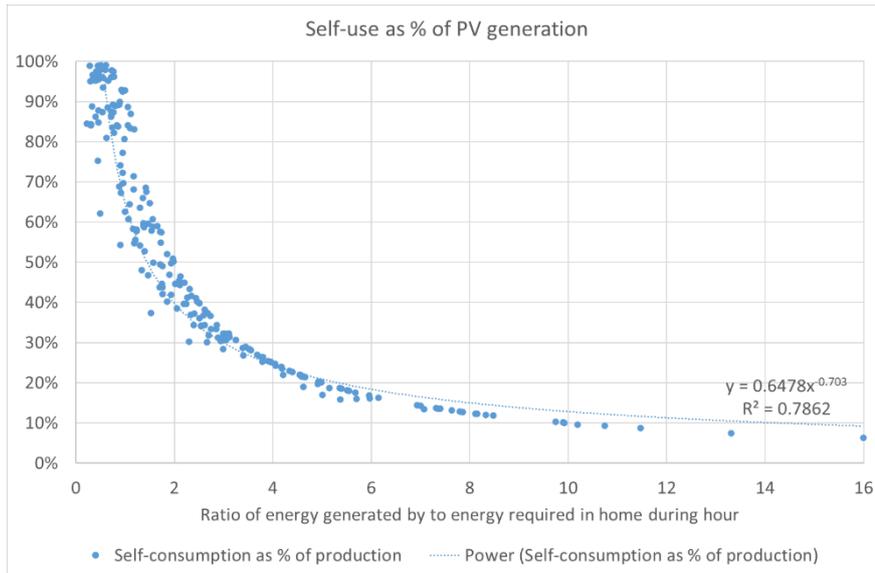
¹⁰ E.g. where the primary water heating system is a gas boiler or a heat pump.

¹¹ The data is owned by two product manufacturers, so it is not possible to share this more widely.

monthly data, which was used to check the results from applying the formula to typical generation and demand profiles. The fraction of self-consumption is calculated as a function of the ratio of PV energy available to the electricity demand (the 'demand ratio') during the time step, based on the field data (see graph below):

$$\text{demand ratio} = \frac{\text{PV energy supply}}{\text{electricity demand}} \quad (3)$$

$$\text{self-consumption factor} = \min(0.6748 \times \text{demand ratio}^{-0.703}, 1) \quad (4)$$



A literature review was undertaken to look at relevant aspects of PV generation and self-consumption. The literature review found similar relationships from other datasets. This equation gives a slightly different result to merely dividing the demand by the available supply, which accounts for the fact that both demand and supply will vary within each hour. For example, if demand and supply are equal, the expected self-consumption factor will be less than 1, because for parts of the timestep the demand may be higher than the supply and for other parts the supply may be higher than the demand. Using this equation therefore captures sub-hourly effects (on an averaged basis).

The predicted self-consumption factor should not be greater than 1/demand ratio, otherwise HEM would potentially predict the demand fulfilled by local generation to be greater than total demand, so this further limit is applied.

2.3 Electric batteries

Battery charging is modelled using a round-trip (charge/discharge) efficiency. It is assumed that the charging and discharging efficiencies are equal, with each is equal to the square root of the round-trip efficiency.

At each timestep, several limits are applied to determine the overall energy flow, taking into account the energy potentially available to charge the battery and the energy demand on the battery:

- 1 Maximum capacity: The amount of charge that can be supplied to the battery is limited by its maximum capacity (in kWh).
- 2 Maximum charge rate: The amount of charge that can be supplied to the battery is limited by the maximum charge rate (in kW).
- 3 Minimum charge rate: The amount of charge that can be supplied to the battery is limited by the minimum charge rate (in kW).
- 4 Maximum discharge rate: The amount of charge that can be drawn from the battery is limited by the maximum discharge rate (in kW).

In HEM, batteries can be charged by surplus electricity generation from PV and also from the grid if this is stated as being possible in the input file and threshold prices are defined¹².

When charging from PV, simultaneous charging and discharging are allowed within the same timestep by calculating net energy flows: charging is treated as negative energy demand, and discharging is positive energy demand. These flows are processed sequentially to determine the battery's energy state for that timestep, incorporating round-trip efficiency losses and ensuring the charge level does not exceed the maximum capacity or fall below zero. This approach simplifies calculations by treating each energy flow as a unified input, rather than separately modelling charging and discharging events.

However, when charging from the grid, simultaneously discharging is not permitted. This avoids unnecessary efficiency losses, since the energy could be directly used from the grid instead.

Battery capacity is adjusted for battery age using the assumption that capacity reduces by 4% per year, based on manufacturer guarantees of 60% remaining capacity after 10 years¹³. Guaranteed performance is likely to underestimate real-world performance, so this may be refined in future.

If batteries are not within the heated space (e.g. in a garage), a reduction factor, F_{cap} , is applied to their stated capacity based on the external temperature:

If $T_{ext} < 20^{\circ}\text{C}$:

$$F_{cap} = 0.8496 + 0.01208 \times T_{ext} - 0.000228 \times T_{ext}^2 \quad (5a)$$

If $T_{ext} \geq 20^{\circ}\text{C}$:

$$F_{cap} = 1 \quad (5b)$$

¹² For each timestep a threshold price is set below which the battery is permitted to charge – this price is compared to a data file containing electricity prices for each timestep. Additionally, a threshold battery charge level below which it can charge from the grid can also be set for each timestep. This could be used, for example, to leave more space for PV energy in summer, but allow more grid charging in winter.

¹³ E.g. Panasonic EverVolt: [EverVolt Battery Warranty Complete Overview | EnergySage](#)

This is based on a single manufacturer dataset¹⁴, so may be updated in future if more data becomes available.

2.4 PV diverters

It is currently only possible to model PV diverters connected to an immersion heater within a hot water tank. If there is surplus energy after instantaneous demand is met within the dwelling and battery storage is full¹⁵ (or there is no battery), the excess capacity for energy storage within the hot water tank is calculated based on the set point and the position of the heating element connected to the diverter along with the position of any associated thermostat. The surplus generation is used to heat the tank up as much as possible within this limit. The amount of energy that can be diverted is also limited by the maximum capacity of the heating element and how much of this capacity for the current timestep has already been used.

Note that there is no cut-in threshold for PV surplus power, which may result in an over-prediction of diverted PV when small surpluses occur, and the installed PV diverter would not have cut in with that little available power.

¹⁴ <https://www.bonnenbatteries.com/the-effect-of-low-temperature-on-lithium-batteries/>

¹⁵ HEM allows the PV diverter to be prioritised over battery storage, if required. However, by default battery storage is prioritised.

Future development

Future development of the PV generation calculation may include accounting for the effect of tracking systems, product-specific module efficiency, temperature coefficients, Normal Operating Cell Temperature, degradation rate, changes in hourly system performance factors and bifacial solar modules.

Bifacial solar modules are able to absorb radiation on both sides, increasing energy yield relative to monofacial solar modules. While the benefits of bifaciality on domestic pitched roof installations are expected to be minor, they can be more significant for systems mounted on flat roofs, or small ground mount systems. An east-west setup could for example be mounted vertically, increasing PV output at peak times of the day.

There is potential to make the priority order of the assignment of generation more flexible to account for different system and control configurations that may be able to respond to incentives such as time-of-use import/export tariffs.

Apart from the very small dataset being used, the application of the instantaneous self-consumption curve (based on hourly data) to half hourly timesteps may also be introducing some degree of error (most likely a slight underestimate of the self-consumption factor, as less variation would be expected within a half-hourly timestep than an hourly one). This area would certainly benefit from further study in future, particularly to check that the relationship is also representative of electrically heated dwellings, which were absent from the data set used.

The electric battery calculation could be further refined if new data becomes available on battery degradation rates and the impact of temperature on battery capacity.

There is scope to develop diverters further in future to allow them to power additional systems, such as heat pumps. The heat pump could for example store surplus generation as hot water more efficiently than an immersion heater.

The generic inverter efficiency equations could be replaced with product specific data via the product database in future to give more accurate assessments and provide a benefit for using the most efficient models.

Some PV diverters have a cut-in threshold, and do not divert until a threshold PV power is reached, e.g. 100 W. Therefore, a configurable cut-in threshold could be added to the calculation.

Annex A – Inverter efficiency

Market share data¹⁶ for 2019 showed the three biggest producers of PV inverters to be Huawei, Sungrow Power Supply and SMA, with these three manufacturers supplying around 45% of the inverters by power capacity.

Efficiency data curves for domestic-sized inverters from each manufacturer was obtained. These are not reproduced here, but can be viewed via the following links:

Huawei SUN2000-5/6KTL-M1:

https://solar.huawei.com/-/media/Solar/attachment/pdf/au/datasheet/SUN2000-5_6KTL-M0-M1.pdf

Sungrow Power Supply SG3K/3K6/4K/4K6/5K/6K-D:

[https://en.sungrowpower.com/upload/documentFile/DS_SG3K%203K6%204K%204K6%205K%206K-D%20Datasheet\(EMEA\)_V12_EN.pdf.pdf](https://en.sungrowpower.com/upload/documentFile/DS_SG3K%203K6%204K%204K6%205K%206K-D%20Datasheet(EMEA)_V12_EN.pdf.pdf)

SMA SB 3600SE-10 / SBS2.5-1VL-10 / SI4.4M-12:

<https://files.sma.de/downloads/BattWr-Efficiency-TI-en-11.pdf>

In each case, the same general trend was observed: the inverters achieve their maximum efficiency at loads of between about 20% and 60% of their rated power, with a sharp decline at low loads (<10%) and slow gradual decline at higher loads.

The maximum efficiencies the units are capable of are 98.5%, 98.4% and 97.2%, respectively – a fairly narrow range.

It was decided to use the data set with the lowest maximum efficiency (SMA Sunny Boy Smart Energy SB 3600SE-10 in PV2AC format) as the basis for HEM's generic inverter efficiency curve. This could be replaced with product specific data via the product database in future.

A mathematical fit to this data was created by using three formulae and then taking the minimum of the three values:

$$eff_1 = 97.2 \times \left[1 - \left(\frac{0.18}{(1 + e^{21 \times LR})} \right) \right] \quad (6a)$$

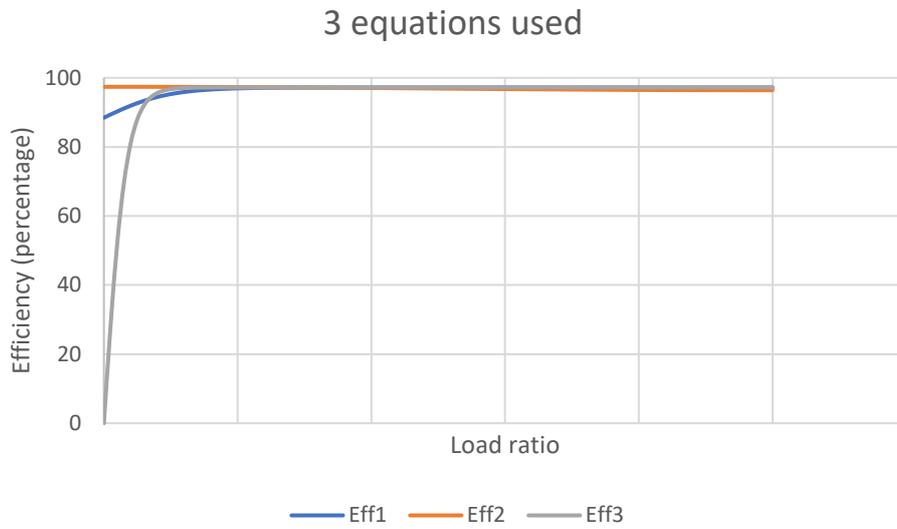
$$eff_2 = 0.5 \times \cos(\pi \times LR) + 96.9 \quad (6b)$$

$$eff_3 = 97.2 \times \tanh(30 * LR) \quad (6c)$$

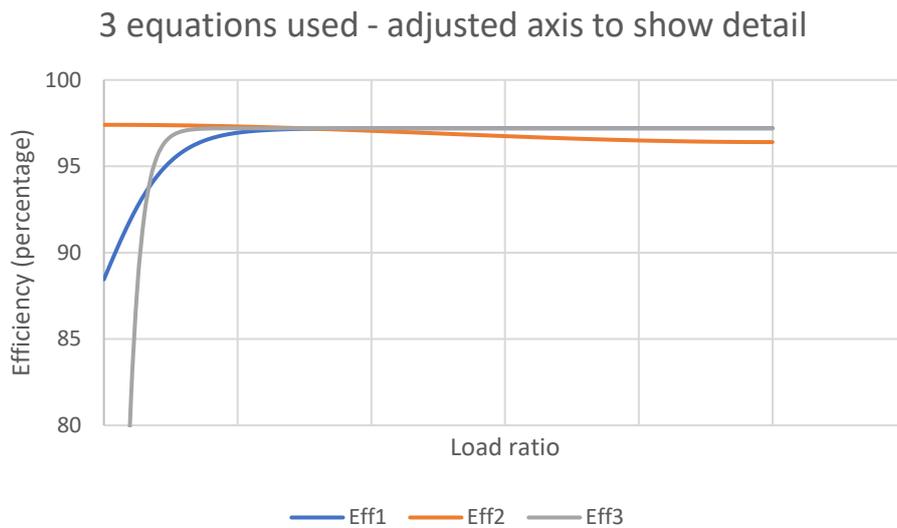
Where LR is the load ratio (the ratio of current input power to maximum rated input power).

¹⁶ [Huawei, Sungrow and SMA dominate global inverter market – pv magazine International](#)

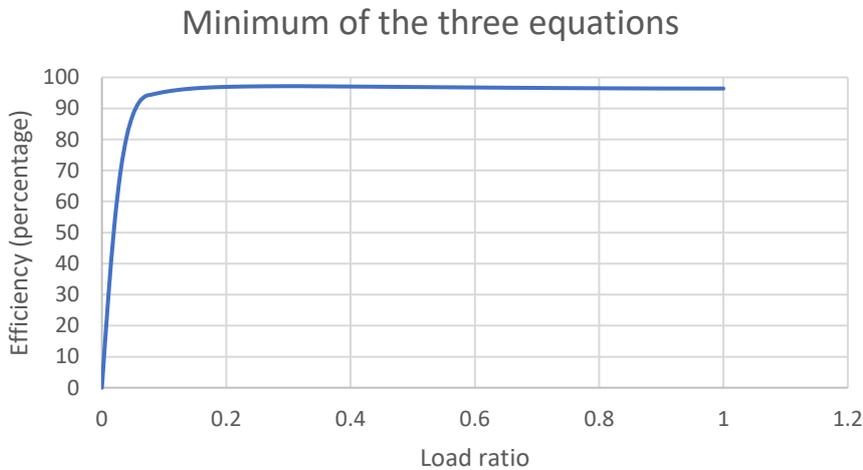
These three equations are plotted to show their behaviour.



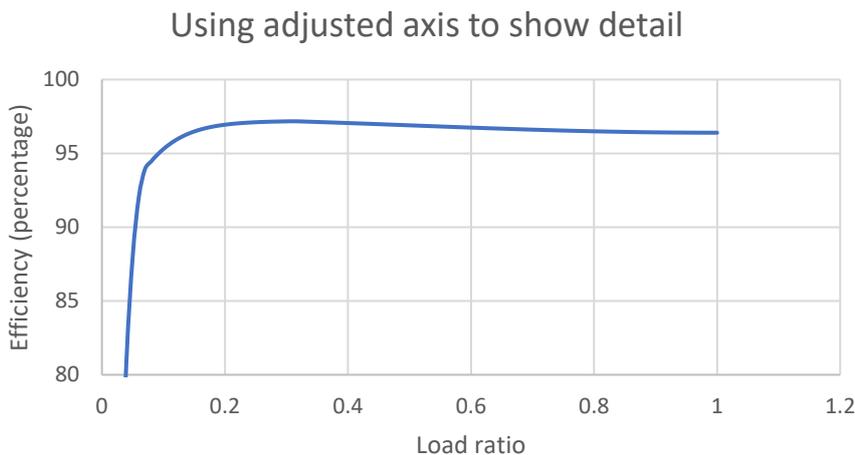
Replotting these with a false zero on the axis shows the detail better:



Combining the three efficiency equations (by taking the minimum of the three results) to give the final fit gives the following relationship:



Adjusting the vertical axis scale shows the detail and allows like-for-like visual comparison with the original SMA data:

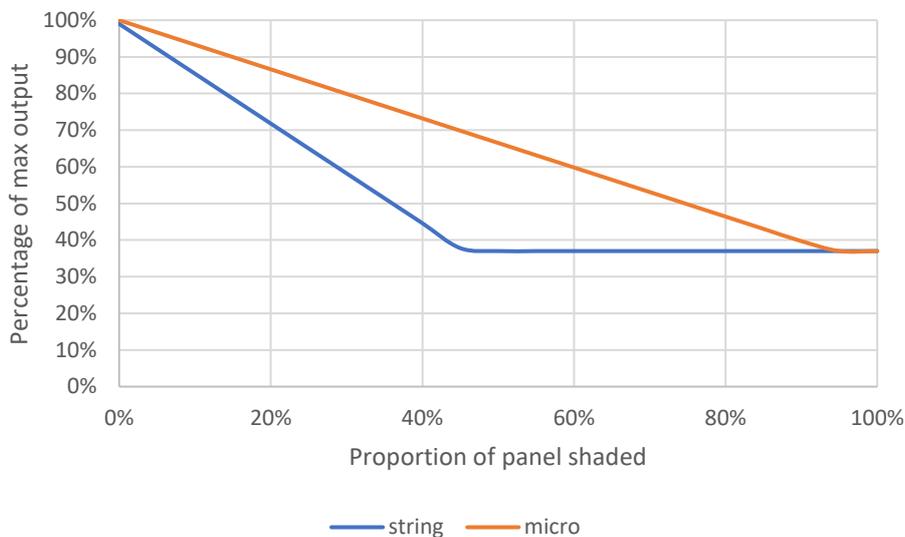


This recreates the key characteristics of the SMA efficiency curve, with a maximum efficiency of 97.2% at around 30% load ratio, falling off sharply at low load ratios and declining gradually at higher load ratios. Note that at load ratios above 1 (i.e. where power input from the panel exceeds the power handling capacity of the unit), 'clipping' will start to occur, so it becomes less meaningful to plot results. This is recreated in HEM by limiting the power input from the panel to the inverter to be no more than the maximum power handling capacity of the inverter, with any excess being discarded. (A separate limit on the unit's maximum output power – which may be lower than the maximum input power – is applied at the power output stage.)

This set of equations (i.e. taking the minimum of equations 6a, 6b and 6c above) is applied in HEM to estimate the inverter efficiency as a function of the load ratio. The maximum efficiency value of 97.2% is used to correct the overall system performance factor, to avoid double counting this reduction factor on the system performance, as described in section 1.1.

Annex B – Impact of partial shading on inverter efficiency

The inverter efficiency reduction due to a partial shading of the PV panels is based on data from 'Partial Shade Evaluation of Distributed Power Electronics for Photovoltaic Systems', Chris Deline et al, Figure 7 (accessed at: <https://www.nrel.gov/docs/fy12osti/54039.pdf>). The equations given in this figure were used to calculate the power output for a range of different levels of panel shading, from 0 to 100%, for the two inverter types represented (string and micro/optimised¹⁷).



The stated 37% transmission rate of the covering material was applied to determine the percentage reduction in incident radiation, $\%radiation$, at each level of coverage, $\%panel_cov$:

$$\%radiation = \%panel_cov * (1 - 0.37) \quad (7)$$

(where 1 means all radiation blocked, 0 means no reduction)

The level of shading was converted to a shading factor of the form used in HEM (where 1 = no shading, 0 = complete shading):

$$f_sh_dir = (1 - \%radiation) \quad (8)$$

Where f_sh_dir is the direct shading factor, as used elsewhere in HEM (see HEM-TP-08).

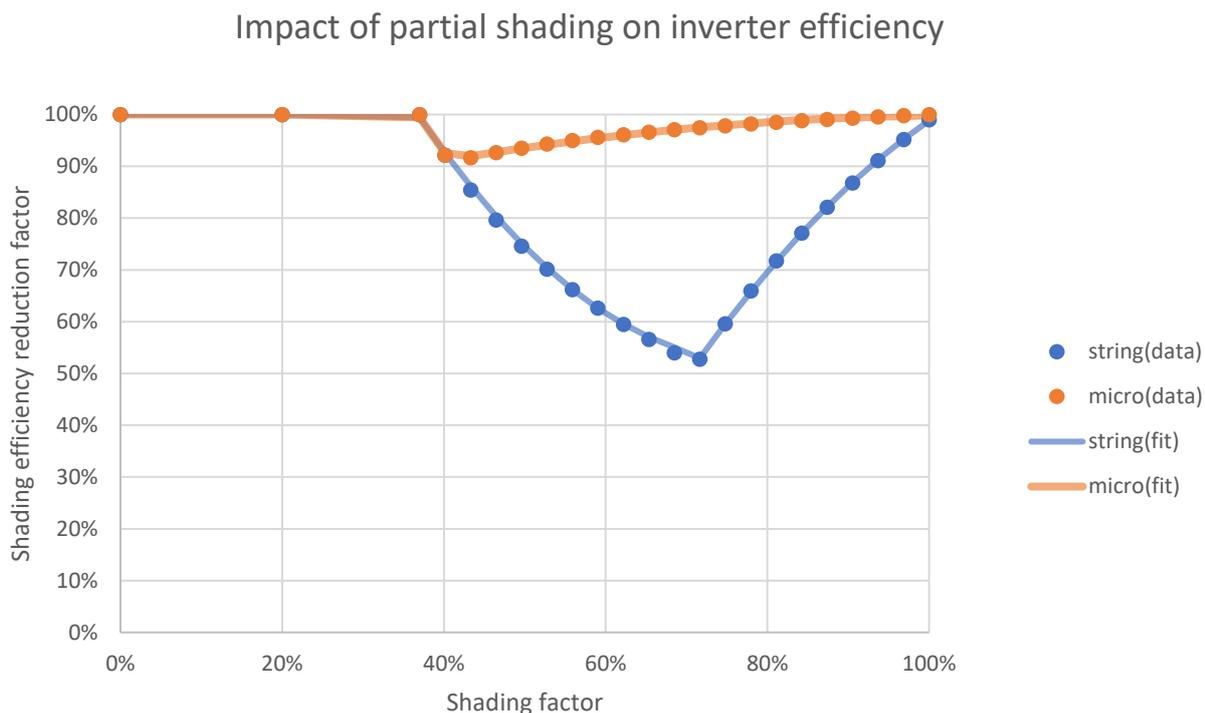
It was assumed that the efficiency reduction being calculated is only related to the shading of direct radiation (not diffuse) on the basis that the efficiency impact is caused by part of the panel being shaded, while the rest is not. Diffuse shading would affect the whole panel approximately equally, so should not affect inverter efficiency in the same way. (Note that the reduction in output associated with the reduction in the overall level of radiation is accounted for elsewhere – see section **Error! Reference source not found.**).

¹⁷ The term 'micro' inverter is used in the source paper, while HEM uses the term 'optimised' inverter.

It was assumed that, in the absence of a reduction due to inverter efficiency, output would be proportional to the incident solar radiation and therefore that the normalised output would be equal to the shading factor - e.g. if 75% of the radiation was transmitted, we would get 75% of the power output compared to the unshaded case.

The difference between this reference output and the output predicted by the equations representing the actual data was assumed to be due to the efficiency reduction of the inverter induced by partial overshadowing. The ratio of the 'expected' output (had the efficiency been unaffected) and the 'actual' output was calculated. This step disaggregates the reduction due to inverter efficiency from the reduction simply due to lower incident radiation, to avoid this being double counted. This therefore gives the efficiency correction needed in HEM to take into consideration the reduced efficiency of inverters when PV panels are partially overshadowed.

Second order polynomial curves were fitted through the resulting inverter efficiency factors (as a function of the direct factor f_{sh_dir}) resulting in the equations used below. A two stage polynomial is used for each inverter type because of the step change in behaviour when the 'lower limit' referred to in the source is reached. As can be seen in the following graph, these equations (the lines on the graph) give an excellent fit to the data points (the dots on the graph) derived from the experimental data.



The following equation and coefficients resulting from the process described above are therefore used in HEM to calculate the efficiency reduction factor due to partial shading of PV panels.

$$F_{PV_part_shaded} = a \times f_{sh_dir}^2 + b \times f_{sh_dir} + c \quad (9)$$

The above equation is used in conjunction with the appropriate coefficients from the table below based on the inverter type and whether it exceeds the threshold levels of overshadowing.

Case	a	b	c
<i>(Inverter type, shading threshold)</i>			
String inverter, $f_{sh_dir} < 0.7$	2.7666	-4.3397	2.2201
String inverter, $f_{sh_dir} \geq 0.7$	1.9012	4.8821	-1.9926
Optimised inverter, $f_{sh_dir} < 0.42$	2.7666	-4.3397	2.2201
Optimised inverter, $f_{sh_dir} \geq 0.42$	-0.2024	0.4284	0.7721

The resulting value of $F_{PV_part_shaded}$ is then applied (multiplicatively) as an additional factor in equation (1), as a now-disaggregated part of the performance factor.

