Solar Energy
Volume 80, Issue 9, September 2006, Pages 1179-1188

PV array <5 kWp + single inverter = grid connected PV system: Are multiple inverter alternatives economic?

P.A.B. James, A.S. Bahaj, R.M. Braid

https://doi.org/10.1016/j.solener.2005.09.010

Abstract

Compared with a single, central inverter, multiple inverter photovoltaic (PV) systems are considered to produce higher system energy yields by reducing mismatch losses within dc strings. This paper considers, from an economic viewpoint, whether multiple inverter systems can ever be justified for PV systems <5 kWp, under the conditions that presently exist in the UK. The UK scenario being one of very high labour costs combined with both relatively low radiation levels and feed in tariffs. Analysis of a 7.2 kWp test façade configured with string and central inverters indicates that the mismatch reductions that can be achieved do not compensate for the additional capital cost of a multiple inverter installation. In addition, unless the mean time to failure of inverters approaches that of the 25 year lifetime of the dc side of the PV system, the economics of small scale grid connected PV in the UK will remain difficult, even when the cost of the PV component falls.

Introduction

In an ideal PV system all the PV cells have the same *I–V* characteristic, producing modules (or laminates) with the same *I–V* response. Mismatch in a PV system is where variation in the *I–V* characteristic between PV modules/laminates in strings creates an overall reduction in the energy output compared to that of all the individual PV modules. The electrical output of a series PV string for example, is constrained by the weakest module in the circuit. Mismatch is inherent in PV modules due to cell variation but can also be created by external factors that may influence a PV array such as shading. For a sensibly located PV array, mismatch is generally considered to lead to a 1–3% reduction in dc power (Benitez et al., 2000, Braid, 2005). The level of mismatch may however, be much higher for PV arrays with complex shading patterns or strings which are formed from PV modules at different orientations/elevations.

To minimise mismatch it is generally accepted that the dc string length should be as short a possible (least number of modules). High voltage thin film modules (open circuit voltage >80 V) can be advantageous in this respect, achieving the required voltage with a relatively short string. Taken to its extreme the minimum dc string becomes the 'AC module' where a miniature inverter is mounted on the rear of the PV module. In this case, there is no external dc wiring and the power output of the module can be simply fed into the grid of the building.

There are typically three possible inverter scenarios for a PV system with a rating <5 kWp.

(1) Single central inverter.

(2) Multiple string inverters—typical string inverter size range 500–2500 Wp.

(3) AC modules—100 Wp typical.

The high cost of photovoltaic solar cells makes grid connected PV systems fundamentally expensive in comparison to other renewable energy generators such as wind. Commercial buildings which use high quality cladding materials such as cut stone are an exception to this rule and may incorporate PV at little or no additional cost. However, for the majority of grid connected PV systems and in particular domestic buildings, the capital saving that can be achieved through exchange of materials is often very small. Estimates of the economic payback time of grid connected domestic PV systems can be as high as 75 years (Oliver and Jackson, 2001). However, some studies have indicated shorter payback times if secondary benefits such as real estate value and change in energy usage patterns are considered (Perez et al., 2004, Bahaj and James, 2004). If the commonly quoted ($/Wp) cost of photovoltaics reaches a sufficiently low level to enable PV to compete with other renewables (estimated to be ~1$/Wp), attention will then switch to the balance of system (BOS) costs to ensure that the technology is economic. At present however, the BOS costs in the majority of grid connected systems (installation, cabling, inverters, etc.) are relatively small in comparison to the cost of the PV laminates or modules used.

This paper considers the case for a central inverter, string inverters and AC modules for domestic PV systems of 1.3 and 5.2 kWp in size. The majority of grid connected PV systems are installed with some form of subsidy, usually an up-front capital grant to cover a proportion of the overall system cost. In UK for example, the Energy Saving Trust (EST), a government funded entity sponsors domestic and commercial building PV programmes through capital grants (Energy Saving Trust). In the case of a domestic homeowner the subsidy can be up to 50% of the overall system cost. Larger housing schemes of multiple PV systems within new build developments are commonly undertaken. Often, in these cases, the capital contribution made by a housing association or local authority is made from a 'one off' special project reserve to support environmental projects. It is highly doubtful however, that subsequent, additional funds can be easily found to support the PV system in the event of hardware failures outside of the warranty period. This problem is exacerbated by the fact that PV modules are quite rightly sold with very long power warranties (20–25 years is typical), which can give a false impression that the lifetime of the entire PV system will be of the same order. Whilst the dc side of a correctly installed PV system (incorporating modules, cabling and connectors) should achieve the 25 year lifetime (Bahaj et al., 2001a, Bahaj et al., 2003) it is unlikely that an inverter will operate without fault for this period of time.

At present multiple inverter or AC module PV systems are often installed through grant programmes with the homeowner/housing association/local authority being unaware of the financial implications or risk of the system selected. Often the system chosen by the PV supplier/consultant is designed to

maximise energy yield, but does not take into account the long term costs of ownership and operation. The lack of an on going subsidy (competitive carbon tariff such as Renewable Obligation Certificate (ROC) for small scale electricity generation) in the UK makes the economics of PV difficult even if the PV system is considered as 'free' to a homeowner/housing association through grant subsidy and a one off payment from a special project reserve.

The study described here considers two possible scenarios:

(1) A PV system which is completely 'free'. The homeowner or housing association pays only for the maintenance of the system.

(2) A PV system where the dc side is free (modules, cabling, switchgear and installation), the homeowner or housing association pays only for the inverters and the maintenance of the system.

The effect of discount interest rates, inverter mean time to failure (MTTF), electricity generation price, inverter, and PV system size on cost to the homeowner for each scenario is discussed.

Section snippets

Experimental quantification of mismatch

Analysis of a reconfigurable 7.2 kWp vertical facade at Southampton University (Bahaj et al., 2002) was undertaken to quantify the energy yield benefit that small string inverters can produce in comparison to a central inverter. The array consists of 24 × 300 W strings, which can be reconfigured at the plant room as required. The array was split into two 3600 Wp blocks with six 700 Wp 'string inverters' (SMA SWR-700, 700 Wp) receiving one block and a single 2500 Wp 'central inverter' (SMA 2500) the...

Inverter selection

There are a range of selection parameters, which would influence the inverter selection for a PV array, these include:...

Scenario 1. PV System is free to the owner who pays only for maintenance and repair

The majority of installed PV systems in the UK are supported by a Government grant which covers the major component of the cost with the remainder coming from private funds. This scenario considers that the additional private funds come from a separate budget (e.g. special environmental projects budget of a local council) which does not need to be considered in terms of financial payback. In reality therefore, if the private funds are seen as a 'one off' payment, the only cost to the owner is...

Discussion

When a PV system is installed at no cost to the homeowner/operator it appears that AC modules or a large number of small string inverters is preferable to a single central inverter. The additional capital

cost of a multiple inverter system is not borne by the homeowner, who merely benefits from the resulting highly modular PV system (built in redundancy), which will not require maintenance or repair even when a fault develops. However, in pure economic terms the additional capital cost of AC...

Conclusions

This paper indicates that in UK unless a grid connected PV system <5 kWp has very unusual mismatch behaviour a single inverter system should always be chosen. It is difficult to envisage a scenario where AC modules will have a competitive economic advantage over a single inverter. The stark reality however, is that unless the MTTF for inverters approaches 20 years, the economics of small scale grid connected PV in the UK will remain difficult, regardless of the inverter type chosen, even if the...

References (19)

R. Perez *et al.*
Quantifying residential PV economics in the US—payback vs cash flow determination of fair energy value
Solar Energy (2004)

M. Oliver *et al.*
Energy and economic evaluation of building-integrated photovoltaics
Energy (2001)

Bahaj, A.S., James, P.A.B., 2004. Direct and indirect benefits of grid connected photovoltaics in low energy social...

Bahaj, A.S., James, P.A.B., McBride, J.W., 2001a. Photovoltaic connector behaviour under accelerated fretting testing...

Bahaj, A.S., Braid, R.M., James, P.A.B., 2001b. Mismatch losses in large PV arrays at Southampton University...

Bahaj, A.S., Braid, R.M., James, P.A.B., 2002. Post installation optimisation of a building integrated PV system...

Bahaj, A.S., James, P.A.B., McBride, J.W., 2003. Predicting photovoltaic connector lifetime. In: Proc. of 3rd World...

Benitez, P., Munoz, F., Minano, J.C., 2000. Optimal classification criterium to minimise the mismatch losses in PV...

Braid, R.M., 2005. Characterisation and mismatch losses of building integrated photovoltaic generation. Ph.D. Thesis,...

There are more references available in the full text version of this article.

Cited by (33)

Solar photovoltaic system design optimization by shading analysis to maximize energy generation from limited urban area

2016, Energy Conversion and Management

> *Citation Excerpt :*
>
> ...Ma et al. [30] have developed a theoretical model to determine the experimental current–voltage characteristic curves of a PV module/string/array and validated their model using PVsyst software. Various factors that influence the instantaneous PV generation [31] are recently analysed for special days under different conditions through the case study of 5 cities in Iran by Nejad [32]. In this article, the energy yield (energy generated/area) is maximized with low-cost system optimization by doing analysis in PVsyst software to adjust additional solar panels in a given area, so as to improve the support for urban energy needs without adding any other external technological components....

Show abstract

Selection and configuration of inverters and modules for a photovoltaic system to minimize costs

2016, Renewable and Sustainable Energy Reviews

> *Citation Excerpt :*
>
> ...Few studies were found with the objective to minimize costs by comparing equipment prices. Multiple inverter systems could rarely be justified for PV systems <5 kW instead of a single inverter [12]. The study evaluates a United Kingdom (UK) scenario with high labor costs combined with both relatively low radiation levels and feed in tariffs. It was concluded that for the proposed scenario, a single inverter was the best option due to the UK market at that time. ...

Show abstract

Performance comparison between micro-inverter and string-inverter Photovoltaic Systems

2015, Energy Procedia

Show abstract

Techno-economic optimization of a supercapacitor-based energy storage unit chain: Application on the first quick charge plug-in ferry

2015, Applied Energy

Show abstract

Advances and challenges in grid tied photovoltaic systems

2015, Renewable and Sustainable Energy Reviews

> *Citation Excerpt :*
>
> ...According to [8], the more efficient operation in a multi-string structure is achievable through increasing the number of parallel inverters. The cost of such a system, however, is likely to rise substantially [21]. Owing to a complex structure, AC-module topology has lower efficiency comparing to the other topologies [15]....

Show abstract

Technical-economic potential of PV systems on Brazilian rooftops

2015, Renewable Energy

Show abstract

View all citing articles on Scopus

Recommended articles (6)

Research article

A novel codification and modified heuristic approaches for optimal reconfiguration of distribution networks considering losses cost and cost benefit from voltage profile improvement

Applied Soft Computing, Volume 25, 2014, pp. 360-368

Show abstract

Research article

Artificial immune simulation for improved forecasting of electricity consumption with random variations

International Journal of Electrical Power & Energy Systems, Volume 55, 2014, pp. 205-224

Show abstract

Research article

Assessing competencies: An evaluation of ASTD's Certified Professional in Learning and Performance (CPLP) designation

Evaluation and Program Planning, Volume 44, 2014, pp. 48-58

Show abstract

Research article

A simple model of ac hopping surface conductivity in ionic liquids

Electrochemistry Communications, Volume 100, 2019, pp. 16-19

Show abstract

Research article

The special status of verbal knowledge in semantic memory: Evidence from performance of semantically impaired subjects on verbalizable and non-verbalizable versions of the object decision task

Brain and Language, Volume 128, Issue 1, 2014, pp. 9-17

Show abstract

Research article

A distributed energy monitoring network system based on data fusion via improved PSO

Measurement, Volume 55, 2014, pp. 362-374

Show abstract

View full text