Comparison of solar radiation and PV generation variability with system dispersion in the UK

Comparison of Solar Radiation and PV Generation Variability: System Dispersion in the UK

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Abstract

This paper investigates how number and location of solar installations may reduce aggregate irradiance variability and therefore lessen the overall impact of PV on grid distribution. The current distribution of UK solar farms is analysed. It was found that variability is linked to site clustering and nearness to coast. The UK solar farm fleet currently comprises a range of system sizes which, when viewed in en masse, reduces variation in PV generation.

Introduction

The installed solar energy base in the UK has increased rapidly in recent years, resulting in the perception that it could place an overall stress on the power system. A total capacity of 8.4 GWp of photovoltaic (PV) power was recorded in December 2015 [1], with installation being expected up to 12-13 GWp by April 2016. National Grid has warned that incorporating more than 10 GWp of solar electricity would adversely affect the transmission system [2]. Concern about operational security and possible power outages has already caused one Distribution Network Operator to refuse grid connection to new large-scale renewable projects for at least 3-6 years in the southwest [3]. These decisions are largely based on worst case assumptions that all systems will follow the same trend. However, studies in the USA, Germany and Australia, suggest that the impact of PV on national electricity distribution systems is related to the number and geographic distribution of installations, rather than the capacity of individual systems. Dispersion of solar systems reduces the variability of energy generation, which arises primarily from smoothing cloud movements.

This paper analyses how size, number and spatial distribution of solar farms mitigate the effects of irradiance variation on the grid in a maritime climate such as the UK.

A demonstration of smoothing due the geographic distribution of PV sites is presented. Having shown the impact of site location on generation output, the current pattern of UK site dispersion is investigated. The five-year trend in solar farm location is studied, together with possible drivers of this trend, with a view to predicting the long-term impact on the transmission network.

Current Knowledge of Influence of PV System Distribution

Several studies have demonstrated that high irradiance variability at a single site will be reduced when the surrounding group of sites is included.

Torpey (2011) [4] reports a substantial reduction (61%) in standard deviation over a short distance for one minute data between 1 site and 6 sites 1-10 km apart in California. He establishes that many small systems in a distribution system are unlikely to be problematic because no single generator can significantly impact system voltage. On the other hand, in the case of single large systems, or groups of relatively large systems, output variability can be an issue.

Similar findings were reported for large areas. IEA PVPS 14 [5] describe smoothing by aggregate PV systems in six regions around the world at various time scales. Variability reduction (VR i.e. variance in irradiance over time at one site divided by the variance of the average of several sites) ranged from 1.0 – 3.9.

It may be seen from these studies that much more capacity can be installed without harmful consequences for the grid if the fleet is considered in aggregate.

Previous authors [4-6] have verified that increasing the number of sites reduces irradiance variability. Yet the same number of points covering the same area may form different patterns e.g. linear, circular etc. To date, accurate point pattern or cluster analysis for the PV fleet are missing. The basis of these is given here.

Categorisation of cluster shapes is useful in many disciplines (e.g. epidemiology, criminology, disaster analysis). It helps to explain the relationship between data records and suggest reasons for their geographic position. Nonetheless, very little research has been done generally in this scientific field. There is no agreed terminology for patterns or shapes, nor are there any classification algorithms.

Sourcing and Calculating PV Site Data

The solar installations utilised in this analysis are from the Department of Climate Change Renewable Energy Planning database, REPD 2015 (575 x 1-50MW installations at September 2015). Hourly global horizontal irradiance for ten years (2005-2014) was interpolated [7] from UK Met. Office ground station readings [8] for each system.

Effect of Size, Number and Cluster Shape on Irradiance Smoothing for Selected Groups of PV Sites.

The literature indicates that the irradiance variability of one large site may be ameliorated when included with readings from surrounding smaller installations. It was decided to test this finding with real solar farm locations in the UK. Six large solar farms were identified (Figure 1). A number of systems around each large farm, equivalent in capacity to the major installation, were selected to test impact of variability. These solar farm groups have various numbers of members and cluster shape (Table 1).

Figure 1: Groups of UK Solar Farms for smoothing analysis. Largest of each group marked with white star.

The hourly irradiance for 2014 (5019 daylight hours when PV generation occurs) was analysed for each major site and averaged for the systems comprising the group. Standard deviation and variance for major site and group was calculated.

Three of the groups exhibit the anticipated decrease in variability (as compared to the larger single site). That is, the percentage reduction in standard deviation between the main single site of the group and the average of the group is positive. VR is greater than one, meaning that irradiance variability is less. The VR range of 0.997 to 1.005 compares well to IEA PVPS 14 [5] results. These authors obtained a VR of 1.3 for 2013 hourly data acquired from 18 weather stations throughout the UK with an overall radius of 600km. Relatively low variability is expected for the UK and for longer time intervals [5], owing to cloud speed.

Location	Capacity MW	No. Sites	Cluster Description	Mean Distance km	Radius of Cluster	% Reduction in Std Dev	VR
Cornwall	40	7	3 diagonal lines SW to NE	0.75	9	0.48	1.005
Pembrokeshire	32	3	Two part clump	3	4	0.26	1.003
Hampshire	48	7	2 horizontal lines W to E	0.7	20	0.25	1.002
Norfolk	50	7	Diagonal line SW to NE	11	33	-0.07	0.999
Wiltshire	70	8	Clump	4.6	12	-0.09	0.999
Nottinghamshire	27	5	Vertical line S to N	3.1	12	-0.34	0.997

Table 1: Details of UK Solar Farm Groups and Results of Smoothing Analysis.

Radius covered by the sites and number of sites do not appear to influence variability, since these differ between groups with high and low VRs. This is in contrast to findings from other researchers in Australia [4].

One the other hand, it is noticeable that the three groups with VR > 1 have low mean distances between group members. The small mean distance values are caused by the spatial layout of the groups. They are multipart with two or three sets of points. The points in each set are close together and the other set or sets in the overall group are at two or three times the intra-set distance. Thus incoming weather systems pass over first one, and then consecutive sets in each group.

This result was surprising. Since weather fronts generally approach the UK from the southwest, it was expected that the long, linear SW to NE Norfolk site would show most smoothing. On the other hand, irradiance is already fairly constant across this flat, low-lying region.

Another point to note, is that the three VR > 1 sites are closer to the coast where weather is more changeable.

It is surmised that irradiance variability is affected by either: (a) a pattern of site layout and intra-site distance, or (b) proximity to coast.

Current Pattern of UK Solar Farm Dispersal and Associated Grid Stresses

The current researchers and others have concluded that stress on the grid is not as great where there are many small sites or a large site surrounded by smaller sites (rather than clusters of large sites). Figure 2 summarises the current installations of solar farms in the UK, showing a large variance in size and distribution.

It may be seen that Cornwall has only one major but many smaller installations. This suggests, that the grid in Cornwall may not be as affected by power fluctuations as elsewhere. The output will be smoothed by the mix of system sizes. However, following an imaginary line in Figure 2 from the Bristol Channel to the northeast, two clusters of high capacity systems may be identified. The substations and high voltage lines they feed into are listed in Table 2.

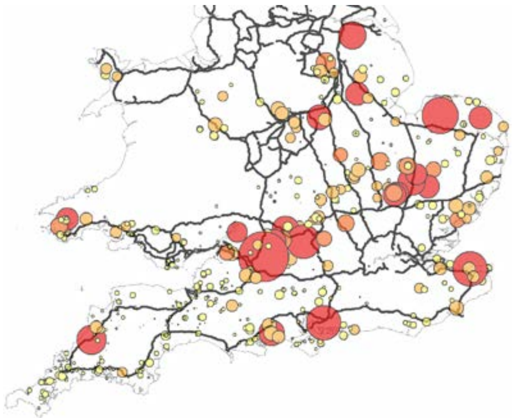

Figure 2: Location of UK Solar Farms (2015) and proximity to high voltage lines. (The larger and hotter the circle, the higher the capacity of the solar farm)

Sub-station Name	County	Rte No.	Route Name
Minety	Wiltshire	ZF	Cowley-Minety
Didcot	Wiltshire	4YG	Bramley–Didcote
Pelham	Hertford-shire	4ZM	Burwell Main–Pelham
Burwell	Cambridge shire	4ZM	Burwell Main–Pelham

Table 2: Parts of UK National Grid Subject to greatest stresses from Solar Farm Output

(Note: Figure 2 is presented in simple point form for brevity. The clusters have been proven to be significant with geostatistical tools.)

On the whole the distribution of solar farms in the UK currently displays a combination of adjacent small systems, or alternatively large and small adjoining. The few exceptions are given in Table 2. This bodes fairly well as far as impact on the grid is concerned. The next section explores the likelihood of future change.

Trends in Solar Farm Location

Analysis of the five years data of the REPD reveals that total number of solar farms is increasing in all areas. The rest of England and Wales is beginning to encroach on the huge lead of the Southwest in terms of percentage.

Mean size of solar farm has increased throughout the country, by an average of

23% per year. 2014 saw a 43% increase in mean installation size.

While sizes are increasing in all areas, the Southwest has one of lowest mean sizes (Figure 3). The largest installations are found in Oxfordshire and Norfolk.

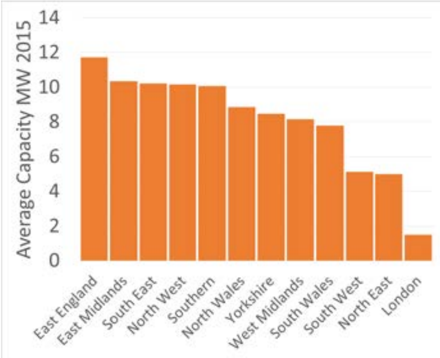

Figure 3. Average Capacity of Solar Farms in each DNO 2015.

Trend Drivers

It has been shown that the trend is for bigger farms and that the largest installations are located in the Southern and Eastern DNOs. Figure 4 reveals that the solar resource, administrative regime and land rents play a role in deciding installation size.

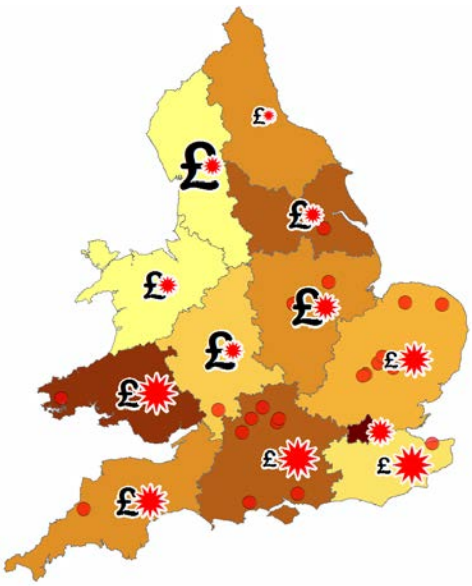

Figure 4: Influence of the solar resource (sun symbols), rural land rents (£, source: RICS), % planning permission granted (background: pale least, dark most) on location of largest UK Solar Farms. (Farms over 30MW depicted as red circles).

Conclusion and Future Work

An alternative method of investigating grid stresses, based on mix of sizes of installations and geographical diversity, rather than number or capacity has been presented. It was observed that irradiance variability is alleviated by either pattern of site layout or proximity to coast. More work is necessary to ascertain which is the most influential. Ignoring the smoothing effect of groups of systems could lead to unnecessary grid restrictions.

Current size distribution of UK solar farms may be described as predominantly low adjacent to low in the Southwest and mostly high-low in the rest of the country. This indicates an attenuation of PV impact on the transmission grid.

In general the trend is for big farms which is unhelpful as regards grid stresses. However, larger solar installations are being positioned outside of the South West, which is the most overloaded DNO. Size of system is being driven mainly by land rental price.

Thus, present solar farm distribution is beneficial for reducing PV impact. This is unlikely to change in the DNO which has the highest input from renewables.

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