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Bachelorstudiengang Energie-, Gebäude- und Umwelttechnik

Ertragsbegutachtung einer Photovoltaikanlage

anhand des Beispiels der Hatchlands Farm in Südengland (Devon)

von

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7 Englische Zusammenfassung für TRESOC

Dieser Teil der Arbeit beinhaltet keinerlei neue Erkenntnisse, sondern lediglich eine Zusammenfassung für das englische Praktikumsunternehmen.

This part of the work does not contain any new expertise. It is only a summary for the english internship company.

History and problem

In 2014 the photovoltaics (PV) installation on Hatchlands Farm was purchased by TRESOC for £168,000. Because of its installation in 2011 a relatively high Feed-in-tariff is paid for the energy it is generating. In 2017 the generation-tariff was 38,5 $\frac{p}{kWh}$, the export-tariff 4,2 $\frac{p}{kWh}$ and the part-purchase-agreement 3,3 $\frac{p}{kWh}$. According to the MCS-Certificate the installation with 49.92 kW should generate around 50,229 kWh a year. With these given numbers TRESOC calculated its predicted income, but the estimated generation was never achieved - it's been 10 to 20 percent underperfomrming each year. This underperformance in the generation leads to a loss of income and therefore needs to be sorted out.

Installation

There was not enough relevant documentation to assess the PV, so the main part of this work was to gather this information to undertake a new analysis and calculate the predicted generation.

The installation consists of 83 modules with 240 Watt on the small roof and 120 modules with 250 Watt on the big roof. All of them seem to be Silken SLK60M6L. With a length of 1.64 m and a width of 0.99 m the 203 panels make 329.59 m^2 of PV-area. The panels are connected to two inverters SMA STP 15,000 and two inverters SMA STP 10,000. According to the data sheet from Silken and SMA the following efficencies apply:

240 Watt: $\eta_{240\,W} = 14,8\,\%$

250 Watt: $\eta_{250\,W} = 15,4\,\%$

STP 15,000: $\eta_{EUR} = 97,7\,\%$

STP 10,000: $\eta_{EUR} = 97,7\,\%$

The angle and orientation were measured with an inclinometer and a compass:

orientation: 152 ° or 28 ° east

angle: 8,5 °

With these numbers it was calculated that the orientation factor (OF) and therefore the absorption of radiation in comparision to a flat surface (which is how radiation is measured) is 106.12 %.

The next step was to calculate the Performance Ratio. According to Global Solar Atlas a PR of 0.919 applies to the area of Hatchlands Farm.

With all this information, the following calculation could be set up:

$$P_{expected} = E_{radiation} * OF * \left(\left(\frac{120 Modules}{203 Modules} \right) * \eta_{250\,W} + \left(\frac{83 Modules}{203 Modules} \right) * \eta_{240\,W} \right) * \eta_{EUR} * PR$$

Now the given numbers could be used to calculate the expected generation according to the radiation of the sun.

$$P_{expected} = E_{radiation} * 106.12\,\% * \left(\left(\frac{120 M.}{203 M.} \right) * 15,4\,\% + \left(\frac{83 M.}{203 M.} \right) * 14,8\,\% \right) * 97,7\,\% * 91,9\,\%$$

With this calculation formula it was calculated if the PV installation did perform right in 2016 - compared with the radiation data from the MetOffice-Station in North Wyke.

Month	solar radiation in kWh	expected generation in kWh	gained generation in kWh	difference in %
January	8,801.366	1,197.587	1,031.667	-13.85
February	14,744.984	2,006.324	1,666.645	-16.93
March	31,784.211	4,324.822	3,411.907	-21.11
April	41,044.736	5,584.886	4,450.784	-20.31
May	57,839.907	7,870.176	5,064.565	-35.65
June	46,086.941	6,270.970	4,833.074	-22.93
July[11]	45,572.305	6,200.944	6,214.294	+0.22
August	49,426.874	6,725.429	5,306.545	-21.10
September	30,331.145	4,127.106	3,248.510	-21.29
October	22,253.300	3,027.968	2,265.302	-25.19
November[12]	60,14.251	818.349	1,308.341	+59.88
December	7,366.177	1,002.303	528.041	-47.32
annual sum	**361,266.198**	**49,156.864**	**39,329.675**	
average				**-22,31**[13]

[11] 5 days are missing in MetOffice-data

[12] 16 days are missing in MetOffice-data

[13] without November

The difference is always the average under- or overperformance for the whole month - not the difference in the sum of kWh. There could be a daily difference in local clouds between North Wyke and Harbertonford which hopefully levels out over a month.
In 2016 there are roughly 10,000 kWh of expected generation missing. That is about 20 % underperformance for this period. After a cleaning in July there is clearly a significant increase in the performance which is diminished a month later already. In the following, I try to clarify why the installation is behind in it's expectations.

Energy-Yield-Survey

Energy-Yield-Surveys are important to estimate the economy of a PV-installation. They are based upon radiation data over a long period. I used the data from Plymouth with a daily average radiation of 2.91 $\frac{kWh}{m^2}$. According to the orientation of Hatchland's PV this equates to 3.09 $\frac{kWh}{m^2}$ as it receives 106.12 % of horizontal radiation.
To assess the overall impact of many different influences on the PV installation a generator-correction-factor was searched for. It compounds as follows:

$$k_G = k_{PM} * k_{NG} * k_{GR} * k_{SP} * k_{TB} * k_{MM} * k_R * k_V * k_S * k_{MPP}$$

Symbol	correction-factor for ...	expectancy range
k_{PM}	underperformance of modules	0.9 ... 1.0
k_{NG}	low irradiation	0.96 ... 0.995
k_{GR}	glass reflection loss	0.96 ... 0.995
k_{SP}	spectral mismatch	0.96 ... 0.995
k_{TB}	partial shading	0.8 ... 1.0
k_{MM}	mismatch	0.95 ... 1.0
k_R	electrical resistance	0.96 ... 0.998
k_V	soiling	0.8 ... 1.0
k_S	snow coverage	0.5 ... 1.0
k_{MPP}	not in MPP working loads	with η_{EUR} of inverter covered

$k_{PM} = 0.97$ because it should be related to the maximum underperformance that the manufacturer guarantees. Silken states a maximum underperformance of 3 % for its modules.
$k_{NG} = 0.975$ because Hatchlands is in a plain area there is more diffuse radiation and not 1000 $\frac{W}{m^2}$ as in STC. Therefore the MPP-Voltage sinks.
$k_{GR} = 0.995$ as glass reflection loss occurs in direct irradiation, so not too much impact

on Hatchlands.

$k_{SP} = 0.975$ because there is a difference in the spectrum a Pyranometer meassures (at MetOffice) and the spectrum a solar cell can use to generate electricity. (Energy gap of Silicium)

$k_{TB} = 1$ as there is no shading on the PV installation on Hatchlands if the cannister was to be moved. If it can't be relocated, this correction factor goes down.

$k_{MM} = 0.985$ as it couldn't be measured how different the modules are, this is an estimated number. Within the same make and model there are small differences in the performances of the modules. They should be sorted and connected by performance. This couldn't be checked during the internship.

$k_R = 0.996$ as according to the researched documents there are 700 m cable with 6 mm^2 which cause 0.4 % loss.

$k_V = 0.90$ as 10 % seems to be the average loss between clean and soiled modules. (more of that later)

$k_S = 1$ as there is now relevant snow coverage in this area.

$k_{MPP} = 1$ because it's already in the calculation as η_{EUR} from the inverters.

If all the numbers are put together it results in the following:

$$k_G = 0.97 * 0.975 * 0.995 * 0.975 * 1 * 0.985 * 0.996 * 0.90 * 1 * 1$$

$$k_G = 0.81$$

which means, that if all the influences are considered, it is assumed that the generator is underperforming by about 19 %. This is mainly due to soiling but also possible mismatch, location and not STC-conditions in this environment.

If this knowledge is applied on the data from 2016, will be discovered that the installation seems to work satisfactorily.

$$P_{expected_{2016_{correction}}} = P_{expected_{2016}} * k_G$$

$$P_{expected_{2016_{correction}}} = 49,156.864\,kWh * 0.81$$

$$P_{expected_{2016_{correction}}} = 39,817.060\,kWh$$

This is reasonably close to the actually gained 39,329.675 kWh with only less than 500 kWh missing in the whole of 2016. This proves that my assumptions can't be too bad and picture the reality quiet good.

In the MCS-Certificate it is stated that the Hatchland's PV installation should generate about 50,229 kWh in a year. This was never achieved in the past. Therefore I undertook new calculations with the generator-correction-factor as explained above. In Plymouth (nearest station with radiation data over a longer period that I could find) the annual radiation is 1,062.15 $\frac{kWh}{m^2}$ on a horizontal area. With the orientation factor of 106.12 % this comes to 1,127.15 $\frac{kWh}{m^2}$ on the tilted solar panels. On a module area of 329.59 m^2 this makes 371,497.3685 kWh. With this radiation, I use the same formula as with the MetOffice data multiplied with the generator-correction-factor.

$$P_{yield} = E_{rad} * \left(\left(\frac{120 Modules}{203 Modules} \right) * \eta_{250\,W} + \left(\frac{83 Modules}{203 Modules} \right) * \eta_{240\,W} \right) * \eta_{EUR} * PR * GCF$$

Now the given numbers could be used to calculate the expected generation according to the radiation of the sun.

$$P_{yield} = 371,497.3685\,kWh * \left(\left(\frac{120 M.}{203 M.} \right) * 15,4\,\% + \left(\frac{83 M.}{203 M.} \right) * 14,8\,\% \right) * 97,7\,\% * 91,9\,\% * 81\,\%$$

$$P_{yield} = 40,944.92\,kWh$$

So according to my calculations it should be expected to gain 40,944 kWh instead of 50,299 kWh in an average year.

All these calculations do NOT consider the degradation of the panels.

According to the data sheet from Silken, the guaranteed maximum degradation is anually 0.7 %. For a six year old installation, this would sum up to 4.2 % loss of performance. This hasn't been taken into account as in the April-TRESOC-board-meeting it was stated that degradation hasn't been experienced so far. It's more a theoretical number. If maximum degradation would be applied, the installation would be over performing, according to my other assumptions and calculations.

Impact of cleaning 2017

As soiling seems to be the major impact on the Hatchlands Farm PV installation, I focussed on the improvement due to cleaning in 2017. The last manual cleaning was in July 2016, so in March 2017 soiling had build up over nine months and led to a difference of generation of -16.95 %. After the cleaning on 3rd April the performance improved and the installation was 1.27 % better than expected. In May, one month after cleaning, it was -3.38 % under performing again.

Month	expected yield	gained yield	difference	average deviation
March	3,406.907 kWh	2,779.814 kWh	-627.093 kWh	-16.95 %
April	5,805.115 kWh	5,922.490 kWh	+117.375 kWh	+1.27 %
May	6,497.529 kWh	6,135.307 kWh	-362.222 kWh	-3.38 %

So the cleaning appears to make a significant difference in the installation's performance. Other than in 2016, one month after the cleaning the performance doesn't drop back to the under performance of the pre-cleaning-month. It slightly decreases. It can't be determined why this is the case. It can only be pointed out that it is different than in 2016 - but for the better. To obtain a full evaluation of the impact of the cleaning, the monthly analysis should be continued untill March 2018 to have data from a whole year. In March the sum of the yield was 18.4 % under the expected amount. Without cleaning this would have continued or became even worse in April and May. This would have caused a loss of 2,260 kWh. With 38.5 $\frac{p}{kWh}$ generation tariff this would have been a financial loss of £870 - not even considering the loss on export tariff. So the cost of £360 for the cleaning is paid back easily due to better performance of the installation.

Next steps

According to the Energy-Yield-Survey the installation seems to work satisfactory within the given environment. Saying this, I assume that the partial shading on the small roof will be eliminated by moving the cannister. If this is not possible, the impact of the shading has to be reconsidered. Affected panels may need to be set on a new string, to ensure that they don't affect the other modules.

Furthermore a monthly comparison of the expected and gained generation should be done until March 2018 or longer. With this, TRESOC will know the impact of soiling and the improvement due to cleaning. It will provide you the numbers to check whether a biannual cleaning is sufficient or if another cleaning in the autumn or winter would make sense and generate more energy and therefore money. The required data is available from the MetOffice for free, but don't ask them monthly or they may ask for a payment sometimes. Do it in two or three bigger blocks of data for free.

The inverters are currently not in the best location. Sitting under the roof of the shed, they are covered in straw and dust. Bad air circulation could lead to thermal under per-

formance of the inverter on hot summer days. They should be moved to the bespoken location on the side of the shed next to the static caravan. This would lead to a better access for neccessary maintenance as well as cleaner and more circulating air in their surroundings.

With this it should be assured, that the calculated annual generation of 40,944 kWh is reached or even exceeded, even though, the installation won't be able to generate the expected 50,299 kWh as stated in the MCS-Certificate. The main reasons for this are the soiling, the shading and maybe the inverter's location. Apart from this, it seems to be working reasonably within the given environment. I couldn't clarify why the MCS-Certificate made another prediction, but it seems as if they are working with different numbers for radiation and Performance-Ratio, which could cause a significant difference.