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Abstract: With the solar power panels as integrated surface elements in new building constructions, solar power will be economic attractive in urban areas, close to the power consumption. In the new dense urban areas, the rooftop areas will be attractive for other purposes, like terraces and green roofs. The solar power panels may instead be placed at the facades of the buildings – this is especially relevant at high geographic latitudes, where the altitude of the sun is low. It may even make sense to mount panels at all facades, better distributing the generation over the day.

1 Introduction

Solar power is expected to contribute significantly to the power generation in the future – even in the Nordic countries, like in Denmark, where the Sun is on the sky only from 8:30 to 15:30 (standard central European time) with a maximum altitude of 10° in the winter, and from 3:00 to 21:00 (standard CET) with a maximum altitude of 50° in the summer.

The solar power can either be produced by larger farms, installed at the ground, far from the consumptions and occupying valuable farmland (there is no unused land in Denmark), or be produced by smaller installations in the urban areas, close to the consumptions, but with the challenges to find the necessary, well exposed and available spaces. The rooftops of the buildings are attractive for many other purposes – like green roofs and recreation – and may therefore not be available for power generation. However, this is not the case for the facades.

A significant (and increasing) part of the cost of solar power is related to the installation and to the maintenance of the panels. These costs may be lower for the large-scale farms on the ground relative to many smaller urban installations, typically installed on top of other constructions, like buildings. The answer to this is to install the solar panels as part of the construction and during the construction phase, and optimally with a double purpose: as building integrated panels that at the same time produce power and are part of the building envelope (the roof or the façade), and thereby substitute other envelope materials. The value of the solar power should then just match the additional cost of the envelope materials, compared to other envelope materials.

A maximum annual energy generation from solar panels installed in Denmark is obtained by installing them towards South with an angle of 45° relative to horizontal. However, that may not necessarily provide the maximum value of the power produced by the solar panels – neither in financial terms nor in economic terms.

If the solar panels are connected to the electricity grid 'behind' the electricity account metre, the financial value of the solar power for the customer very much depends on the dynamic balance between the generation and the consumption, due to the different prices for, respectively, buying power from and selling power to the public grid (as you pay for using the grid as a 'buffer'), and maybe also to the dynamic electricity prices over the day. You can therefore maximise the value of the power generation from the solar panels through a more intelligent installation of the panels, so the production better follows the demand (and the dynamics in the prices), and through time shift of the consumption, so the consumption better follows the generation from the solar panels (flexible consumption). This is demonstrated by the Copenhagen International School (CIS) in Copenhagen, Denmark.

2 The Copenhagen International School

The CIS was built in 2016 in Nordhavn in Copenhagen, Denmark, next to the sea (towards South). No other buildings block the free insolation from the Sun to the school. However, the building is constructed with four 'towers' (along an East–West line), and the building is in addition irregular in its construction (see Fig. 1). The construction therefore shadows for the Sun for other parts of the building. From a scientific point of view, this can be used to study the impact of shadows from other buildings in a dense urban area.

Most of the facades are equipped with facade protection elements that are also solar power panels – towards North, East, South and West. The photo voltaic (PV) facade elements cover in total 6000 m^2 distributed on 12,000 modules of each 50 W_p, The modules are electrically interconnected in series in groups of 6–12 modules (see Fig. 2), and then connected to the electric LV grid via 1200 single-phase micro-inverters. All modules will only be exposed with direct insolation from the Sun part time of the day – either due to the orientation of the facade or due to local shadows from the building construction itself (see Fig. 3). The buildings (or their facades) are oriented 10° clockwise relative to the exact North, East, South and West. In addition, for architectonic reasons, each PV module is individually angled few degrees relative to the facades.

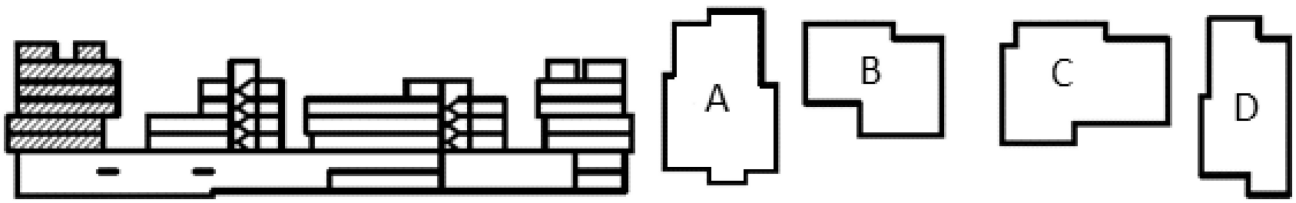

Fig. 1 *Copenhagen International School consists of four 'towers' – A towards West, D towards East*

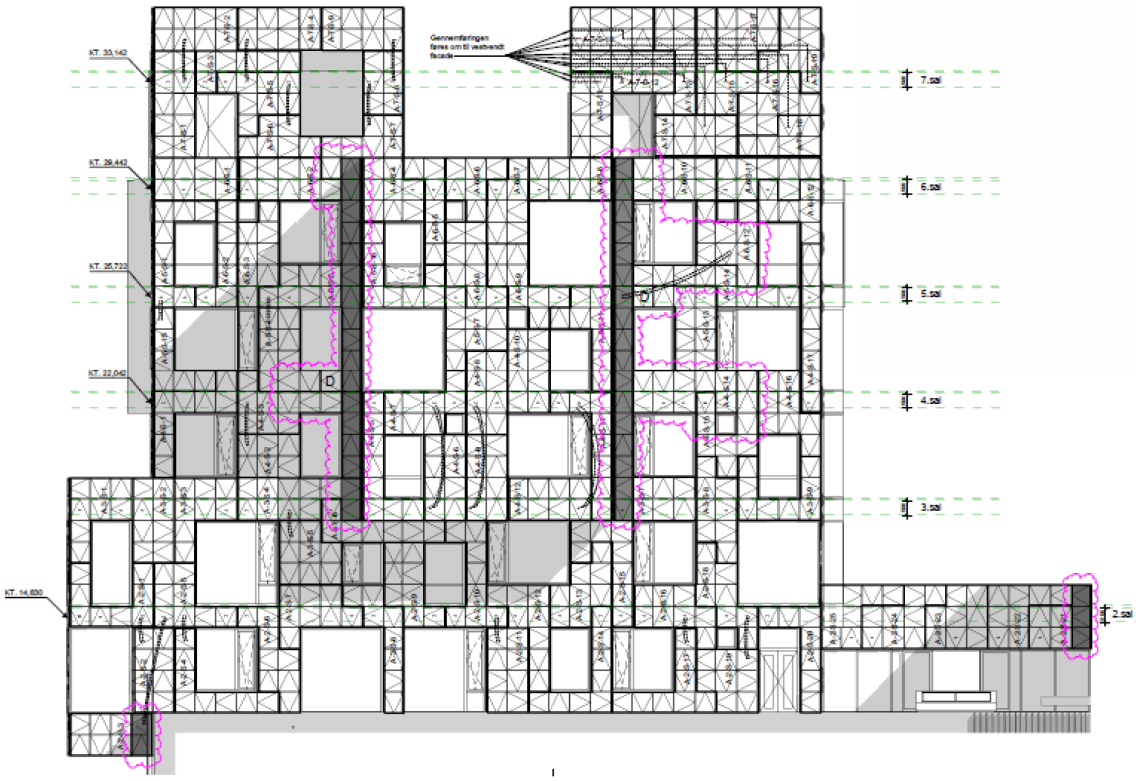

Fig. 2 *Copenhagen International School, indicating the position and grouping of the squared PV modules*

Fig. 3 *Copenhagen International School, with most of the facades covered by PV modules (Photo: Per Nørgård)*

PV generation data have been collected from most of the micro-inverters for a full day, almost without clouds. Data were not available from all the micro-inverters, but sufficient, representative data were provided. Data are available for each 10 min period, both as instantaneous power at the DC side, P_{dc}, as instantaneous power at the AC side, P_{ac}, and as energy generation at the AC side, E_{ac}. The 10 min energy generation data have been used in the analysis. The energy data used in the analyses have been normalised relative to the specific areas of the PV modules involved.

Two main analyses have been performed as part of a master thesis [1]: (i) the generation from the PV modules towards North, East, South, West and in total; and (ii) the generation from a single micro-inverter, part time in shadow from another part of the building.

2.1 Generation over the day

Fig. 4 shows the normalised generation over the day with a 10 min resolution from most of the PV modules at the facades towards North, East, South and East for tower A, B, C and D, respectively. Even the PV modules towards North contribute significantly to the generation.

Fig. 5 shows the normalised generation on an hourly basis from all facades at tower A, B, C and D, respectively. There is a relative constant generation from sunrise to sunset – at least for Tower A, B and D. This corresponds very fine to the demand at the school.

2.2 PV panels in shadow

Generation data from a single micro-inverter, feeded from eight PV modules at a South façade, and part time partly in shadow from another part of the building, have been analysed. The generation

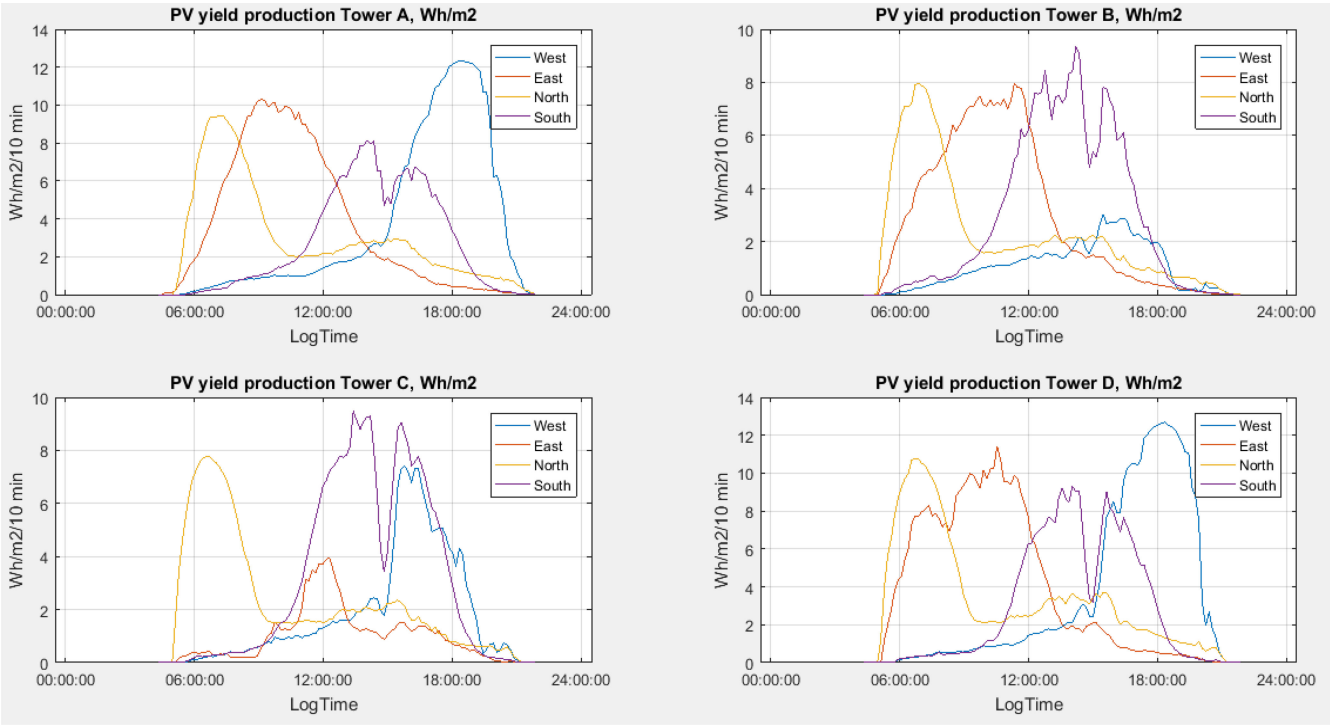

Fig. 4 *Normalised generation per 10 min from the PV modules at the four towers and at the facades towards North, East, South and West, Copenhagen International School, 6 July 2017*

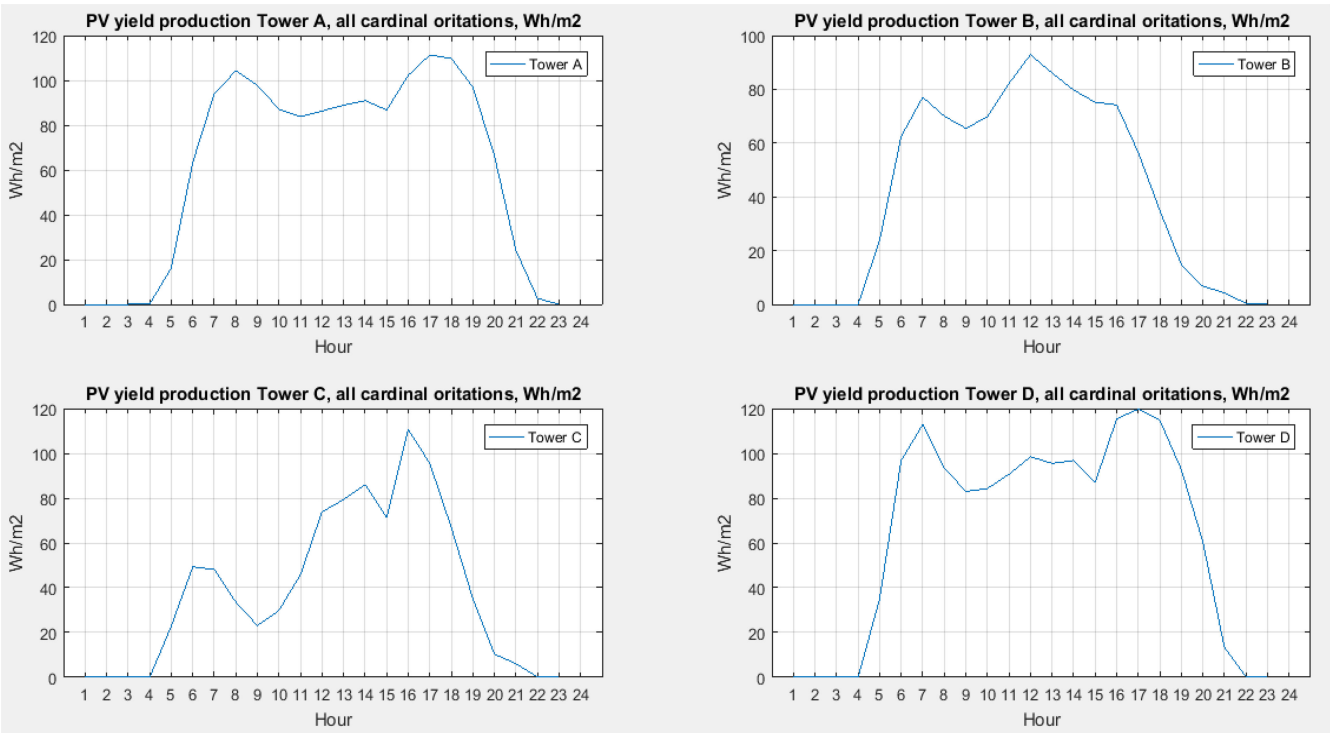

Fig. 5 *Normalised generation per hour for all the PV modules at each tower, 6 July 2017*

has been compared to the generation from another inverter, feeded from eight PV modules at the same façade, but fully exposed by the Sun. The shadow of the eight modules in question has been simulated. The simulation of the shadow and the generation from the two inverters are presented in Fig. 6.

The generation is almost fully blocked from the eight modules in partly shadow until all eight modules are fully exposed. This indicates that no bypass diodes have been used in the electrical design. And, as many of the PV modules at the building will be partly in shadow part time of the day, there seems to be a potential for increasing the generation by introducing bypass diodes in the electrical design at the DC side of the inverters.

3 Conclusion

Intelligent integration of power producing façade protection elements as part of a building design and as part of the construction of the building can at the same time minimise the (additional) installation costs of electricity generating elements in urban areas, and maximise the value of the electricity produced by these electricity generating elements. The value of the generated electricity can be maximised either in financial terms (if the power is generated 'behind' the account metre), or in economic terms (by maximising the value of the power generation for the power or energy system).

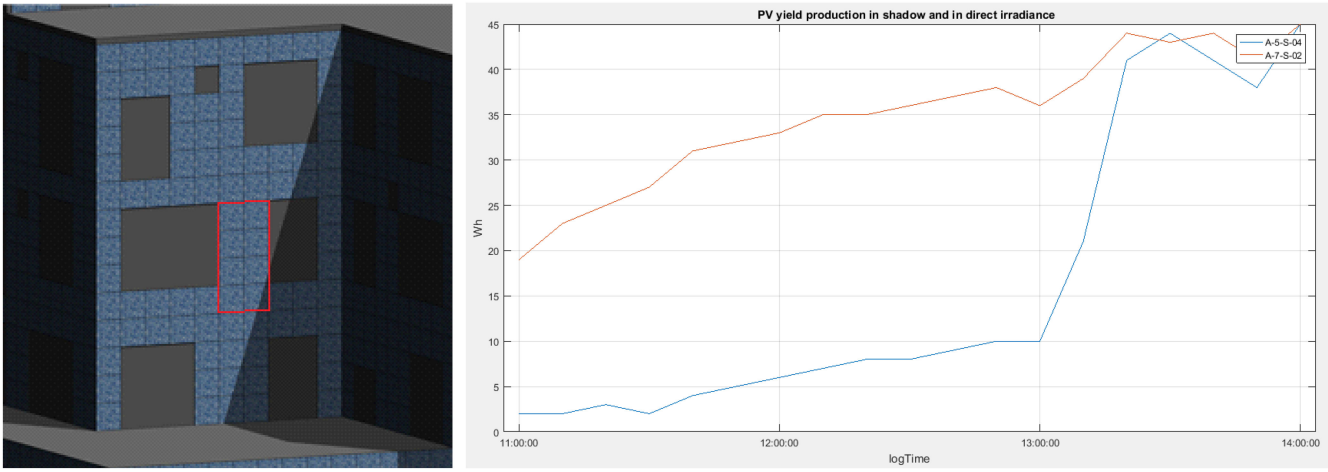

Fig. 6 *Left: Simulated visualisation of the shadow of the PV panel A-5-S-04 consisting of eight PV modules (indicated by the red line) at logtime 12:50. Right: Normalised generation from the shadowed PV panel A-5-S-04, compared to the normalised generation from PV panel A-7-S-05 with no shadow. Copenhagen International School, 6 July 2017*

At least in the Nordic countries, like in Denmark, it makes very good sense to design new buildings with façade elements that at the same time protect the surface of the construction and produce electricity. The façade mounting of the electricity producing elements saves the rooftop for other purposes. And mounting the electricity producing elements in more geographical directions, distributes the generation over the day, typically with a better match to both local consumption patterns and power/energy system needs.

Façade mounted electricity generating elements may be partly in shadow part time of the day. This must be taken care of in the electrical design in order to optimise (the value of) the generation.

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5 References

[1] Poder, S.H.: 'Potentials and challenges of façade mounted PV in urban areas – with Copenhagen International School as case'. DTU master thesis, 2018.