Study Committee C4

Power System Technical Performance

ID:10542_2022

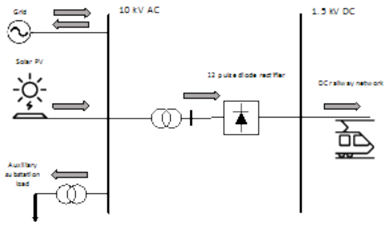
Integration of a 1.5 MWp Photovoltaic (PV) plant into the railway electricity network of the Netherlands

Michalis POIKILIDIS*, Robert HEUCKELBACH*, Teun PLOEG*, Fedor TEN HARVE**, Gerald OLDE MONNIKHOF**

DNV*, ProRail**

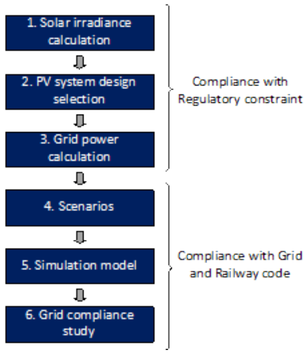
Motivation

- The railway network operator of the Netherlands has the ambition to become energy neutral and to facilitate the integration of renewable energy sources (RES) into the railway network in the light of the energy transition.
- An increasing number of owners of RES units in the Netherlands request to connect their units to the railway network, due to the proximity of the railway network to the location of their units. Therefore, there is an uprising need to assess the compliance of RES plants with the railway network requirements and assess the impact on its operation.



Methodology

- To assess the compliance, a 1.5 MWp solar plant has been integrated in a Dutch railway substation as reference case.
- The railway operator is constrained by the regulator to transfer the whole PV generation to the railway network. No power should flow towards the distribution grid to avoid congestions. The compliance with this regulatory constraint was evaluated.
- The compliance with the grid code (DSO) requirements, but also with the railway network requirements was assessed.



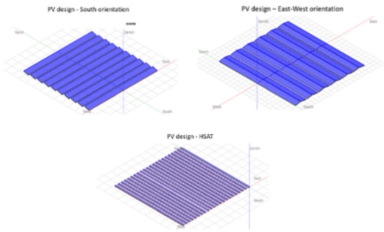
Step 1: Solar irradiance calculation

- the global horizontal irradiance (GHI), diffuse horizontal irradiance (DHI) and the ambient temperature were derived in monthly resolution.

Step 2: PV system design selection

- the potential energy yield and hourly production profiles of three hypothetical solar PV systems at the specific location were generated:

- ❑ South facing ("South"), fixed tilt angle, 15 degrees
- ❑ East-West facing ("East-West"), fixed tilt angle, 10 degrees
- ❑ Horizontal single-axis tracker ("HSAT"), variable angle, -60 to 60 degrees

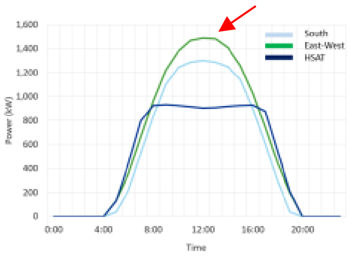


→East-West was selected due to highest energy production

Key first-year simulation results per PV system

Parameter	South	East-West	HSAT
Total system capacity	1393 kWp	1672 kWp	1010 kWp
Net energy production	1255 MWh	1390 MWh	987 MWh

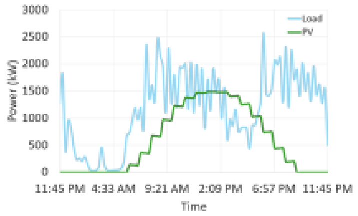
Daily power generation



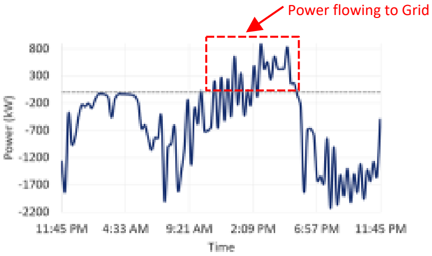
Step 3: Grid power calculation

- The PV generation and load profiles were available
- The daily power that flows towards the grid was calculated by substracting the daily load from the daily PV generation profile
- The daily and yearly energy that flows to the grid were computed
- The number of days per year during which energy flows to grid were also calculated

Estimated daily PV and load profiles

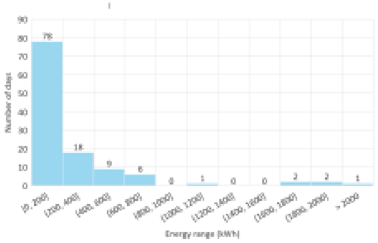


Power-to-Grid



- It is shown that PV power can flow towards the grid throughout the year
- For 117 days over a year, energy flows towards the grid
- **Therefore, the regulatory constraint cannot be respected at all times!**

Power-to-Grid: number of days per annum



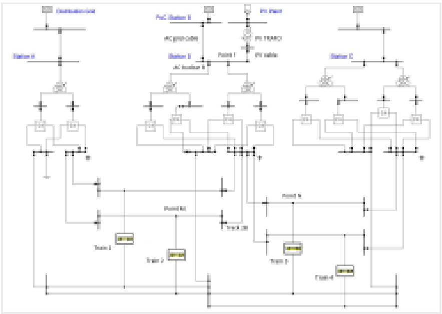
Step 4: Simulation study scenarios

- Three scenarios were considered in the grid compliance study
- Maximum PV generation: 1500 kW
- Maximum Load (of substation B): 4000 kW
- **Scenario 3** was selected because it has the biggest impact on the operation of the network

Scenarios	PV power	Load of substation B
Scenario 1	PV_{max}	0
Scenario 2	0	$Load_{max}$
Scenario 3	PV_{max}	$Load_{max}$

Step 5: Simulation model

- The model of the railway network was built
- The model consists of three substations and two trains were added between two consecutive substations



Step 6: Grid compliance study

- The compliance with the grid code and railway requirements was assessed
- To evaluate the compliance of the PV plant, five criteria were defined
- Load flow, Harmonic and Short-Circuit analysis simulation studies were performed to assess the compliance with the criteria

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6.1: Network Compliance Criteria

i. Network components should not be overloaded

ii. Voltage distortion at PoC should be acceptable (IEC, IEEE harmonic limits and THD<5%)

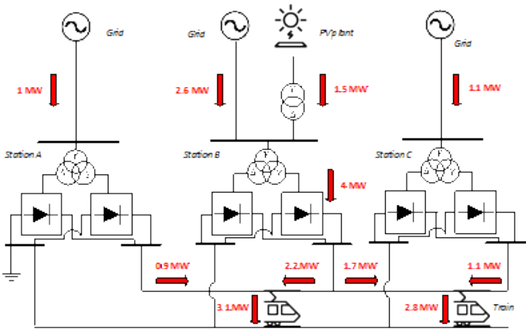
iii. Voltage magnitude variation at PoC within ±5 % of nominal value

iv. DC load voltage variation should be maintained within the acceptable range (1350 – 1820 V)

v. Short circuit current should not exceed the rated equipment values

6.2: Load Flow Analysis

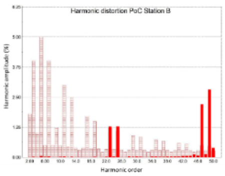
- TRAFO of Station B and PV MV cable: 100% loading
- Feeder Track Station B: 135% loading
- **<u>Compliance check</u>**:
  - No components are overloaded
  - DC and AC voltages are within limits



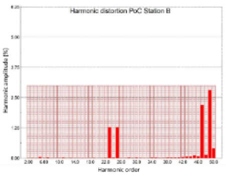
6.3: Harmonic Analysis

- PV harmonic injection profile – IEC 61000
- Frequency-dependent component characteristics
- **<u>Compliance check</u>**:
  - THD=4% < 5%
  - Compliant with IEEE
  - Some exceedance for IEC

IEC 61000-3-6



IEEE Std 519



6.4: Short-Circuit Analysis

- Max currents for 3-phase fault at busbar B
- **Compliance check:**
  - All short-circuit ratings are respected

Current	AC busbar B	AC grid cable	PV TRAFO
Ith (kA) for 1s	12.27<20	12.27<22	0
Ip (kA)	22.8<50	22.8<70	0

- **The integration of the PV plant is compliant with the grid code and railway requirements!**

Conclusion

- The regulatory constraint cannot be respected continuously. Power will flow towards the grid at any moment when the PV plant power production is higher than the load. That can practically happen on any day, at any moment. It was found that energy is returning to the distribution grid for almost one third of the total days of a year.
- The integration of the PV plant is compliant with the grid code and railway requirements and all the relevant criteria are respected. The IEEE harmonic limits were fully respected while some of the IEC limits were exceeded.

Discussion

- The regulatory constraint cannot be respected at all times. Annual data of solar and rail profiles prove that power can flow towards the grid. Mitigation measures such as energy storage or PV inverter control could be used to limit the power flowing to the grid. Discussions with the operator should be initiated to evaluate the necessity of this regulatory constraint.
- The integration of the PV plant is compliant with the grid code and railway requirements. However, some of the IEC harmonic limits were exceeded. This can be easily mitigated using low-pass harmonic filters.

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