OUTDOOR CHARACTERIZATION OF BIFACIAL MODULES AT HANWHA Q CELLS

BifiPV Workshop 2018, 10th September, Denver, CO

Hanwha Q CELLS GmbH

Dominik Buß, Evelyn Herzog, Christoph Scholz, René Zimmermann, Björn Eisenhawer

ABOUT HANWHA Q CELLS

OVERVIEW

WHO WE ARE

Hanwha Q CELLS Co., Ltd. (NASDAQ: HQCL) is the largest cell manufacturer and one of the largest solar module manufacturers in the world.

HEADQUARTERS

South Korea (Global Executive HQ) and Germany (Technology & Innovation HQ)

TECHNOLOGY LEADERSHIP

R&D Centers in 4 countries (Germany, South Korea, Malaysia and China)

MANUFACTURING FACILITIES

Manufacturing Plants in 3 countries (South Korea, Malaysia and China)

40+ SALES NETWORK

Spanning Europe, North America, Asia, South America, Africa and the Middle East

CELL AND MODULE PRODUCTION CAPACITY OF

8+ GW

As of Q1, 2018

OUR PRODUCT RANGE

MODULES

KITS & BUNDLES

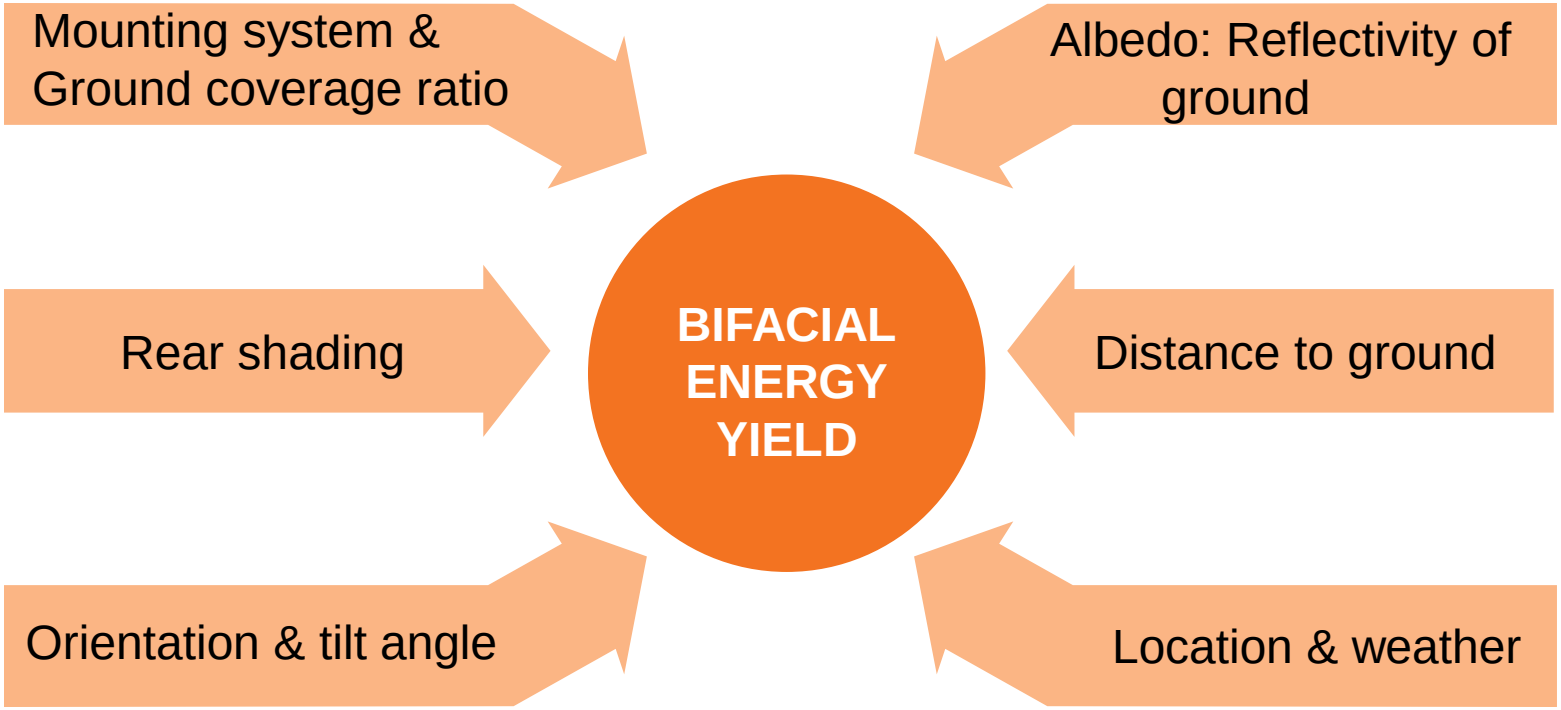
POWER PLANTS

Hanwha Q CELLS

OUTLINE

1. **MOTIVATION**
2. REAR SHADING & MISMATCH
3. LONG TIME ENERGY YIELD
4. SUMMARY & RESULTS

External influences which effect the energy output of bifacial systems



Approach here:

As a starting point, put bifacial modules in a “monofacial” system design

Two questions:

- Shading in monofacial systems leads to serious mismatch.

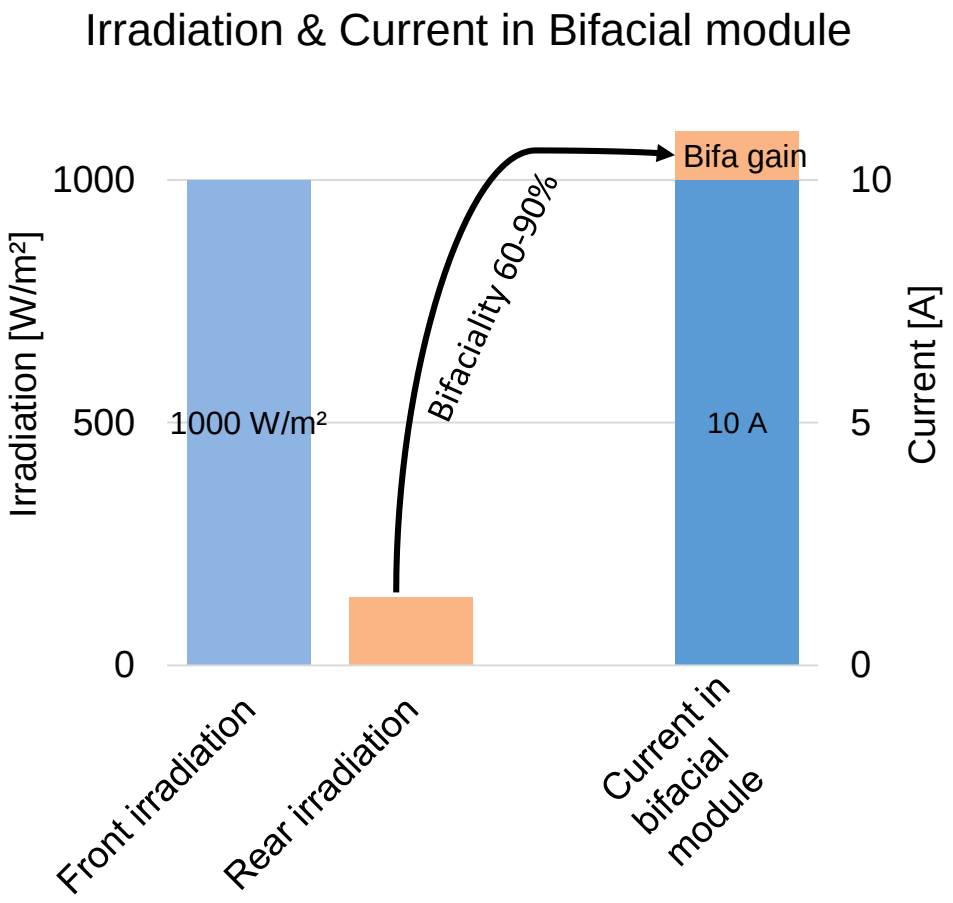
  Is rear shading & mismatch a serious problem, too?

- Which bifacial energy yield gain can be expected?

OUTLINE

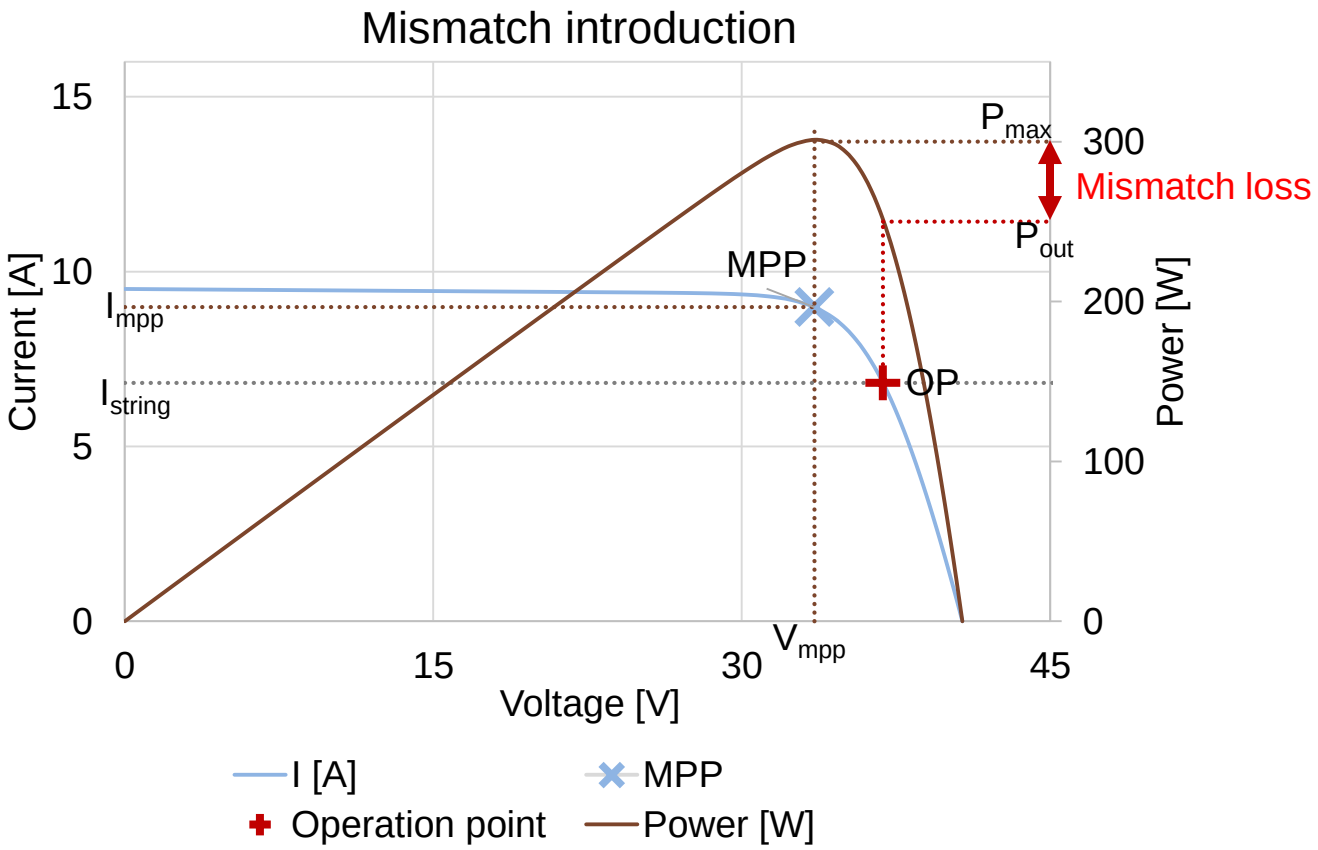
1. MOTIVATION
2. **REAR SHADING & MISMATCH**
3. LONG TIME ENERGY YIELD
4. SUMMARY & RESULTS

2. REAR SHADING & MISMATCH
- Introduction-



Variations in rear side contribution are small compared to total current

Mismatch losses arise at operation at non-optimal current/voltage



Mismatch losses come on top of the optical shading losses

Features of 72 cells instrument module

Rear side:
Spatially resolved irradiation measurement

Front side:
3 cells to measure front side irradiation

Data visualisation:
Rear irradiation w/ respect to front side irradiation

16%	17%	16%	17%	16%	16%
8%	9%	8%	9%	8%	8%
10%	11%	11%	11%	11%	10%
13%	13%	13%	14%	13%	13%
12%	13%	13%	13%	13%	13%
12%	13%	12%	12%	12%	12%
12%	13%	12%	12%	12%	12%
11%	12%	12%	12%	12%	12%
11%	12%	12%	12%	12%	11%
10%	11%	11%	11%	11%	11%
8%	9%	9%	9%	9%	9%
9%	9%	9%	10%	10%	9%

Special instrument module for spatially resolved irradiation measurements

2. REAR SHADING & MISMATCH
- Rear irradiation along a string -

Approach

- Existing PV-System
- Move Instrument module along the string and measure rear irradiation

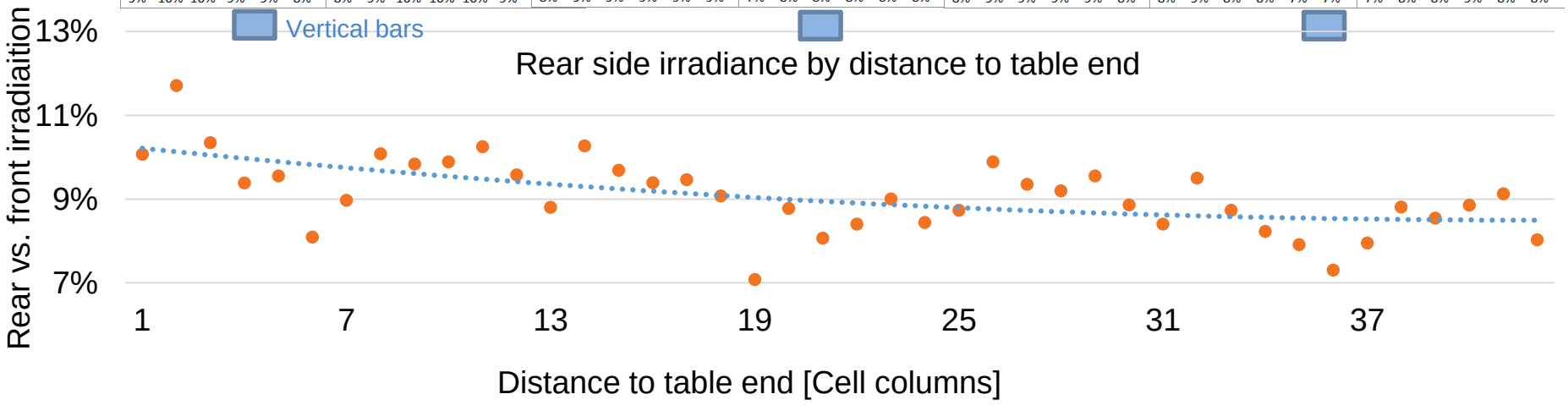
2. REAR SHADING & MISMATCH
- Rear illumination along a string -

Hanwha Q CELLS

Module table end

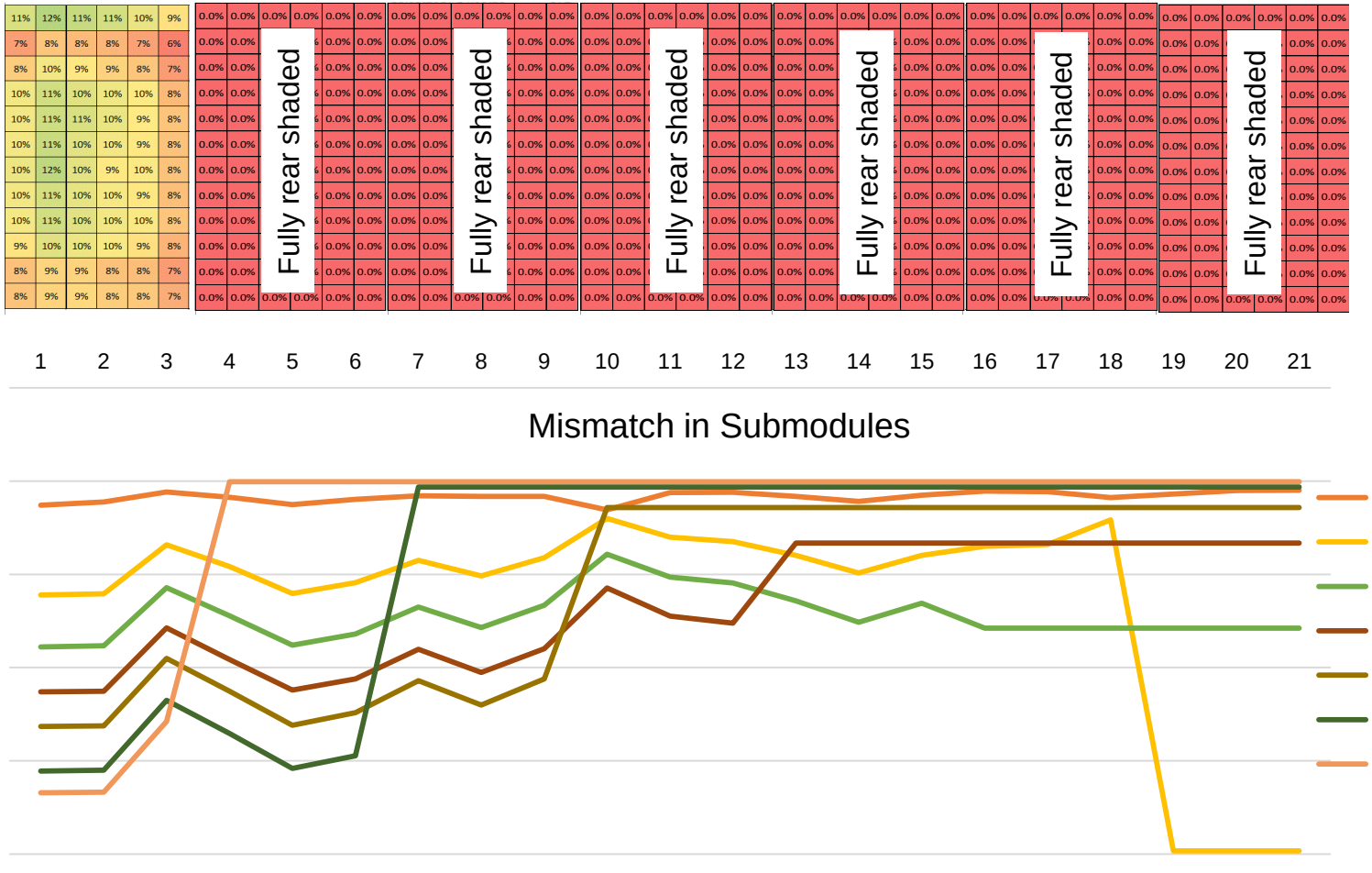
18.05.2017 14:18:39					956	18.05.2017 14:09:49					970	18.05.2017 14:00:28					972	18.05.2017 13:48:31					973	18.05.2017 13:39:41					967	18.05.2017 13:26:37					984	18.05.2017 13:14:22					988
11%	12%	11%	11%	10%	9%	10%	11%	11%	11%	10%	10%	10%	11%	10%	10%	10%	10%	9%	10%	9%	10%	9%	9%	9%	10%	10%	10%	10%	9%	9%	10%	10%	9%	8%	9%	10%	10%	10%	9%	9%	9%
7%	8%	8%	8%	7%	6%	9%	10%	10%	10%	10%	9%	8%	9%	9%	9%	9%	8%	6%	8%	8%	8%	8%	8%	8%	9%	9%	9%	9%	8%	7%	8%	8%	7%	7%	6%	7%	8%	7%	8%	7%	7%
8%	10%	9%	9%	8%	7%	6%	6%	6%	6%	6%	6%	5%	6%	6%	6%	6%	6%	4%	6%	5%	6%	6%	5%	5%	6%	6%	6%	6%	6%	5%	6%	6%	6%	5%	5%	5%	6%	6%	6%	6%	6%
10%	11%	10%	10%	10%	8%	9%	9%	9%	10%	10%	9%	8%	9%	9%	9%	9%	8%	7%	8%	8%	8%	8%	8%	8%	9%	8%	9%	9%	8%	8%	8%	8%	8%	8%	7%	7%	8%	8%	9%	8%	8%
10%	11%	11%	10%	9%	8%	9%	10%	10%	10%	10%	10%	8%	10%	10%	10%	9%	9%	7%	8%	8%	9%	9%	8%	8%	9%	9%	9%	9%	9%	8%	9%	9%	8%	8%	8%	8%	8%	9%	9%	9%	8%
10%	11%	10%	10%	9%	8%	9%	10%	10%	10%	10%	10%	9%	10%	10%	10%	9%	9%	7%	8%	8%	8%	9%	8%	8%	9%	9%	9%	9%	9%	8%	9%	8%	8%	8%	7%	8%	8%	8%	9%	9%	8%
10%	12%	10%	9%	10%	8%	9%	10%	10%	10%	10%	10%	9%	10%	10%	9%	9%	9%	7%	9%	8%	8%	9%	8%	9%	10%	9%	9%	10%	9%	8%	10%	9%	8%	8%	7%	8%	9%	9%	9%	9%	8%
10%	11%	10%	10%	9%	8%	9%	9%	10%	10%	10%	10%	9%	10%	10%	10%	9%	9%	7%	8%	8%	9%	9%	8%	9%	9%	9%	9%	9%	9%	8%	9%	9%	9%	8%	7%	8%	8%	8%	9%	9%	8%
10%	11%	10%	10%	10%	8%	9%	10%	10%	10%	10%	10%	9%	10%	10%	10%	10%	9%	7%	9%	8%	9%	9%	9%	9%	10%	10%	10%	10%	9%	9%	9%	9%	9%	8%	8%	8%	9%	9%	10%	9%	9%
9%	10%	10%	10%	9%	8%	9%	10%	10%	11%	10%	10%	9%	10%	10%	10%	9%	9%	7%	8%	8%	9%	9%	9%	9%	10%	10%	10%	10%	9%	8%	9%	9%	9%	8%	7%	8%	8%	9%	9%	9%	9%
8%	9%	9%	8%	8%	7%	8%	9%	9%	10%	10%	9%	8%	8%	9%	9%	9%	8%	6%	7%	7%	8%	8%	8%	8%	9%	9%	9%	9%	9%	8%	8%	8%	8%	7%	6%	7%	7%	8%	8%	8%	8%
8%	9%	9%	8%	8%	7%	7%	8%	8%	8%	8%	8%	7%	7%	8%	8%	7%	7%	6%	7%	7%	7%	7%	7%	7%	7%	8%	8%	8%	7%	7%	8%	8%	8%	7%	7%	7%	7%	8%	8%	8%	7%
9%	10%	10%	9%	9%	8%	8%	9%	10%	10%	10%	9%	8%	9%	9%	9%	9%	9%	7%	8%	8%	8%	8%	8%	8%	9%	9%	9%	9%	9%	8%	9%	9%	9%	8%	7%	7%	8%	8%	9%	8%	8%

Middle of module table



- Rear side irradiation decreases with increasing distance from frame end
- **Average rear shading factor: 8%**

2. REAR SHADING & MISMATCH
- Worst case simulation-

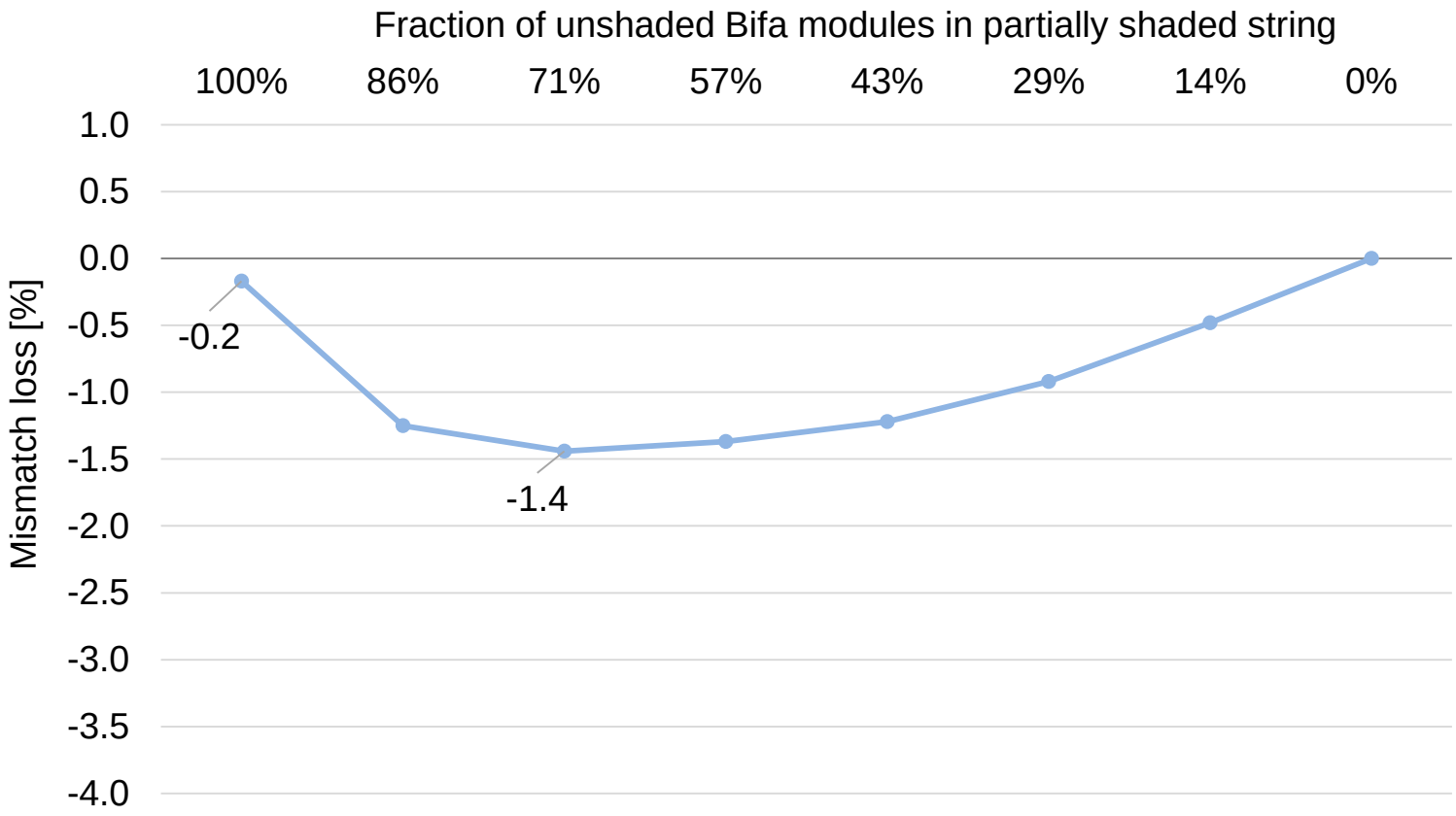


Partially rear shaded Bifa string:
MM in particular module < 4% depending on ratio unshaded/shaded

2. REAR SHADING & MISMATCH
- Worst case simulation-

Hanwha Q CELLS

Mismatch for different unshaded/shaded Bifa-String configurations



Total mismatch losses in bifacial string around 0.2 % (only mounting structure shading)
Worst case mismatch losses in string are 1.4% (for moderate rear irradiation*)

* around or below 10% of front contribution

OUTLINE

1. MOTIVATION
2. REAR SHADING & MISMATCH
3. **LONG TIME ENERGY YIELD**
4. SUMMARY & RESULTS

3. LONG TIME ENERGY YIELD
- Long term track record -

Long term measurements in realistic mounting scenario

Field configuration

- Modules placed within module row
- Other rows in front and back
- Row distance: 5.9 m / GCR = 34%
- Orientation: South, 30°
- Height over ground: 1.2 m
- Grass ground
- Bifaciality: 60%

Compare Measurements to PVSYST-Simulation

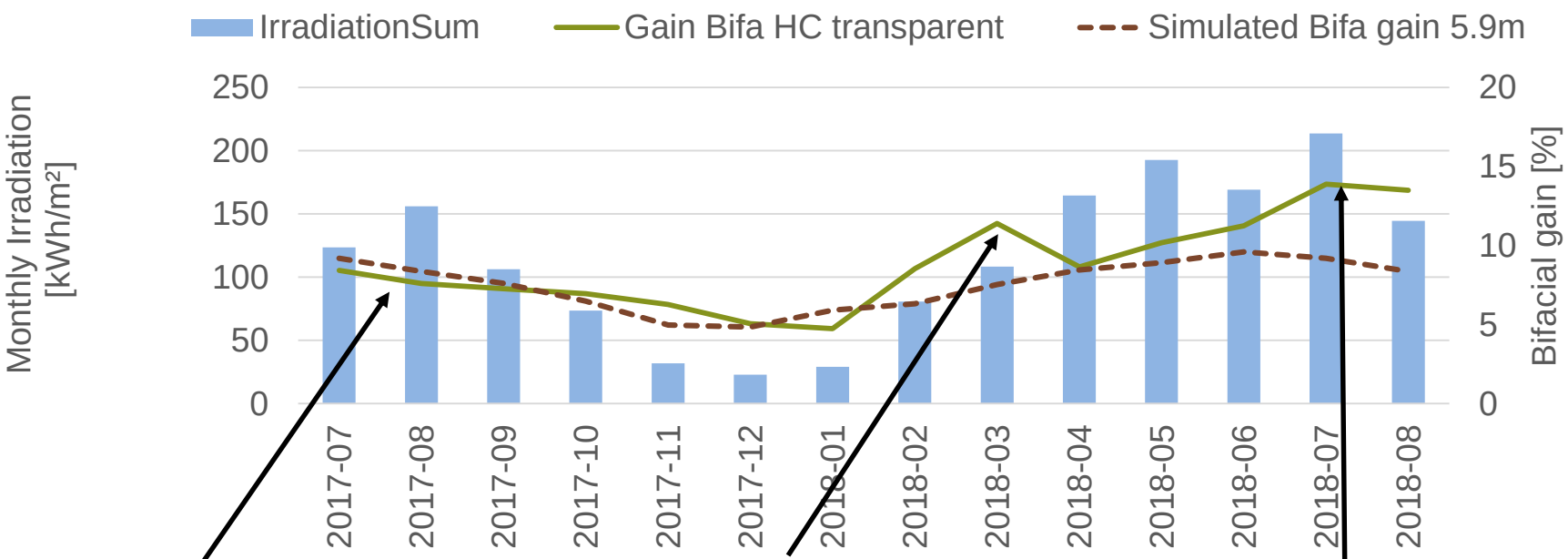
- Version 6.6.7
- Albedo: 25%
- Rear shading factor: 8%
- Bifaciality: 60%
- Rear mismatch loss: 2.2%

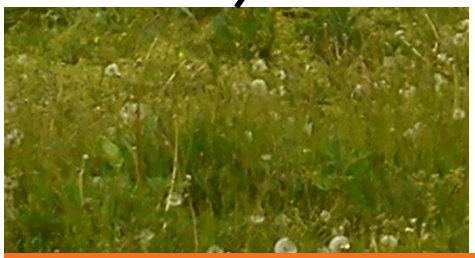
  0.2% total MM equals 0.2% / 9% = 2.2% rear MM

3. LONG TIME ENERGY YIELD
- Long term track record -

Hanwha Q CELLS

Comparsion of measured to simulated bifacial energy yield gain





- Total measured gain: 9%
- Total simulated gain 8%
- Generally good fit, weather conditions led to variant Albedo

OUTLINE

1. MOTIVATION
2. REAR SHADING & MISMATCH
3. LONG TIME ENERGY YIELD
4. **SUMMARY & RESULTS**

RESULTS

- Significant bifacial energy yield gains can be achieved even under non-optimized conditions (here: 9% p.a.)
- Mismatch due to rear shading is only a minor problem (<1.4% MM loss) for moderate* rear side irradiation
- Simulation in the right order of magnitude but in tendency conservative due to Albedo variances (Snow / yellowed grass)

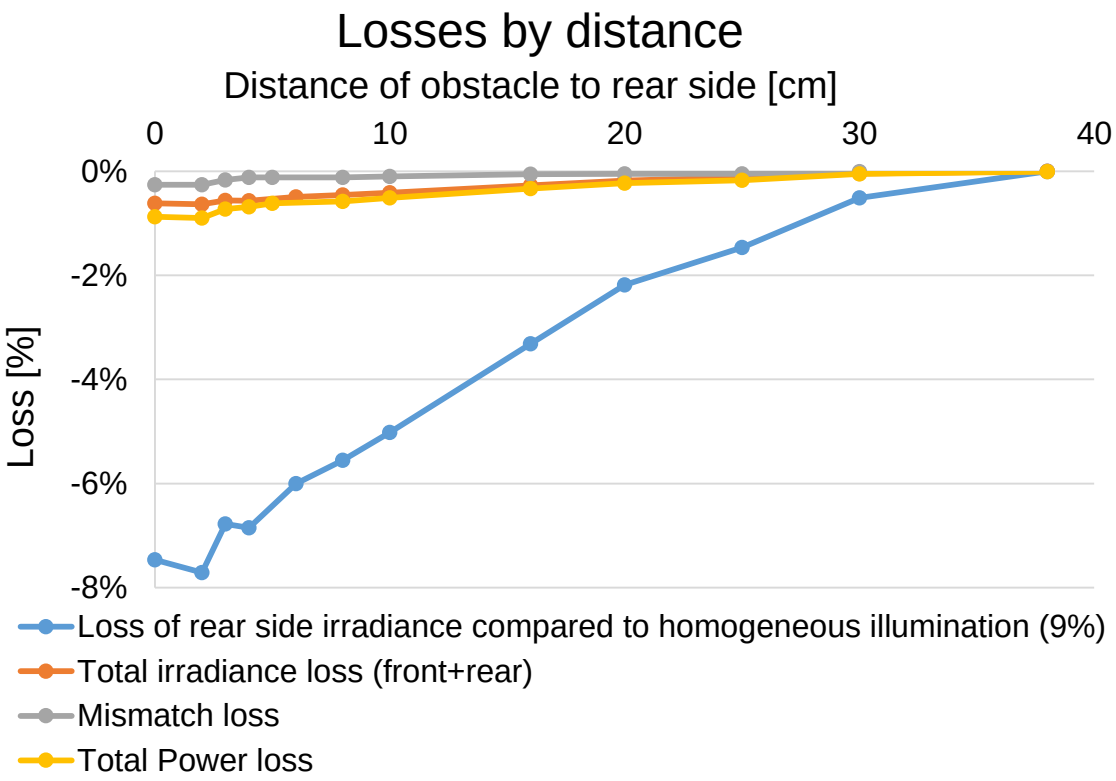
* around or below 10% of front irradiation

BACKUP

2. REAR SHADING & MISMATCH
- Shading bar in varying distance -

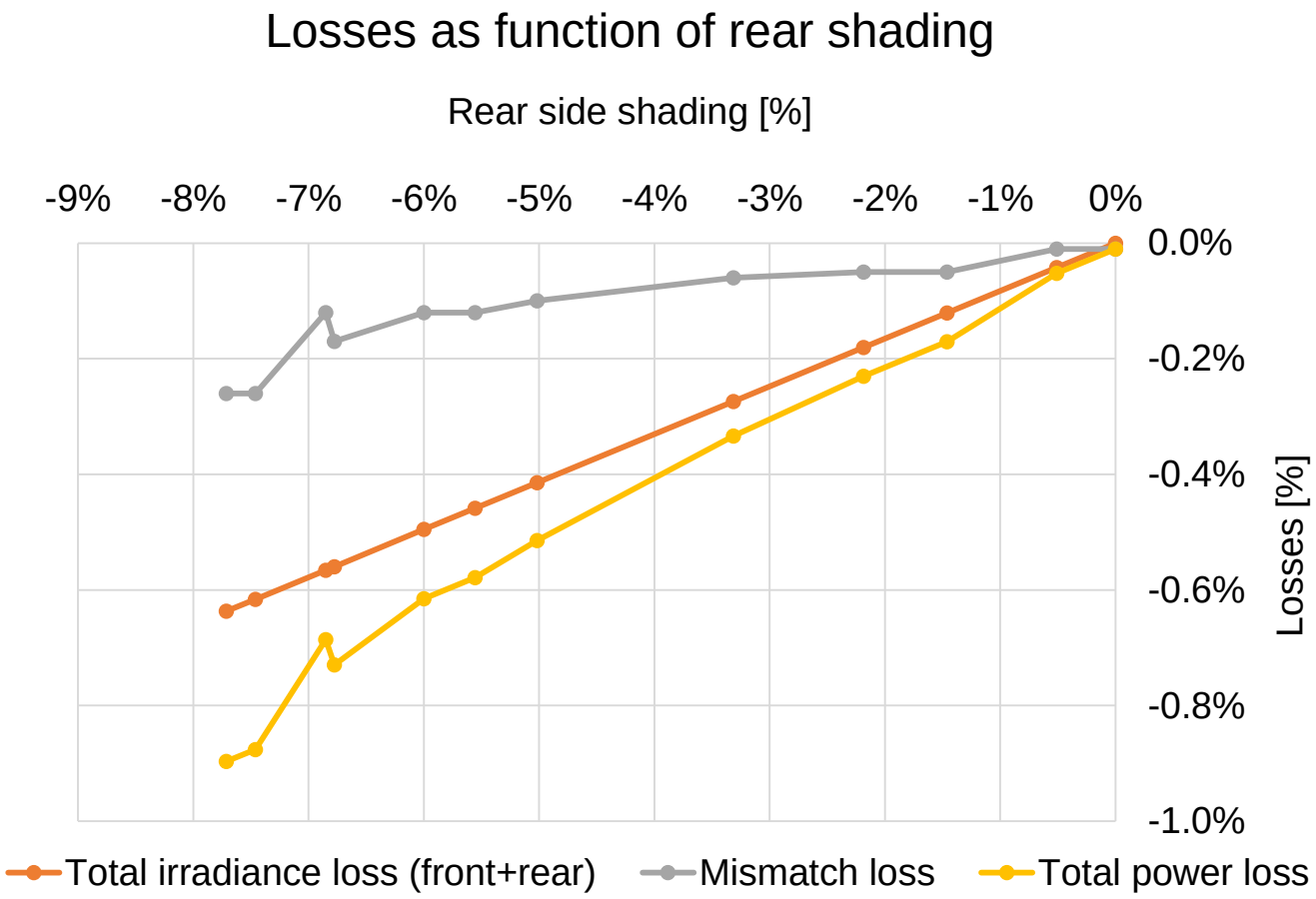
Experiment: Varying distance of shading bar to rear side

- shading bar: 6 cm x 10 cm
- short side facing module rear



9%	9%	9%	9%	9%	9%
9%	9%	9%	9%	9%	9%
9%	9%	9%	9%	9%	9%
9%	9%	9%	9%	9%	9%
9%	9%	9%	9%	9%	9%
7%	7%	7%	7%	7%	7%
4%	4%	4%	4%	4%	4%
8%	8%	8%	8%	8%	8%
9%	9%	9%	9%	9%	9%
9%	9%	9%	9%	9%	9%
9%	9%	9%	9%	9%	9%
9%	9%	9%	9%	9%	9%

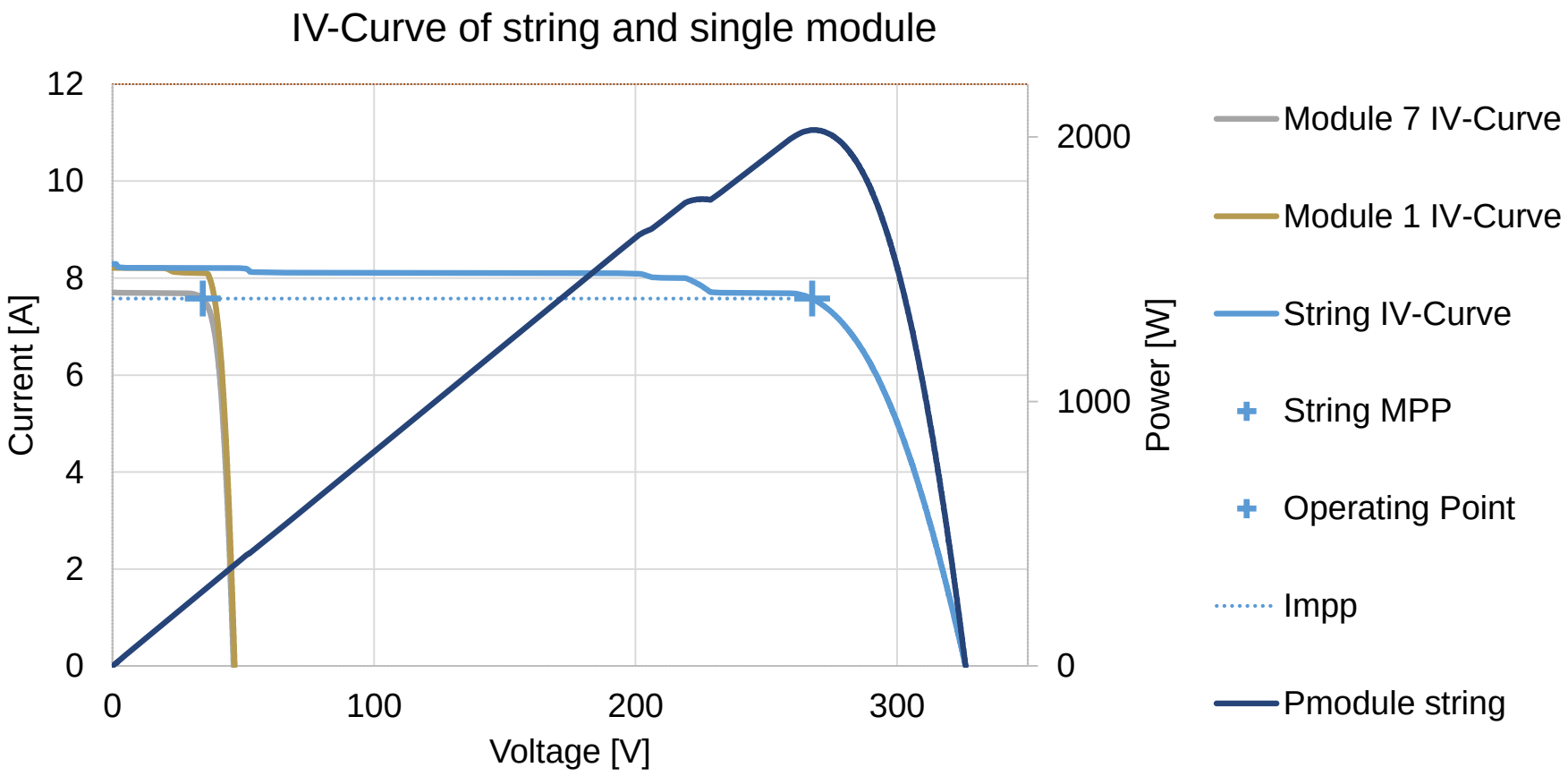
2. REAR SHADING & MISMATCH
- Shading bar in varying distance -



Mismatch behaves nearly linear under moderate(*) rear irradiation and shading

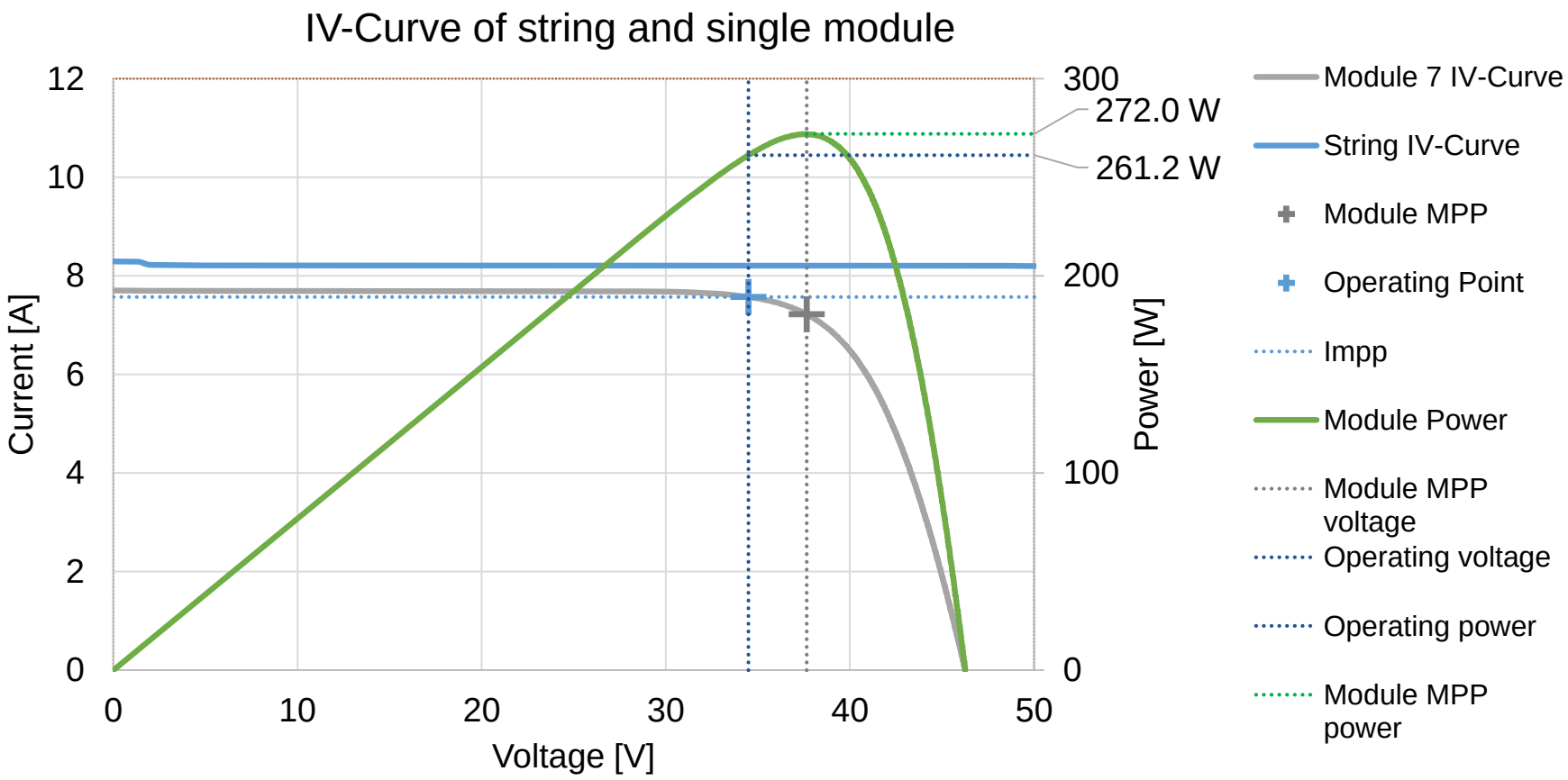
(*) around 10% of front irradiation

2. REAR SHADING & MISMATCH
- Introduction -



- Inverter MPPT controls string current to global MPP
- Each module in string is operated at this current

2. REAR SHADING & MISMATCH
- Introduction -



Mismatch loss due to operation of module with beyond-MPP current