University of Stuttgart
Institute of Machine Components
Reliability Department

Investigation of the influence of inverter reliability and repair strategy on the availability of photovoltaic systems under economic aspects

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Outline

- Introduction
- Structure of a PV System
- Approach
- Results
- Summary & Next Steps

Introduction

Introduction

Energy Supply Concepts

Fossil fuels …

… are limited resources

… have negative impact on climate change

… are depending on natural resources or imports

Renewable energy …

… are sustainable & inexhaustible

… are emission-free

… are independent from third parties

Introduction

Photovoltaics

Photovoltaics (PV) …

… converts solar radiation into electrical energy

… is usable all over the world

… sufficient space for PV system

→ unused rooftops in urban environment

… different concept designs

… different application scenarios

→ guarantee economical operation

Introduction

Economical Operation

What is the Influence on the economical operation of a PV system?

earnings
~ power feed in
~ self-consumption

costs
~ investment
~ repair

→ highly affected by **reliability** and **repair strategy**

Introduction

Objective

What is the Influence on the economical operation of a PV system?

earnings	⟷	**costs**
~ power feed in ~ self-consumption		~ investment ~ repair

→ highly affected by **reliability** and **repair strategy**

Investigation of the influence of reliability and repair strategy on the availability of photovoltaic systems under economic aspects

→ considering different concept designs

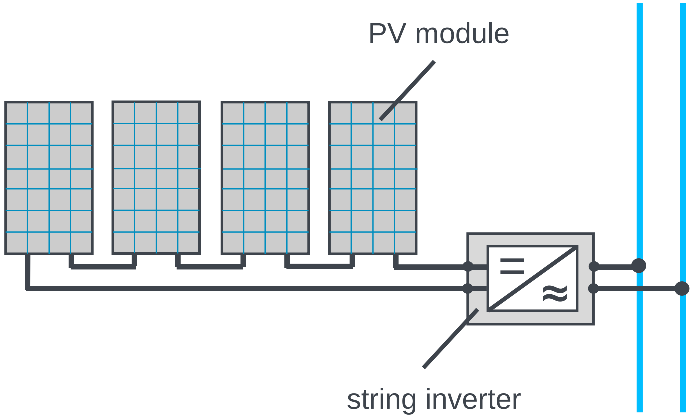
→ considering different application scenarios

Structure of a PV System

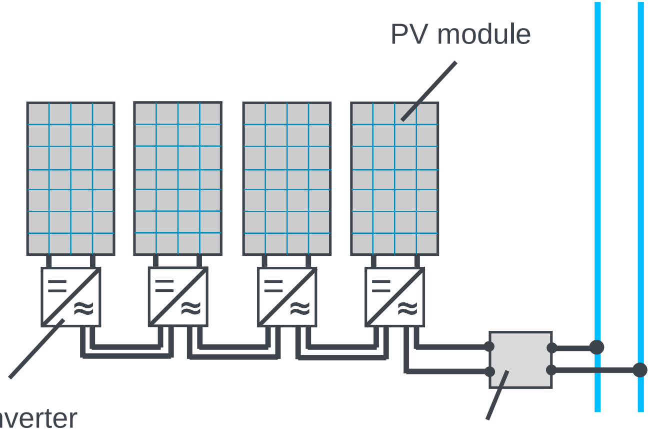
Structure of a PV System

Structure of String and Module Integrated Concept

String concept (SC)

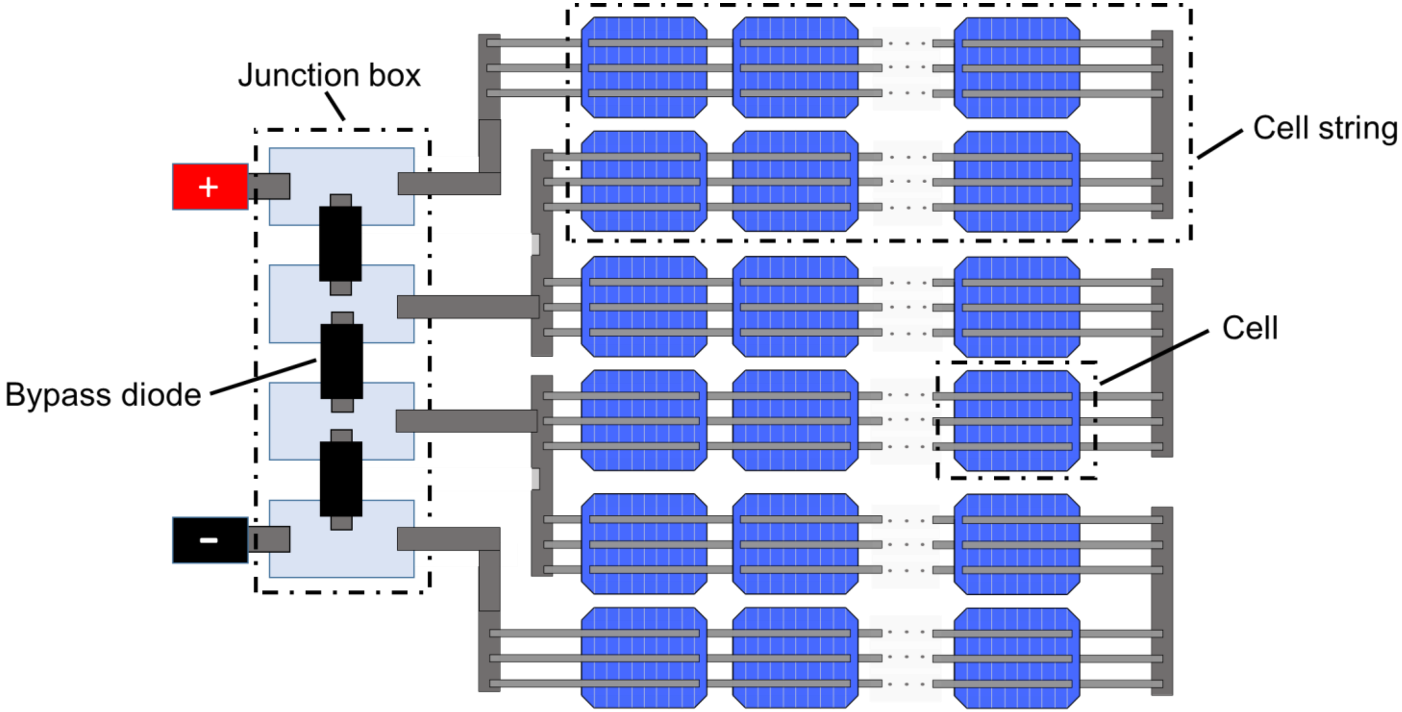


Module integrated concept (MIC)



Structure of a PV System

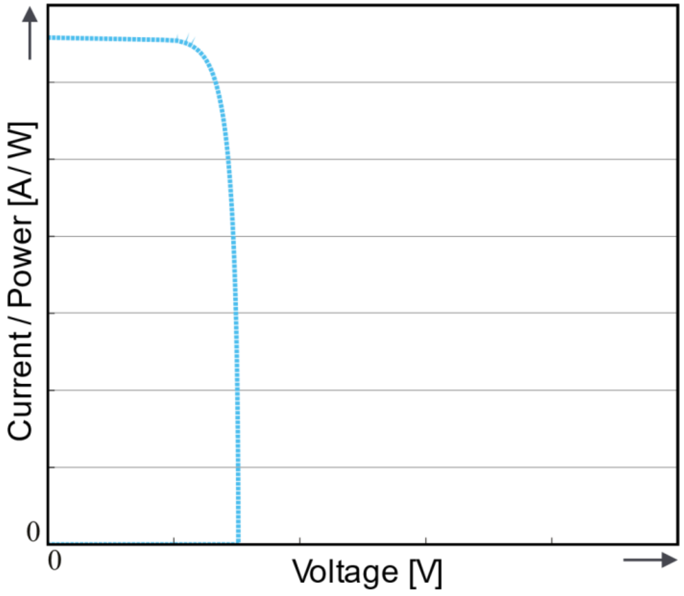
Structure of a Full-Cell PV Module



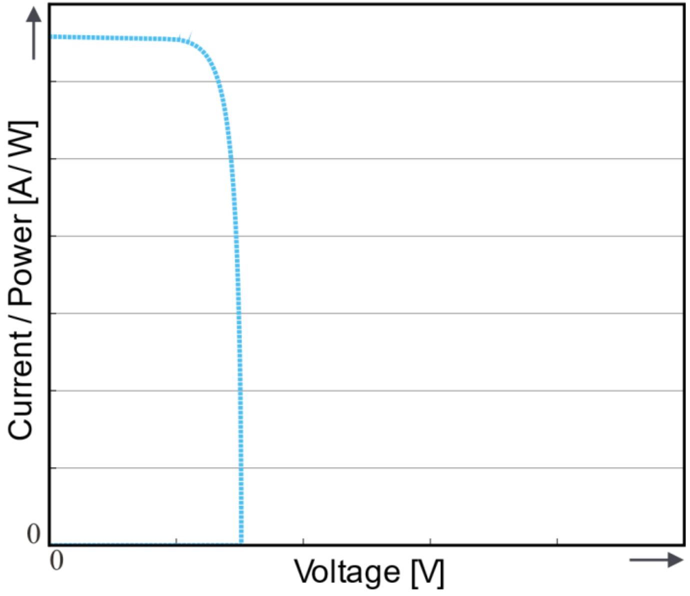
Structure of a PV System

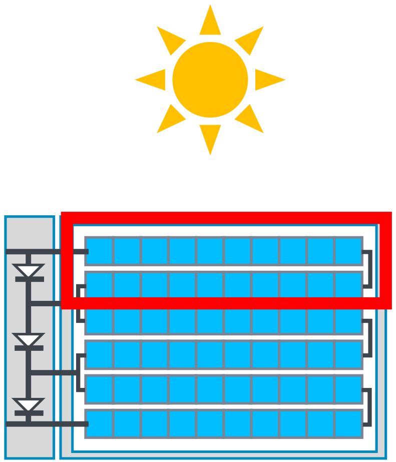
Characteristics of PV Module

without bypass-diode



with bypass-diode

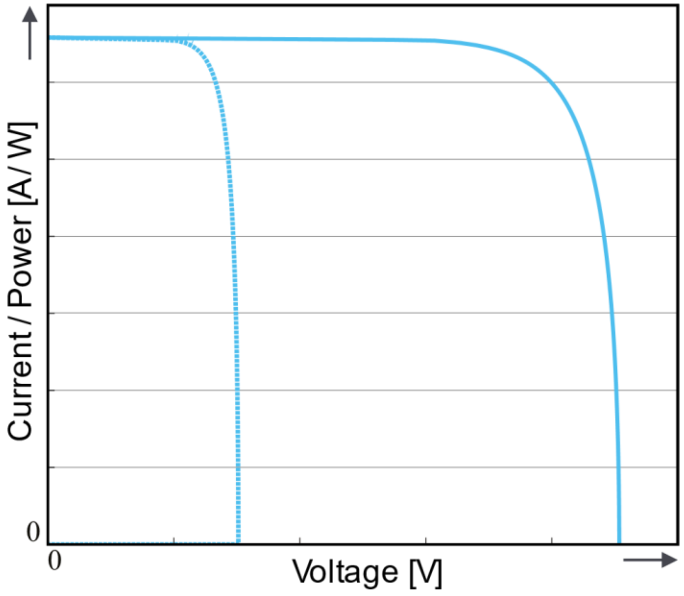




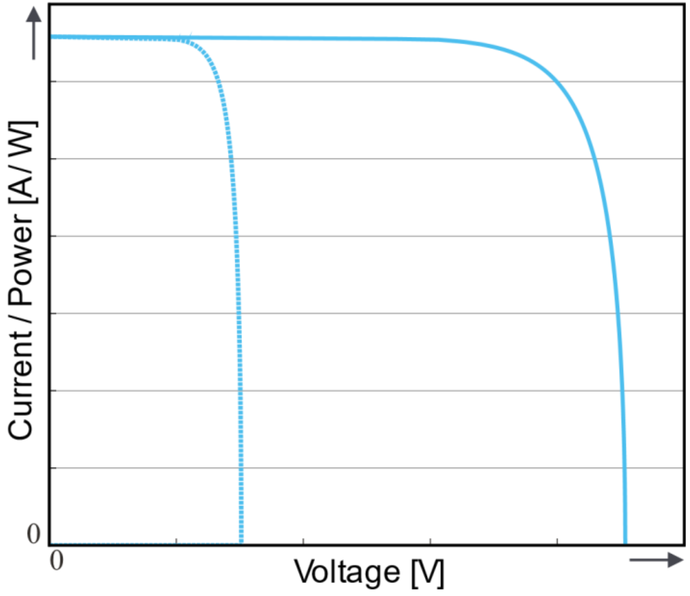
Structure of a PV System

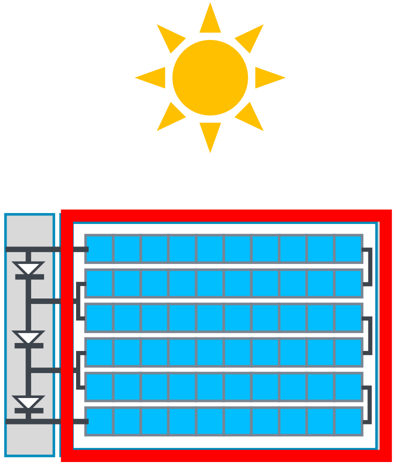
Characteristics of PV Module

without bypass-diode



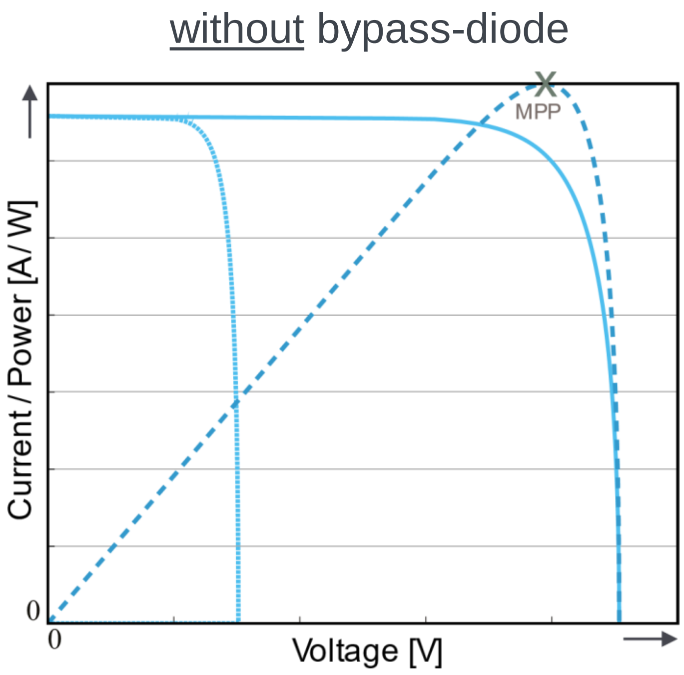
with bypass-diode

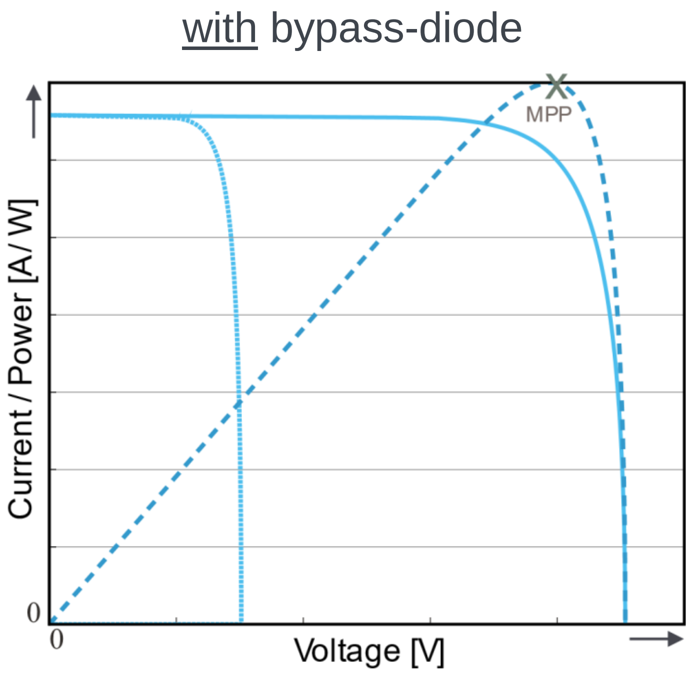


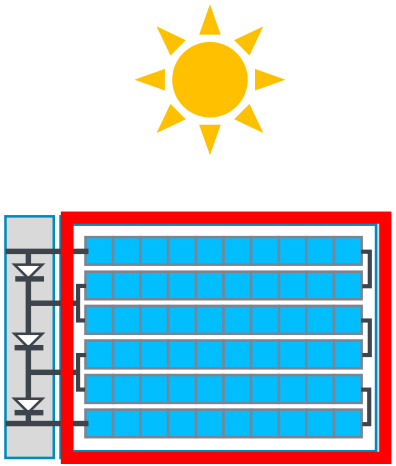


Structure of a PV System

Characteristics of PV Module







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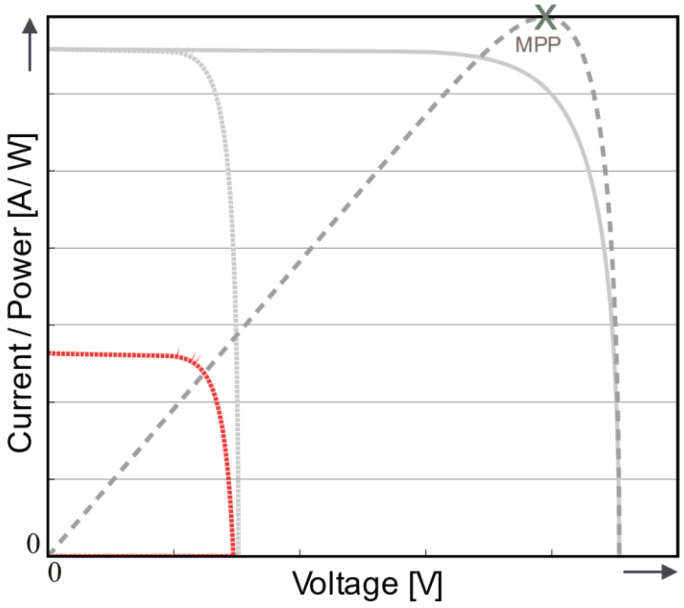
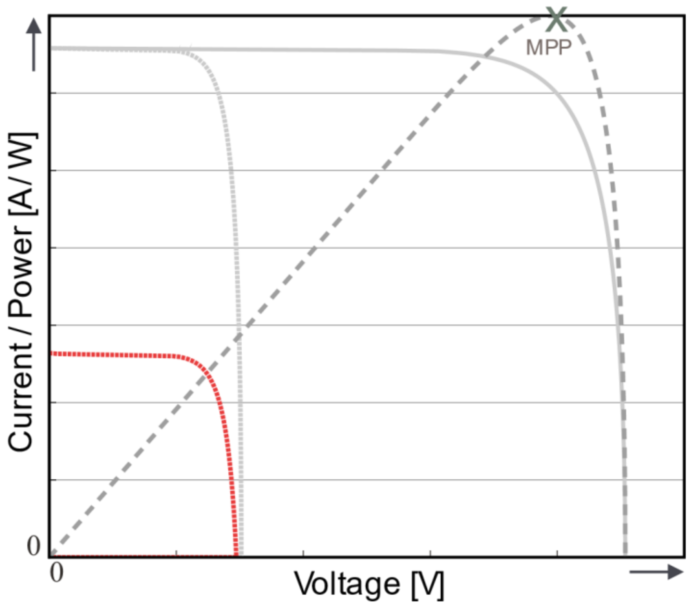
Structure of a PV System

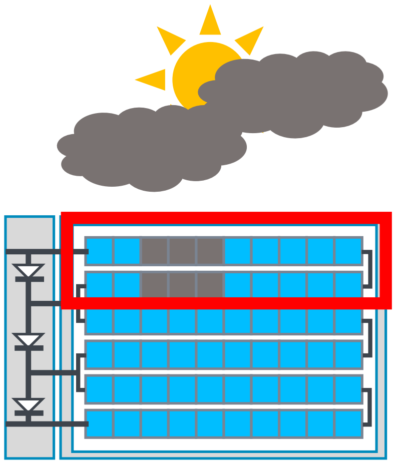
Characteristics of PV Module

<u>without</u> bypass-diode



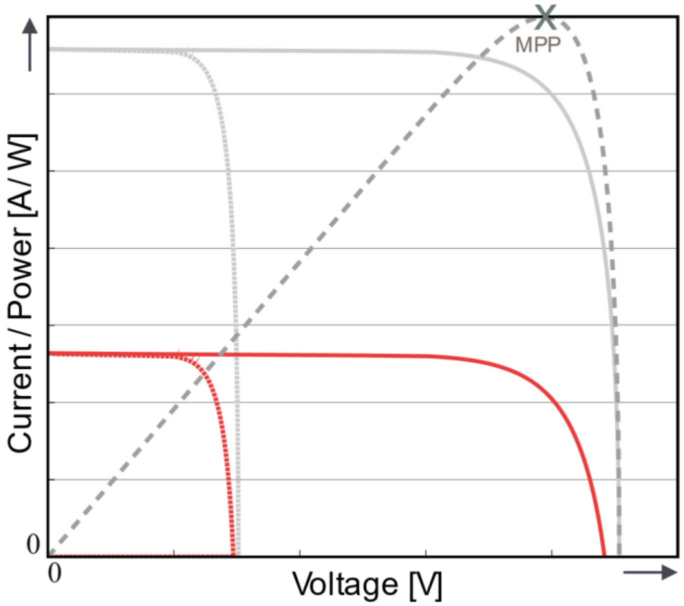
<u>with</u> bypass-diode



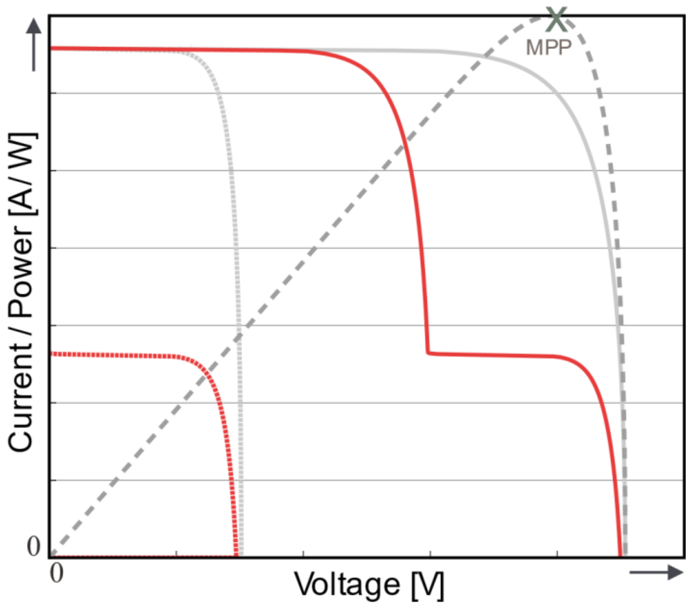


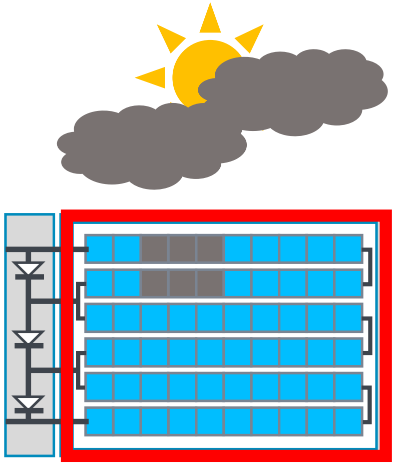
Structure of a PV System
Characteristics of PV Module

without bypass-diode



with bypass-diode





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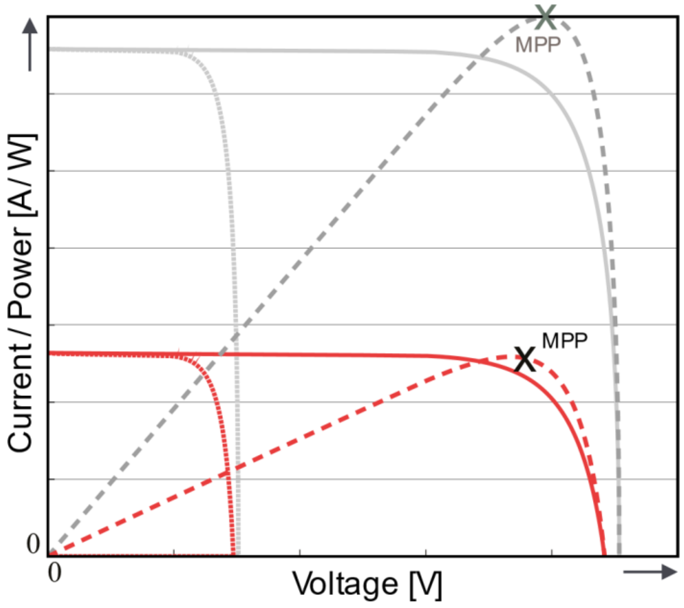
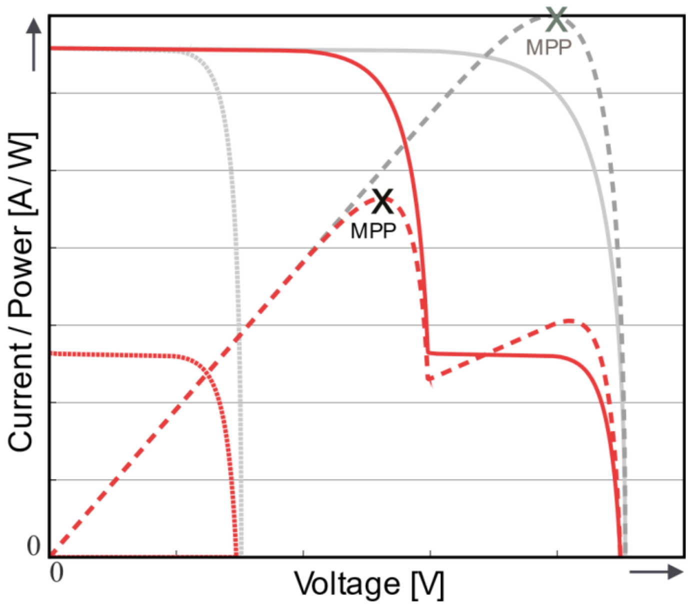
Structure of a PV System

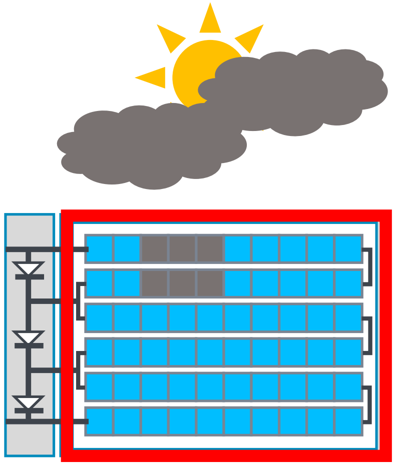
Characteristics of PV Module

<u>without</u> bypass-diode



<u>with</u> bypass-diode





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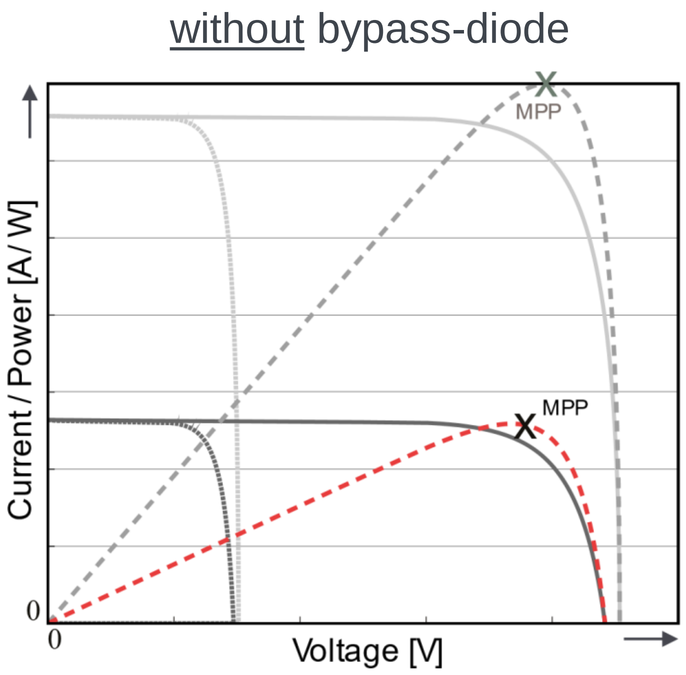
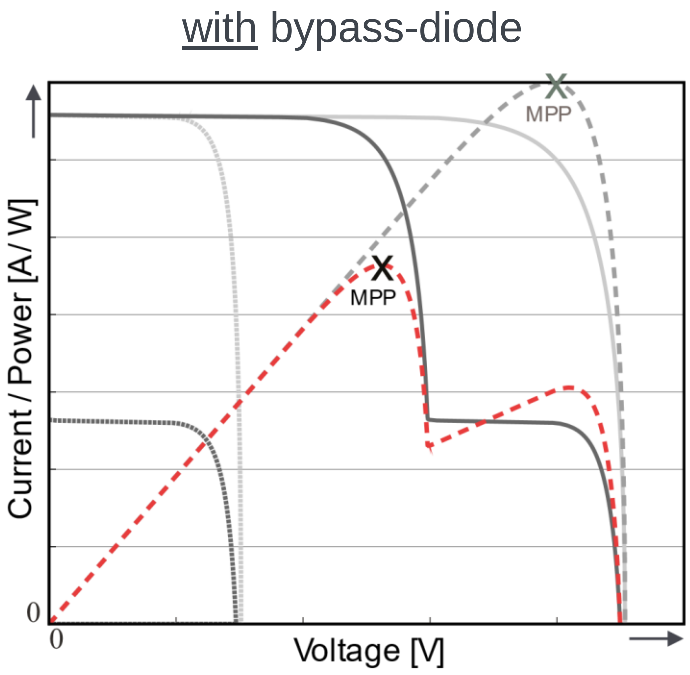
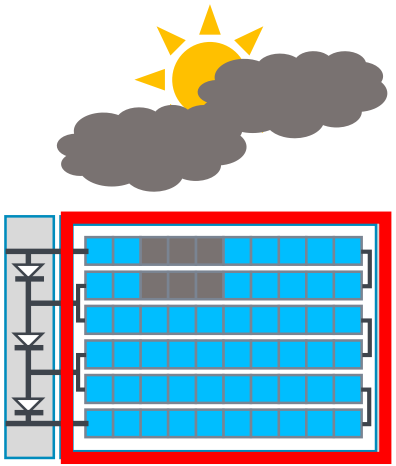
Structure of a PV System
Characteristics of PV Module







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Approach

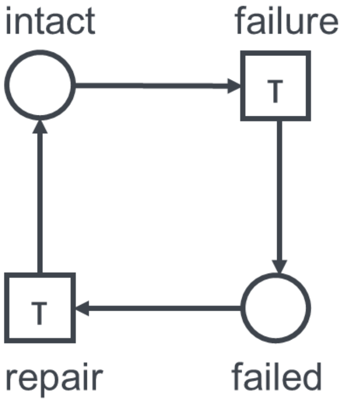
Approach
Overview

Investigation of the influence of reliability and repair strategy on the availability of photovoltaic systems under economic aspects

→ considering different concept designs

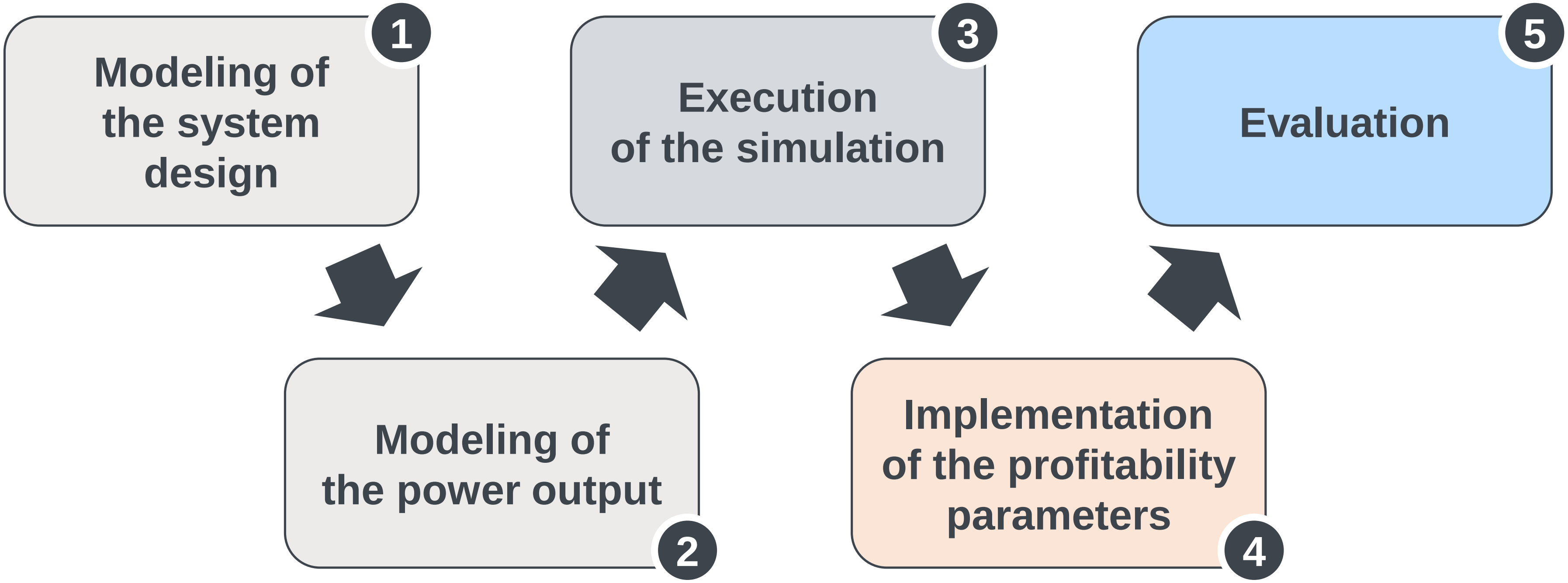
→ considering different application scenarios

- Simulation based on Petri nets
- Model complex systems
- Dynamic failure and repair behavior
- Focus on inverter



Approach

Procedure of the simulation based on Petri nets



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Approach

Step 1 − Modeling of the system design

Modeling of the system design 1

concept

String concept	Module integrated concept

system size

3 PV modules	10 PV modules	20 PV modules

components / failure modes

Inverter $\gamma = 0$, $\beta = 3$, η varied	PV module with 3 BD (SC) → open and short circuit	Interconnections → logic for RBD

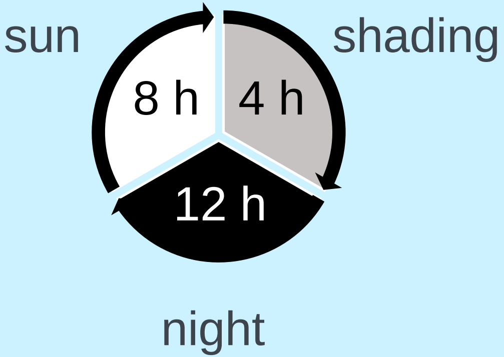
Approach
Step 2 − Modeling of the power output

Modeling of the power output 2

Power PV module

- nominal module power: 400 Wp
- radiation intensity: 1000 kWh/(kWp·a)
- efficiency of the electronics: 95 %

Daily shading cycle



Shading scenarios

- no shading
- one cell string
- two cell strings
- PV-Module
- 3 PV-Modules

Approach

Step 2 − Modeling of the power output

Modeling of the power output 2

Repair strategy

power limit to start maintenance	R1	R2	R3	R4	R5	R6	R7	R8	R9
power reduction [W]	100	150	300	600	1000	1500	2000	3000	4000

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Approach

Step 3 − Execution of the simulation

Execution of the simulation ❸

<u>Monte Carlo Simulation</u>

- ➢ 1500 replications

<u>Duration</u>

- ➢ 30 years

<u>Parameter study</u>

- ➢ scale parameter inverter(s)
- ➢ repair limit

Approach

Step 4 − Implementation of the profitability parameters

Implementation of the profitability parameters 4

- Investment costs
- Repair costs
- Self-consumption share of 20 %
- Remuneration rate
- Electricity price

Approach
Step 5 − Evaluation

Evaluation 5

- ❖ Power availability (power output)
- ❖ Profitability

→ Compare concepts and investigate the influence of …
… inverter reliability
… repair strategy

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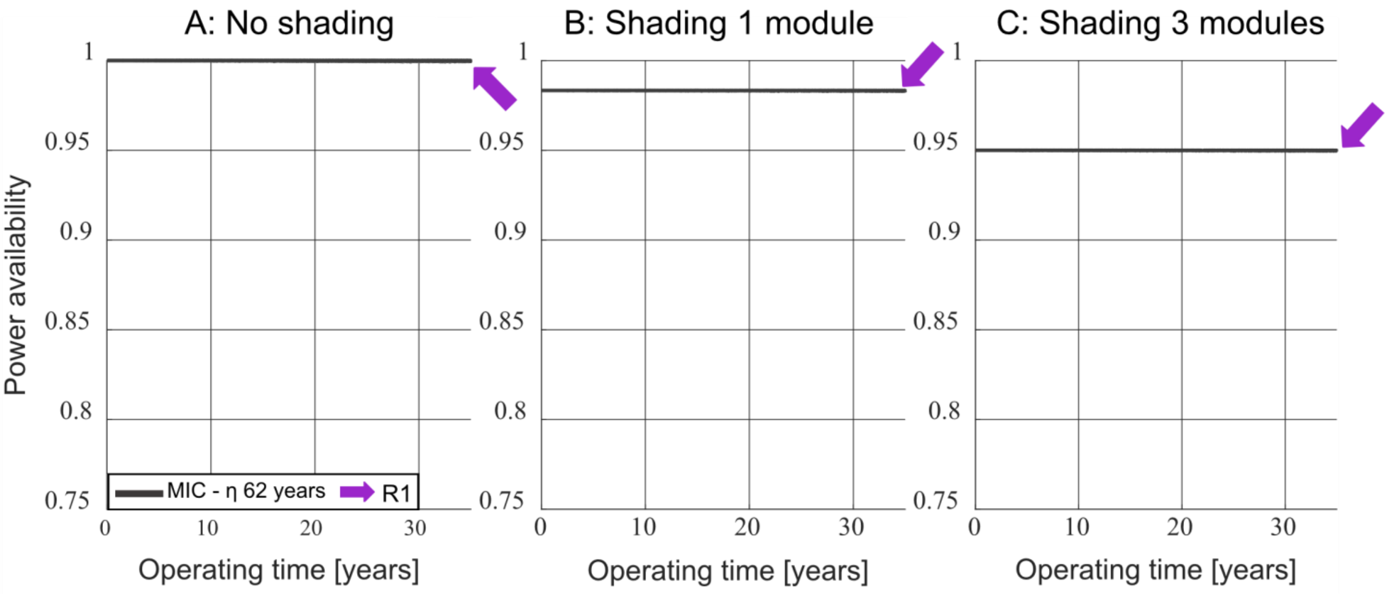
Results

Results

Power Availability of the PV System − MIC



R1 = 100 W

→ **repair immediately**

Case A: PA = 100 %

Case B: PA = 98 %

Case C: PA = 95 %

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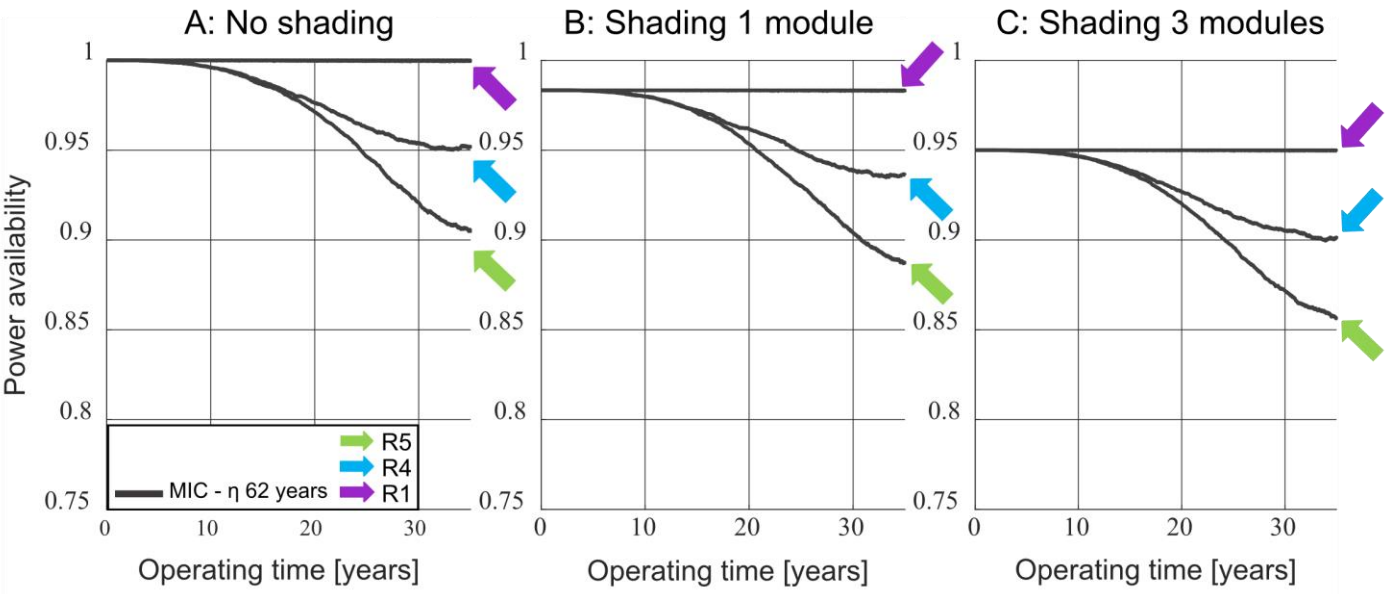
Results

Power Availability of the PV System − MIC



R4 = 600 W

R5 = 1000 W

→ **repair not immediately**

→ **drop of PA**

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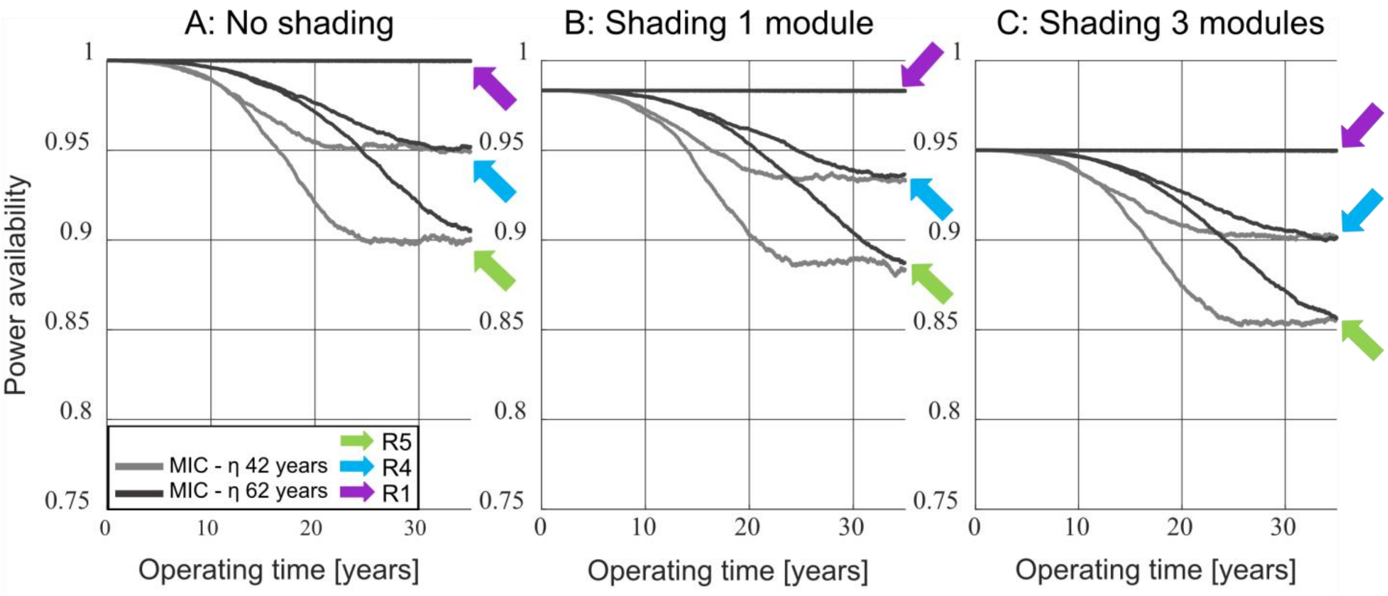
Results

Power Availability of the PV System − MIC



reduce scale parameter

→ **drop of PA is earlier**

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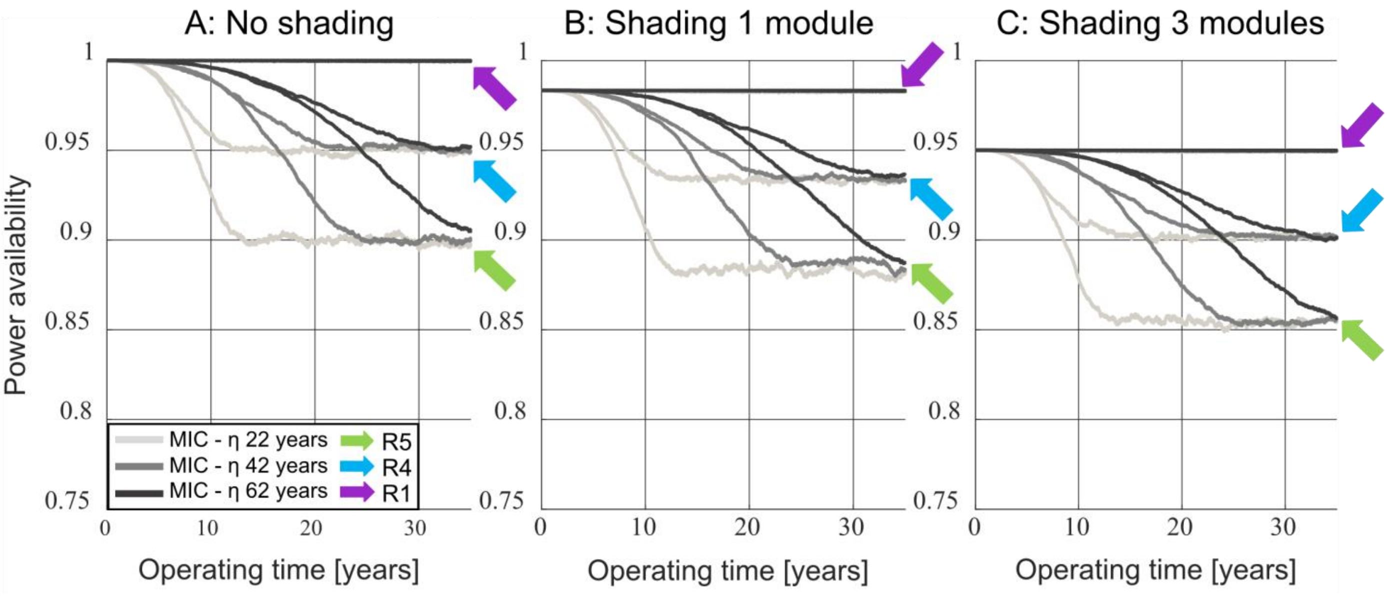
Results

Power Availability of the PV System − MIC



reduce scale parameter

→ **drop of PA is earlier**

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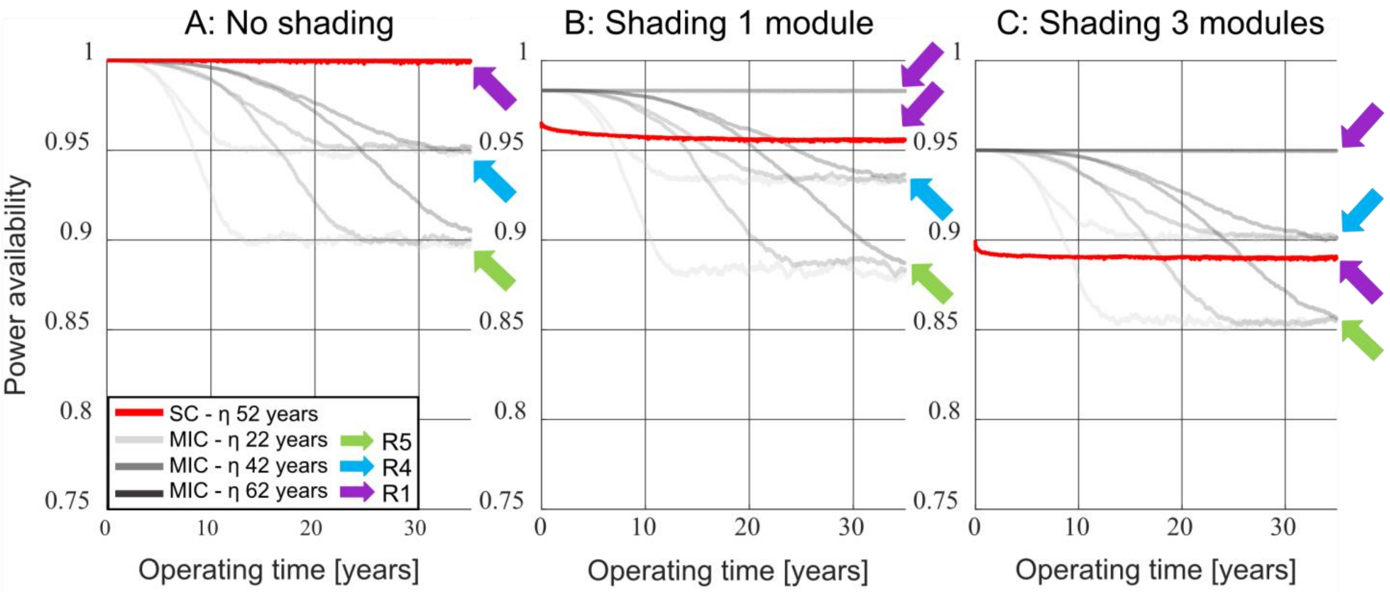
Results

Power Availability of the PV System − SC



R1 = 100 W

→ **repair immediately**

Case A: PA = 100 %

Case B: PA = 95 %

Case C: PA = 89 %

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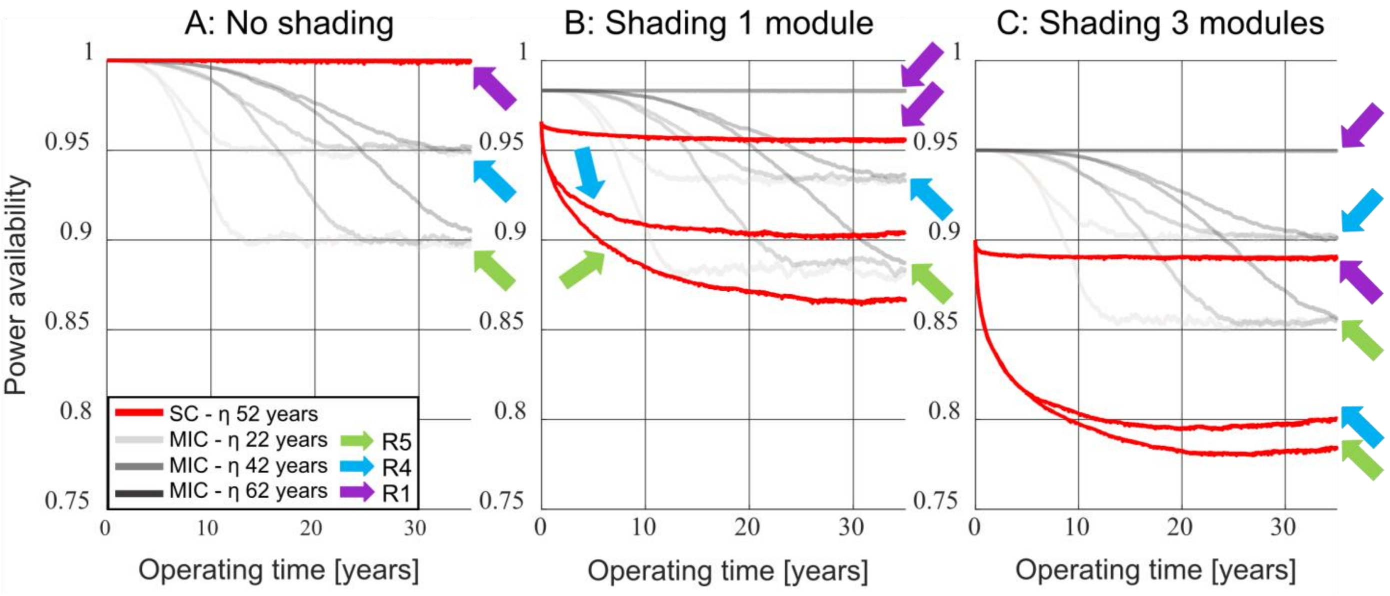
Results

Power Availability of the PV System − SC



R4 = 600 W

R5 = 1000 W

→ **case A: repair immediately**

→ **case B & C: repair <u>not</u> immediately**

→ **drop of PA**

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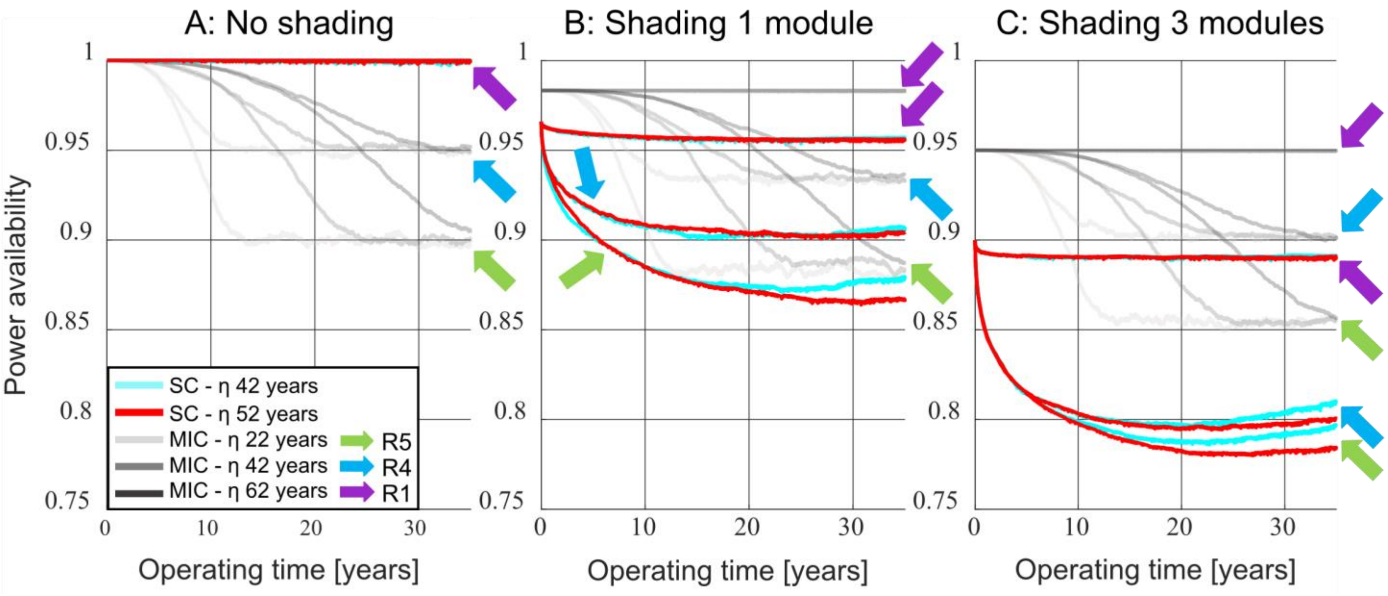
Results

Power Availability of the PV System − SC



reduce scale parameter

→ **increase of PA**

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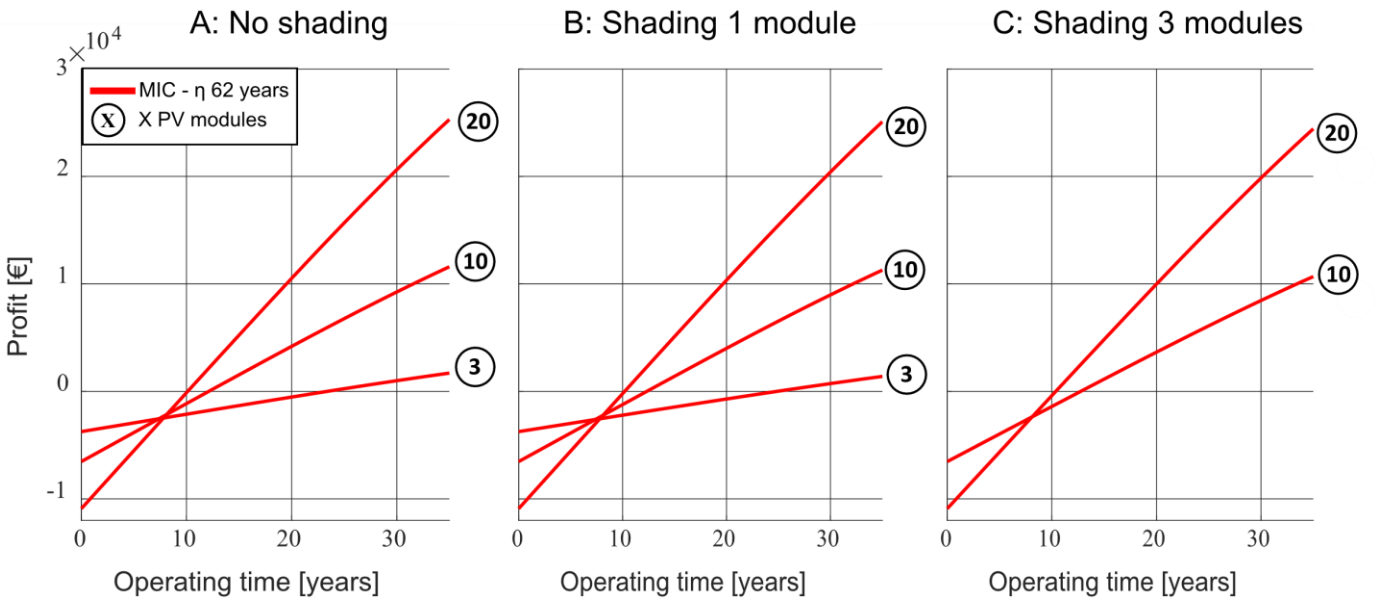
Results

Profitability of the PV System − MIC



optimal repair strategy

→ **the higher the system size, the steeper the curves**

→ **no difference with shading**

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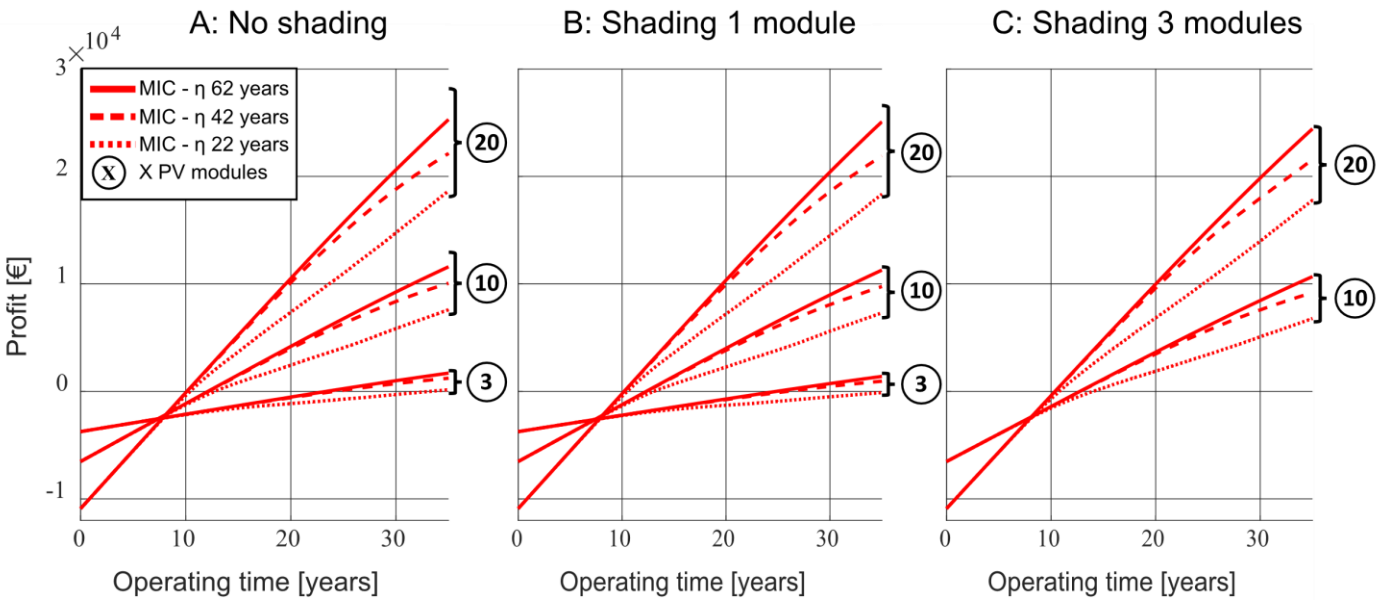
Results

Profitability of the PV System − MIC



reduce scale parameter

→ lower profit

→ the higher the system size, the bigger influence of R

→ no difference with shading

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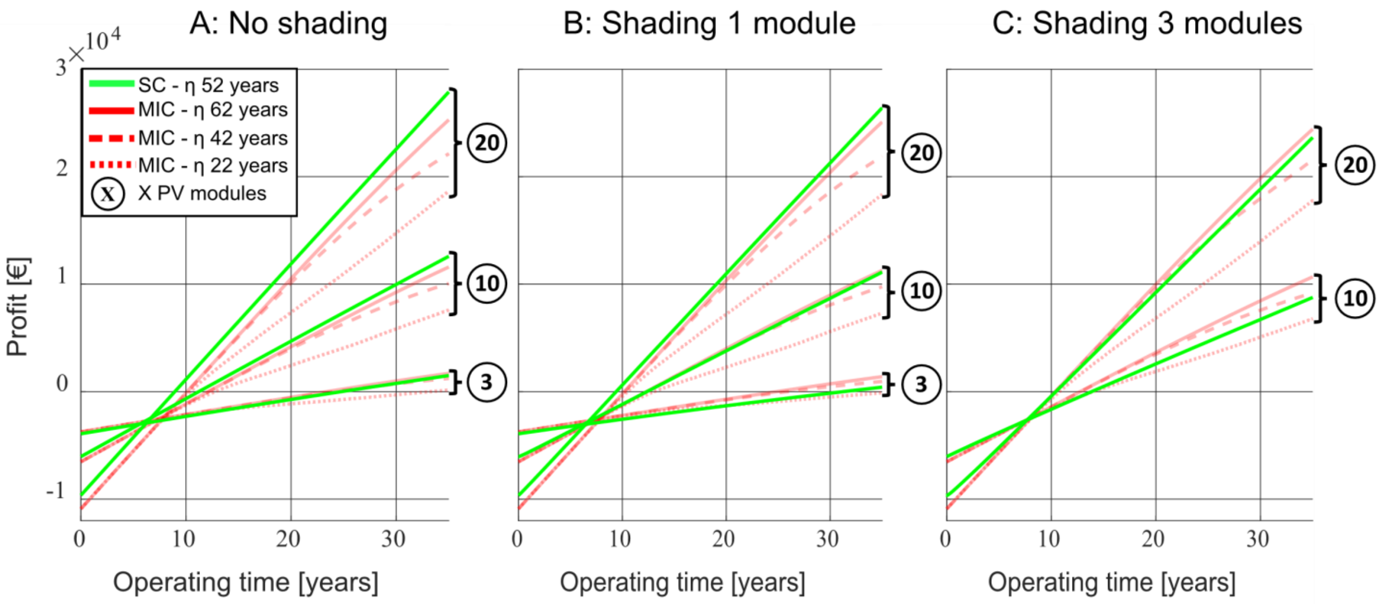
Results

Profitability of the PV System − SC



→ difference with shading

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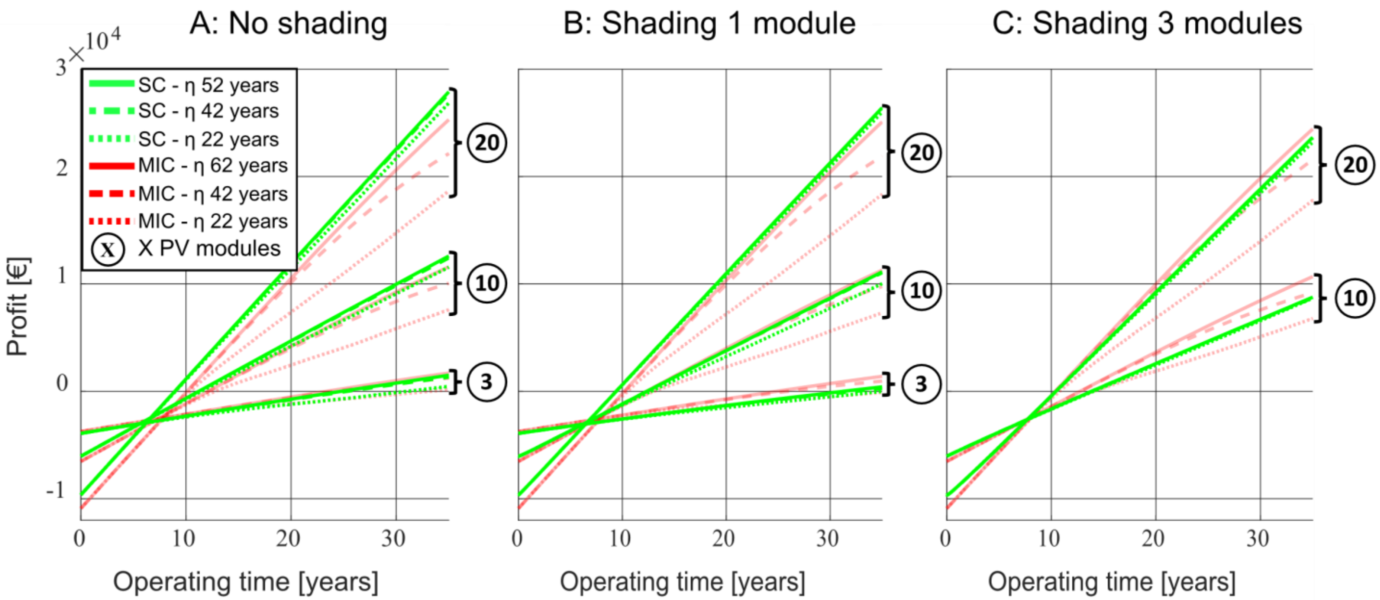
Results

Profitability of the PV System − SC



reduce scale parameter

→ small influence of R

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Summary & Next Steps

Summary

- **Developed a petri net model to perform a simulation …**

  … to investigate different PV system concepts

  … for different application scenarios

  … considering failure and repair behavior

- **Investigate influence of reliability and repair strategy on …**

  … power availability

  … profitability

  → Comparison of PV system concepts under economical aspects

  → Determine an optimal repair strategy

Next Steps

- **Change application scenario and extend study to investigate more …**

  … locations

  … power sizes

  … shading cases
- **Implement logic for**

  … aging effects

  … other failure modes
- **By defining a specific application scenario …**

  … derive reliability requirements for inverter / other components

  … determine an ideal system design for best economical operation

  … predict profit

Thank you!

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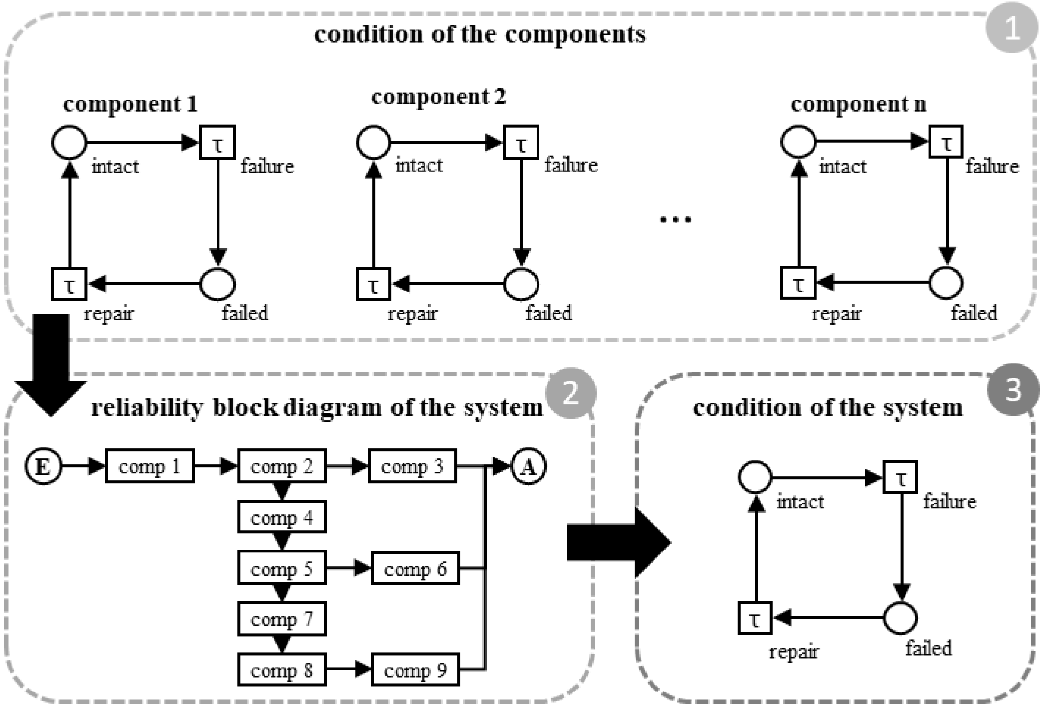
References

- Photo PV-System [Mmphoto / Adobe Stock]
- All icons [flaticon.com]

Backup Slides

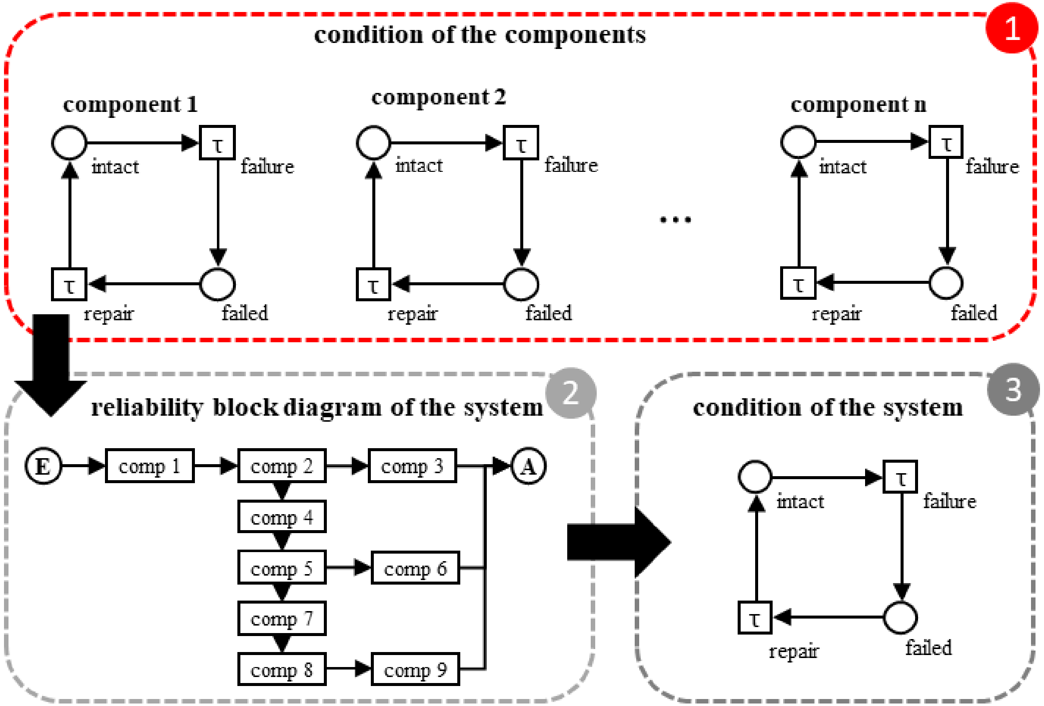
Modeling PV System Concepts in Petri Nets

Realistic Modeling of the PV system with 3 steps:



Modeling PV System Concepts in Petri Nets

Step 1 − Modeling of the components



Modeling PV System Concepts in Petri Nets

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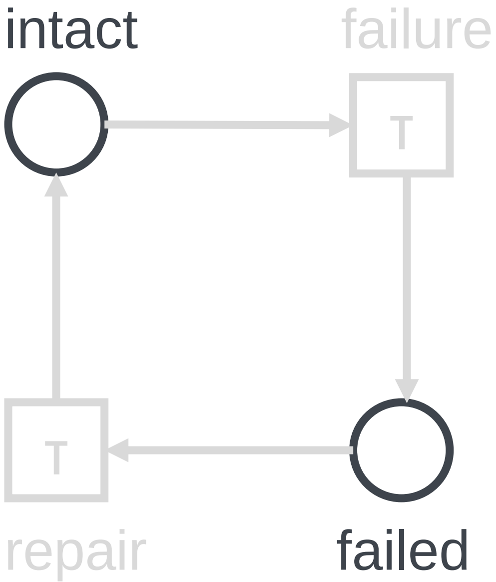

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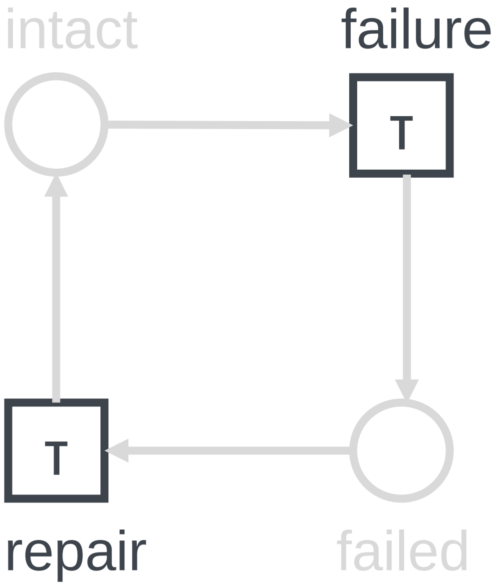

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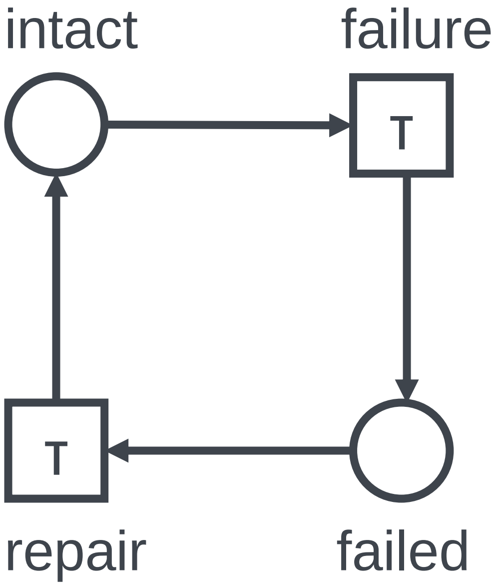
Step 1 – Modeling of the components



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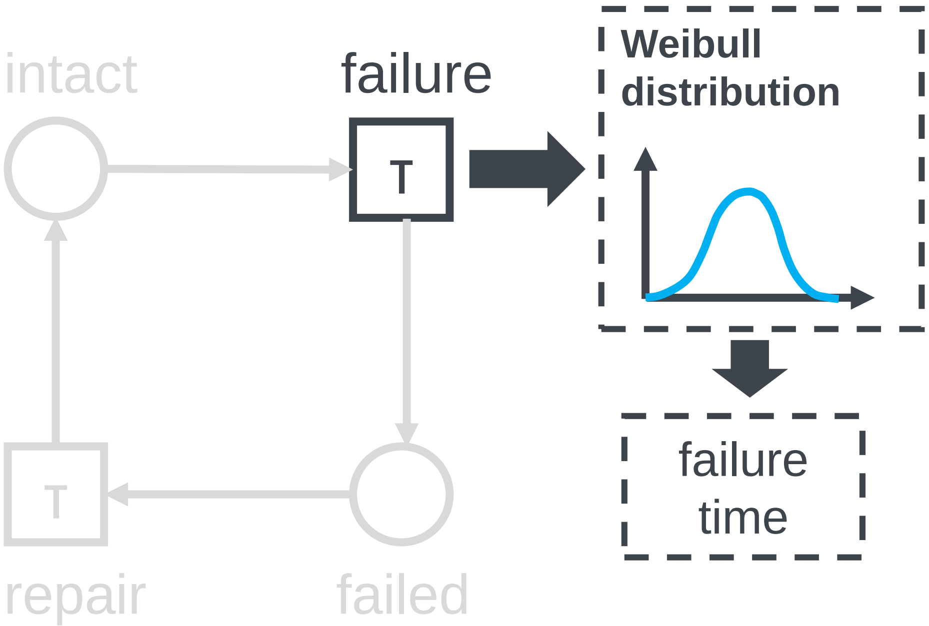

Modeling PV System Concepts in Petri Nets

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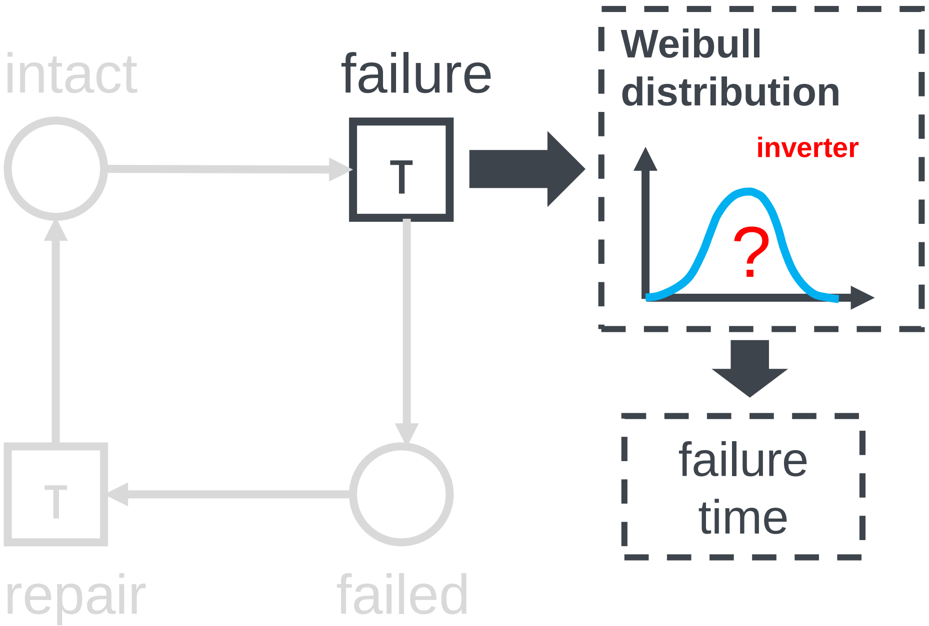

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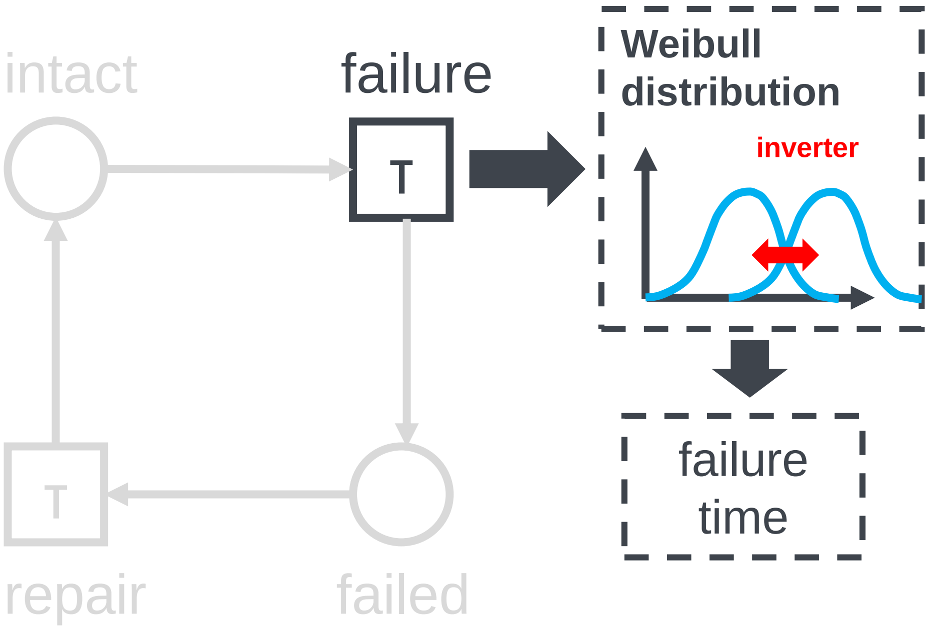

Modeling PV System Concepts in Petri Nets

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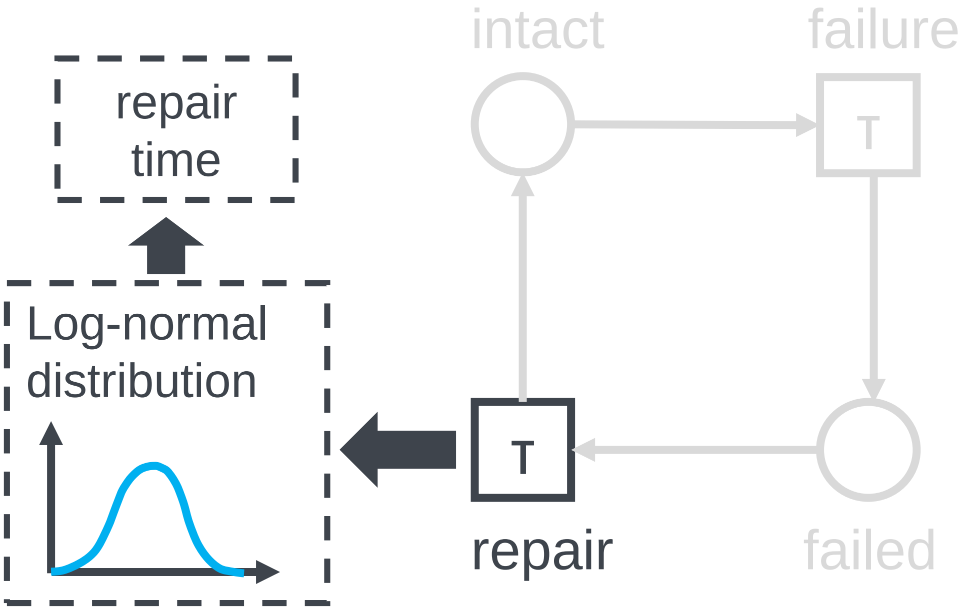

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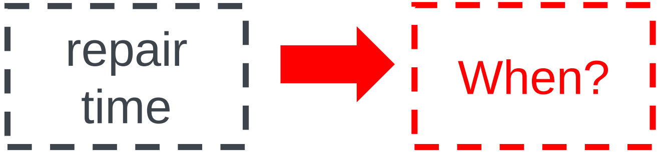

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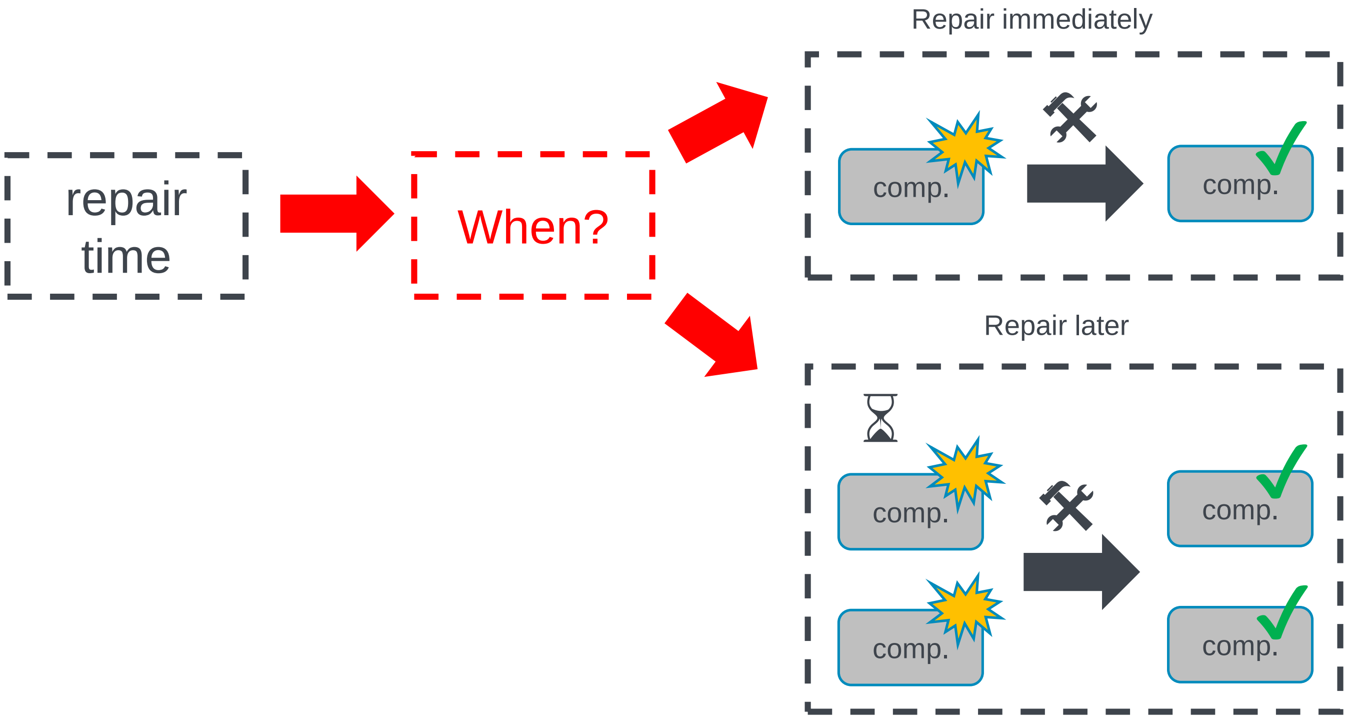
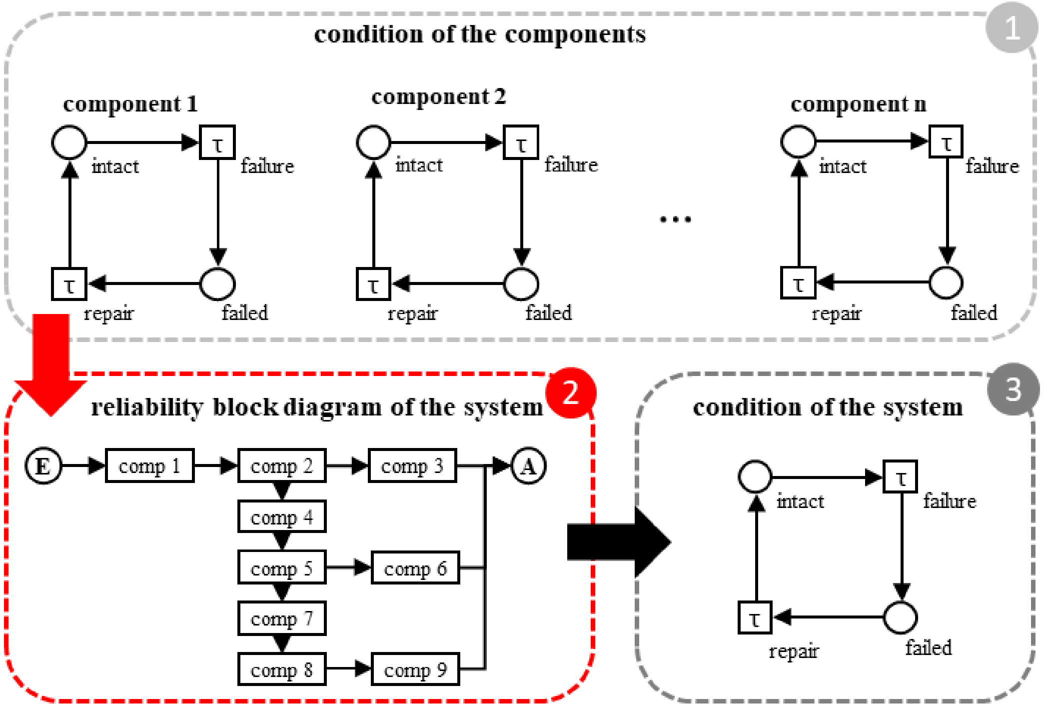


Modeling PV System Concepts in Petri Nets

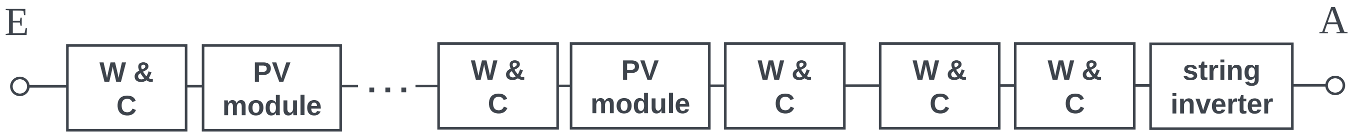
Step 2 − Modeling of the reliability block diagram



Modeling PV System Concepts in Petri Nets

Step 2 − Modeling of the reliability block diagram

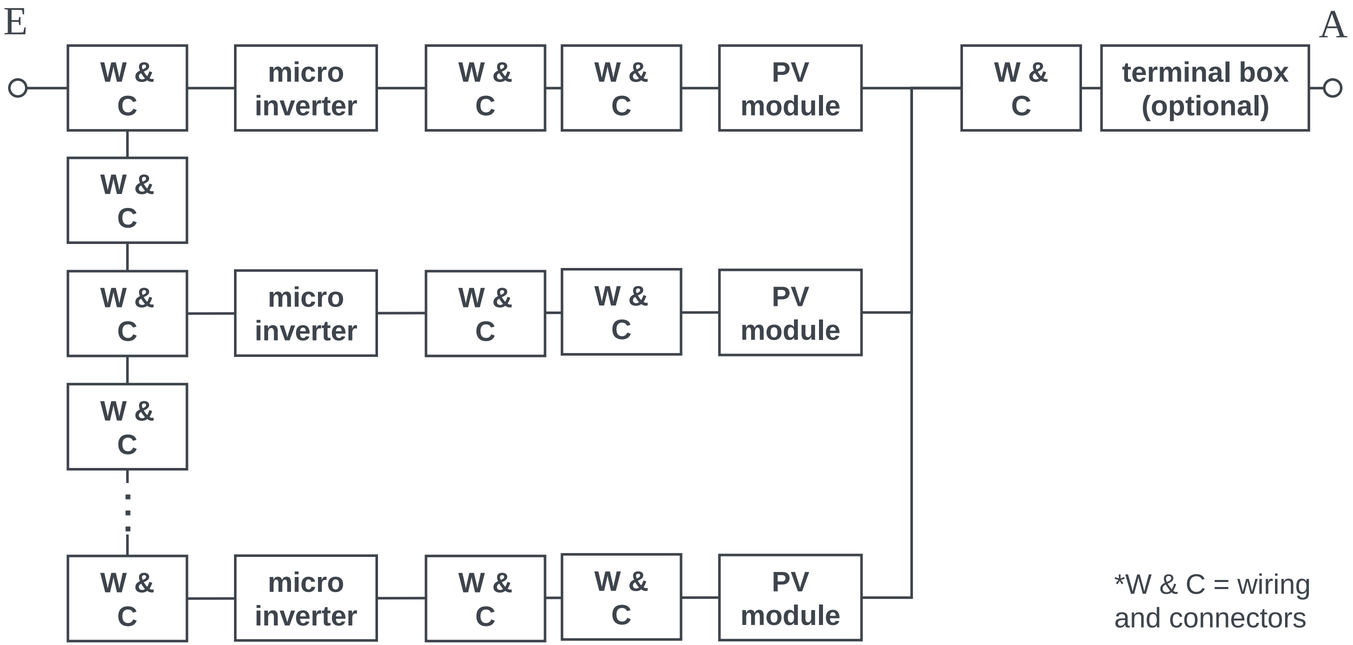
String concept



*W & C = wiring and connectors

Step 2 − Modeling of the reliability block diagram

Module integrated concept



*W & C = wiring and connectors

Modeling PV System Concepts in Petri Nets

Step 3 − Modeling of the condition of the PV system