Smooth PV Project

Considerations on the Modeling of Photovoltaic Systems for Grid Impact Studies

V. Ćuk, P.F. Ribeiro, J.F.G. Cobben, W.L. Kling,

Eindhoven University of Technology

F.R. Isleifsson, H.W. Bindner

Risø, Technical University of Denmark

N. Martensen

Energynautics GmbH

A. Samadi, and L. Söder

KTH Royal Institute of Technology

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Introduction – Smooth PV project

European project "Smart Modelling of Optimal Integration of High Penetration of PV" (Smooth PV)

http://www.smooth-pv.info/

Participants:

- **Energynautics GmbH**
- **University of Cologne**
- **KTH Royal Institute of Technology**
- **Risø, Technical University of Denmark**
- **Eindhoven University of Technology**

Motivation:

Technical and economic impact of high PV penetration in the distribution network and in the overall European power system

Objective of the paper

Overview of the literature about PV system modeling

Overview of existing models for different types of studies:

- **Power flow**
- **Stability**
- **Short-circuit**
- **Transients**
- **Harmonics**

Generalized initial approach for the modeling process

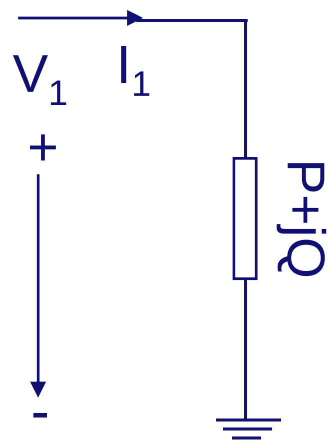
Power flow studies

PQ model – constant active and reactive power

Voltage control – PU node, Q depends on U (new grid codes)

U and Q control – DU node

Aggregation - arithmetical



Short-circuit studies

Previously – immediate disconnection during a grid fault

New grid codes – fault ride through required (for certain dips)

1. Synchronous generator model; not very accurate, reactive current limited to In (independent of fault distance)

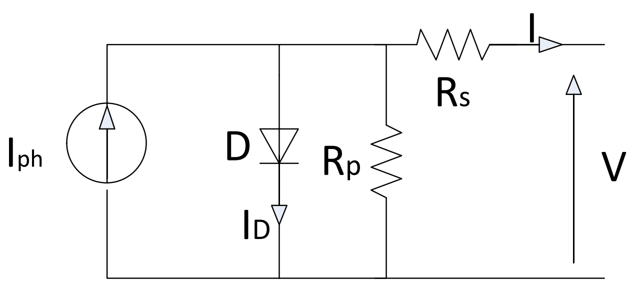
2. Dynamical simulation – very accurate, parameter set large

3. Iterative approach – non-linear inverter model, difficulty of implementation between 1 and 2

Aggregation: No simplified models available

Models of PV panels (1)

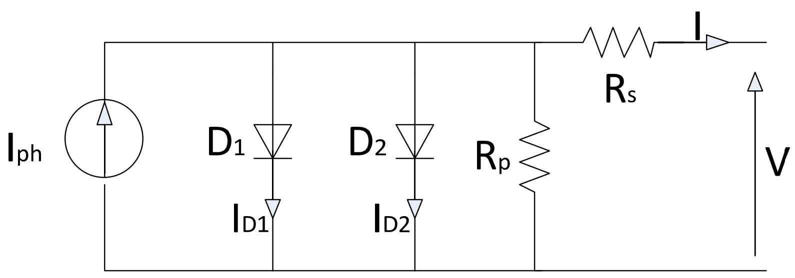
Single diode model



Less accurate

Less complicated

Double diode model

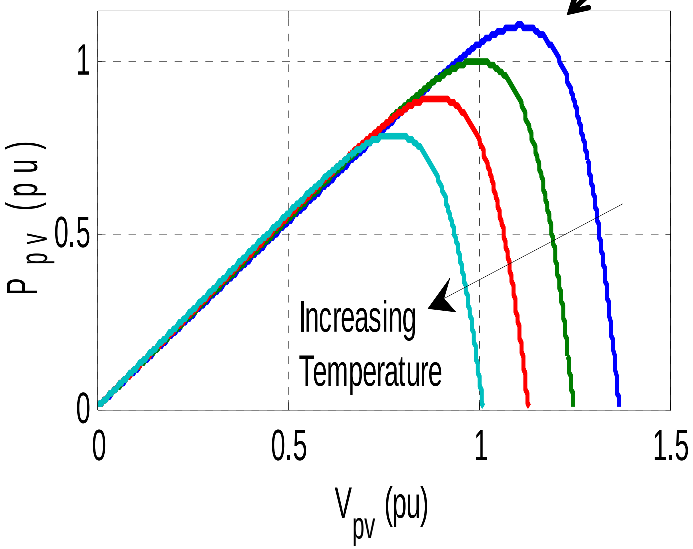


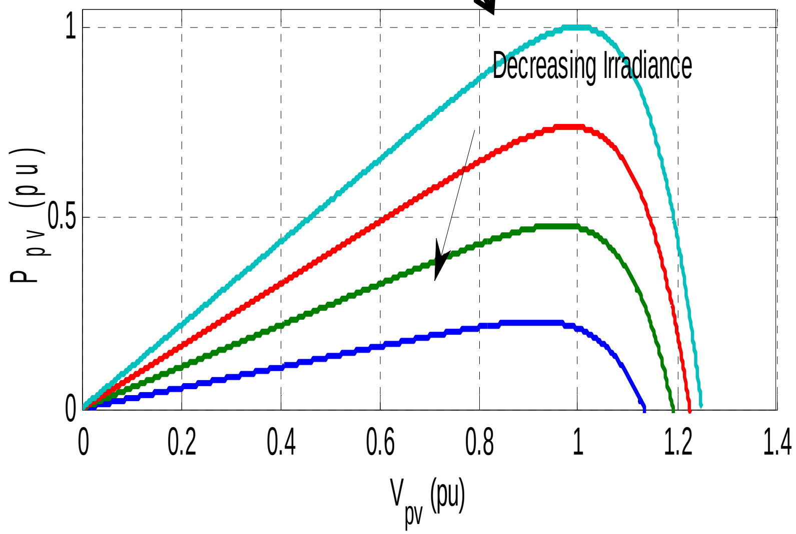
More complicated

More accurate

Models of PV panels (2)

Influence of temperature and irradiance





Voltage stability studies (1)

Rapid power output changes can lead to rapid voltage level changes

It is important to model PV input and real time consumption changes

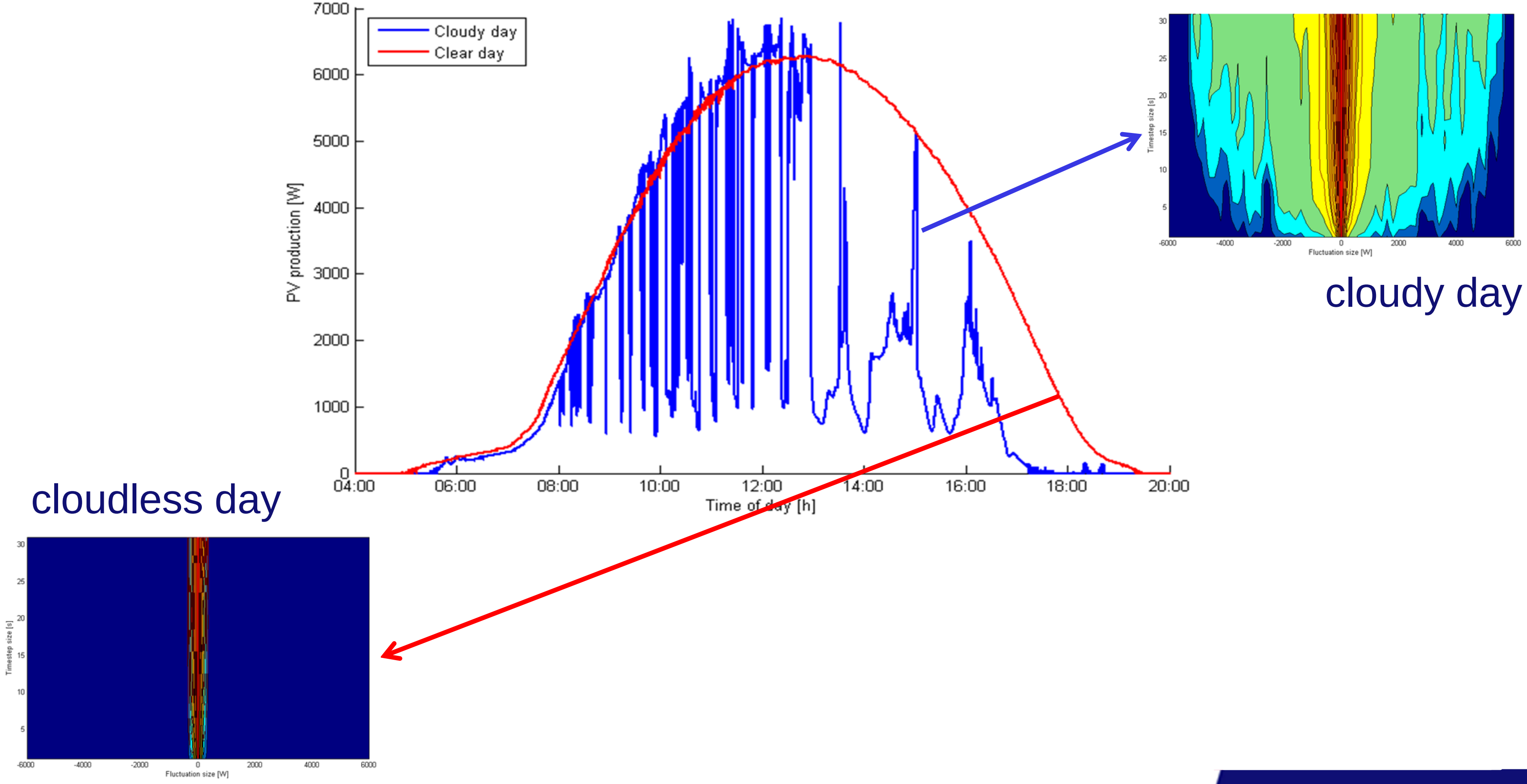
Outputs: size of fluctuations and distribution of voltage levels

Weather conditions important – not only temperature and irradiance, but also cloud formations

No aggregated models available

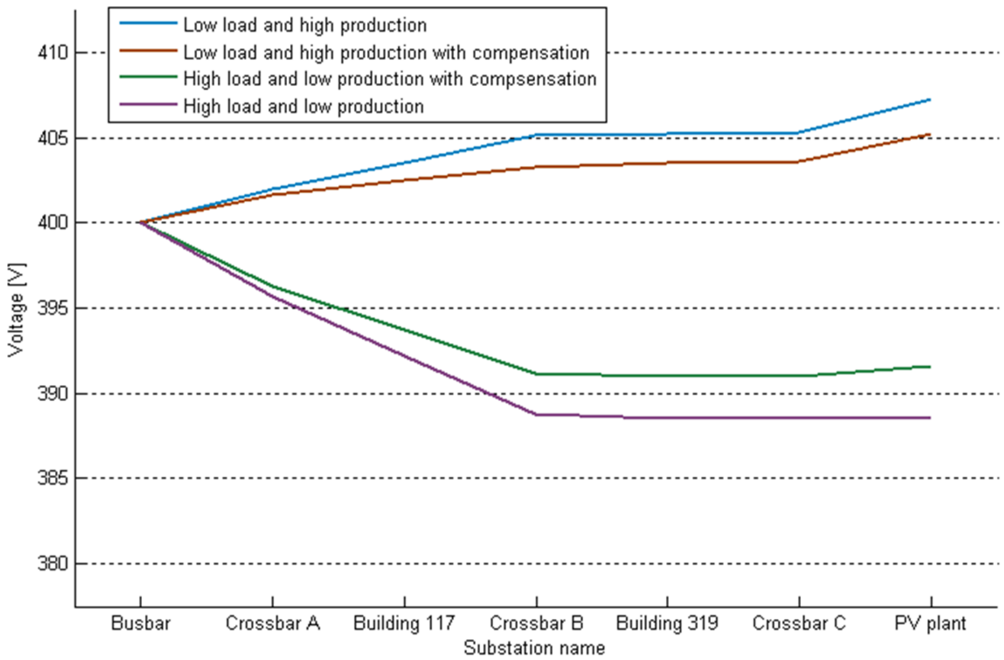
Voltage stability studies (2)

P production – 2 days with different cloud coverage



Voltage stability studies (3)

Voltage levels along the feeder – different loads, with/without reactive power compensation



Harmonic interaction studies (1)

Time domain modeling:

- **Differential equations**
- **Detailed model with controls**

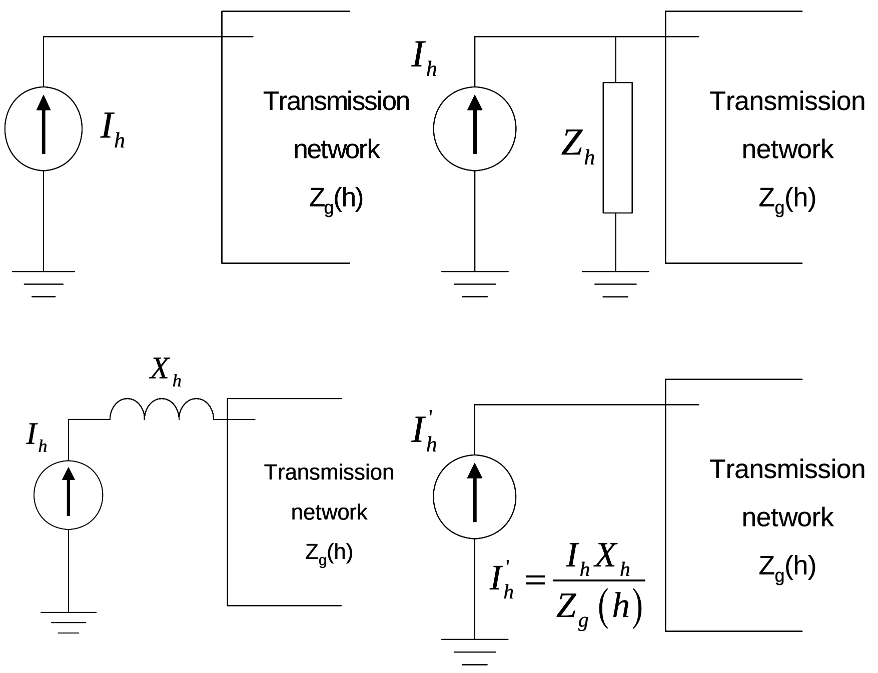
Pros/Cons:

- **Very good accuracy**
- **Good coverage of various conditions**
- **Difficult to implement (large number of parameters)**

Harmonic interaction studies (2)

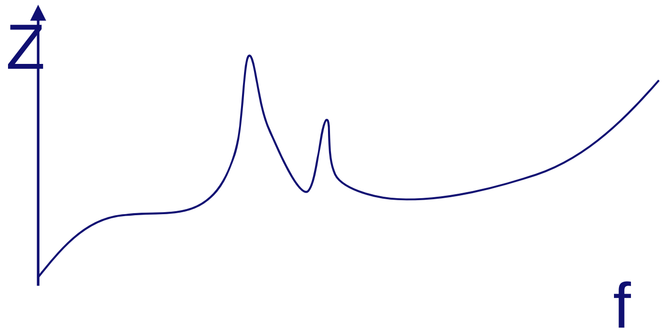
Frequency domain modeling:

- **Current source method**
  simple, least accurate
- **Power flow method**
  more complicated and
  more accurate
- **Iterative harmonic analysis**
  most complicated and
  most accurate



Harmonic interaction studies (3)

- **Harmonic currents relatively low**
- **Frequency dependent impedance of the system**
- **Impedance of inverters important**



Aggregation with summation coefficients

Phase angle diversity - the sum is smaller than arithmetical

$$I_{SUM} = \sqrt[\beta]{\sum_i I_i^\beta}$$

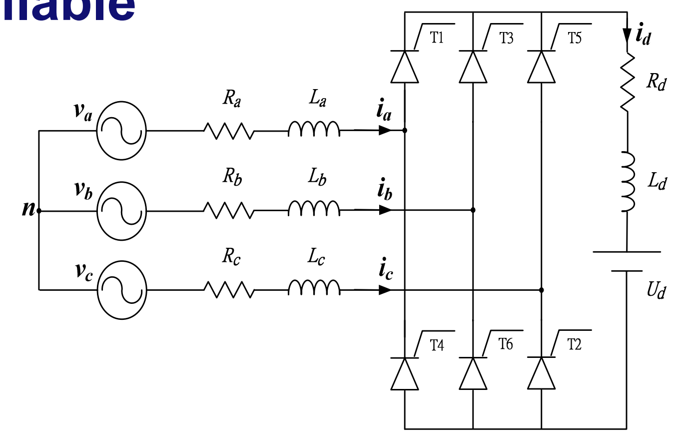
Transient studies

Time domain models:

- **Very good accuracy**
- **Difficult to implement (large number of parameters)**

New grid codes - fault ride through even for small units

No simplified or aggregated models available



Conclusions

Applications and limitations presented

Different studies emphasize and/or neglect different details

New grid codes change the behavior of converters (e.g. fault ride through, voltage regulation)

More work needed on the aggregation of a large number of units