Considerations on the Modeling of Photovoltaic Systems for Grid Impact Studies

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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

\[ V_1 \quad I_1 \]

\[ P+jQ \]
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**

![Single diode model diagram](image)

- $I_{ph}$
- $D$
- $R_p$
- $R_s$
- $V$
- $I$
- $I_D$
- $I_{ph}$
- Less accurate
- Less complicated

**Double diode model**

![Double diode model diagram](image)

- $I_{ph}$
- $D_1$
- $D_2$
- $R_p$
- $R_s$
- $V$
- $I$
- $I_{D1}$
- $I_{D2}$
- More complicated
- More accurate
Influence of temperature and irradiance

Increasing Temperature
Decreasing 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

- Cloudy day
- Cloudless day
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

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