COLUMBIA | ENGINEERING
The Fu Foundation School of Engineering and Applied Science

# PSCAD Simulation of Grid-Tied Photovoltaic Systems and Total Harmonic Distortion Analysis

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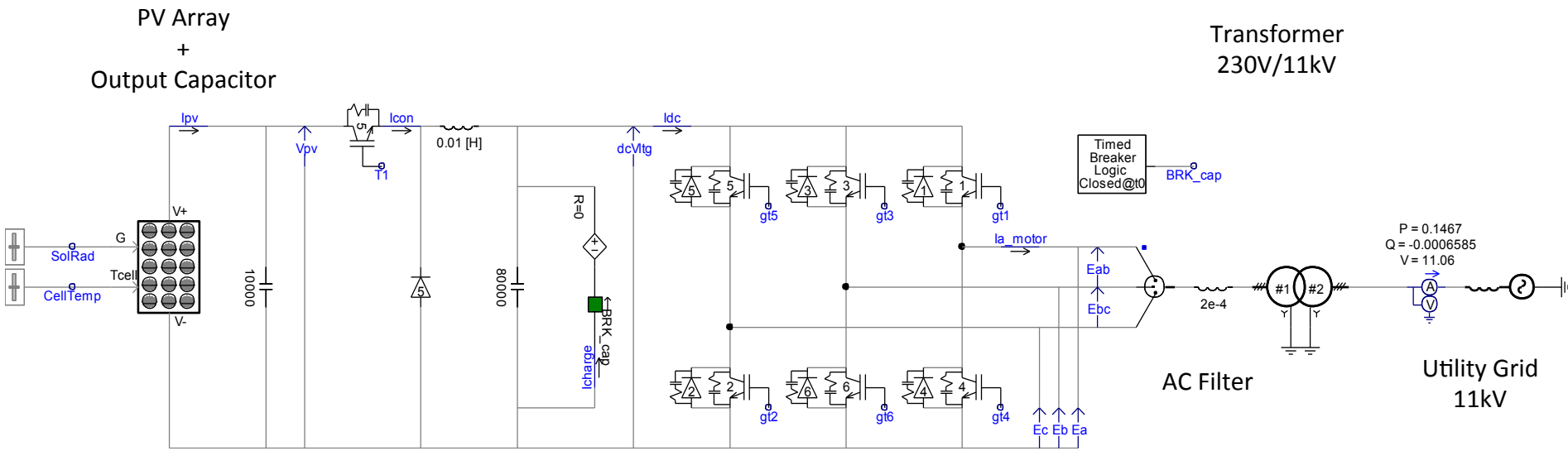
# Paper Structure

- **PSCAD Model of Grid-Tied Photovoltaic System**
  - Detailed description of all model components and the control blocks
- **Total Harmonic Distortion (THD) Analysis**
  - IEEE Std 929- 2000 "IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems"
  - THD analysis using PSCAD
  - Effects of solar irradiation on both current and voltage THD

# PSCAD Model Of Grid-Tied Photovoltaic System

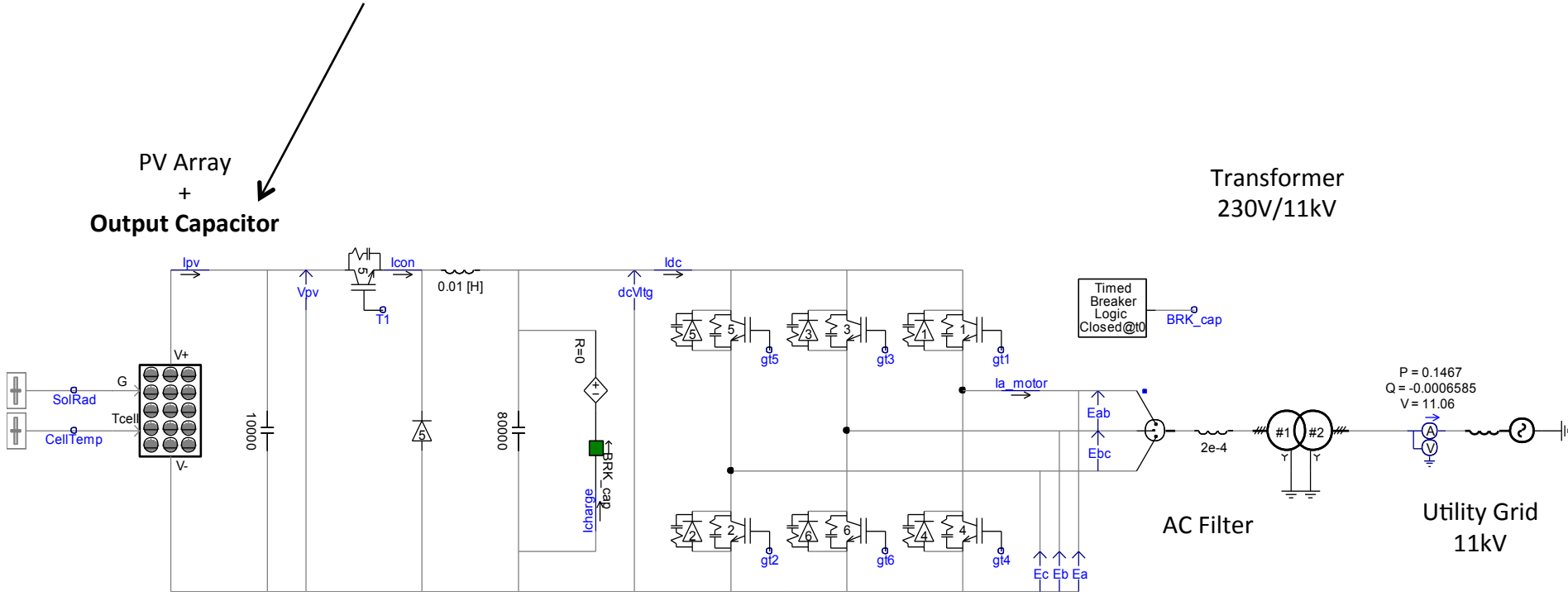
# Pscad Model Of Grid-Tied Photovoltaic System

- Model provided by PSCAD support team



# Pscad Model Of Grid-Tied Photovoltaic System

**minimizes the ripple of the PV source current**

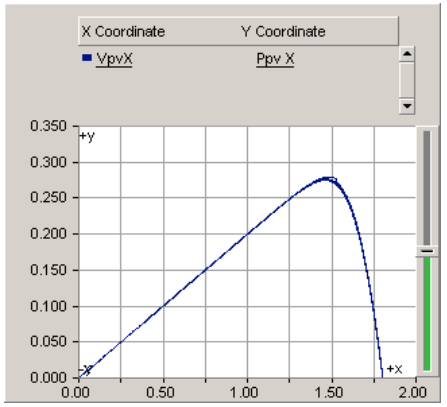


# Pscad Model Of Grid-Tied Photovoltaic System

## Operating at Maximum Power Point

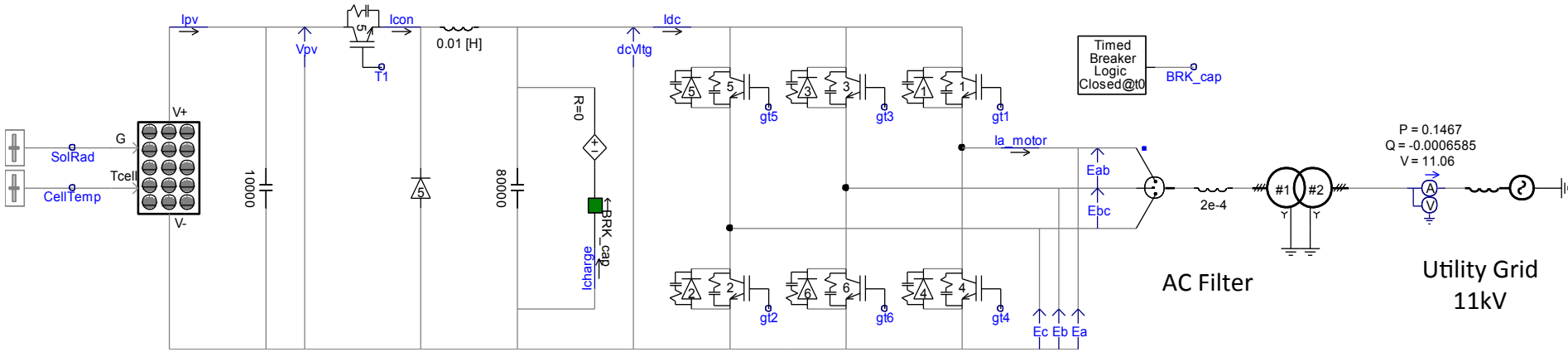
Incremental Conductance Tracking Algorithm

$$\begin{cases} \Delta I/\Delta V = -I/V, & \text{at MPP} \\ \Delta I/\Delta V > -I/V, & \text{left of MPP} \\ \Delta I/\Delta V < -I/V, & \text{right of MPP} \end{cases}$$




PV Array + Output Capacitor

Transformer 230V/11kV




AC Filter

Utility Grid 11kV

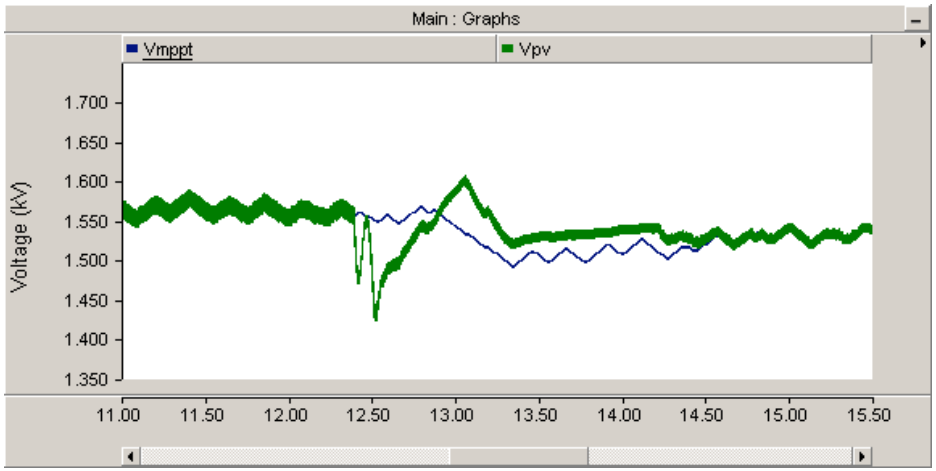
Solar Radiation + Cell Temperature Data

**DC-DC Converter for MPP Tracking**

3-phase Inverter Bridge

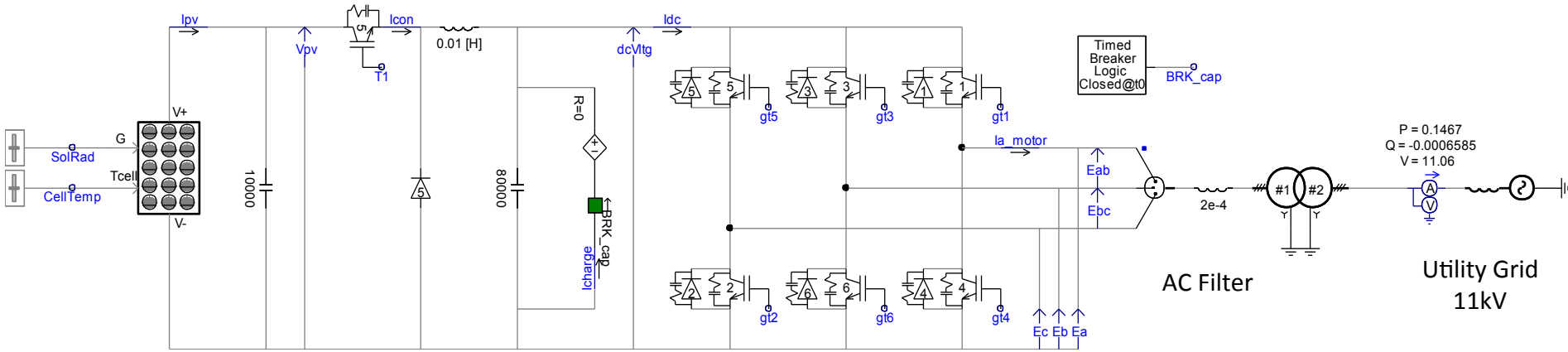
# Pscad Model Of Grid-Tied Photovoltaic System

**Creating MPPT voltage reference**




PV Array
+
Output Capacitor

Transformer
230V/11kV




Solar Radiation
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Cell Temperature
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**DC-DC Converter for MPP Tracking**

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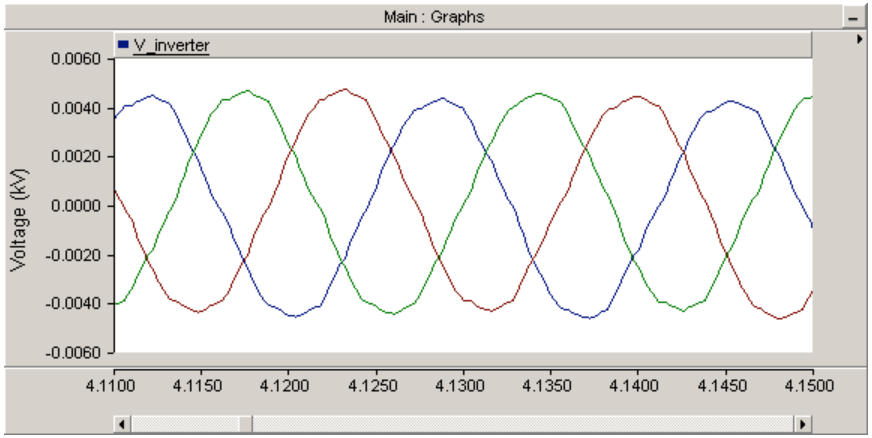
# Pscad Model Of Grid-Tied Photovoltaic System

**Connect DC system to AC system**




Transformer
230V/11kV

PV Array
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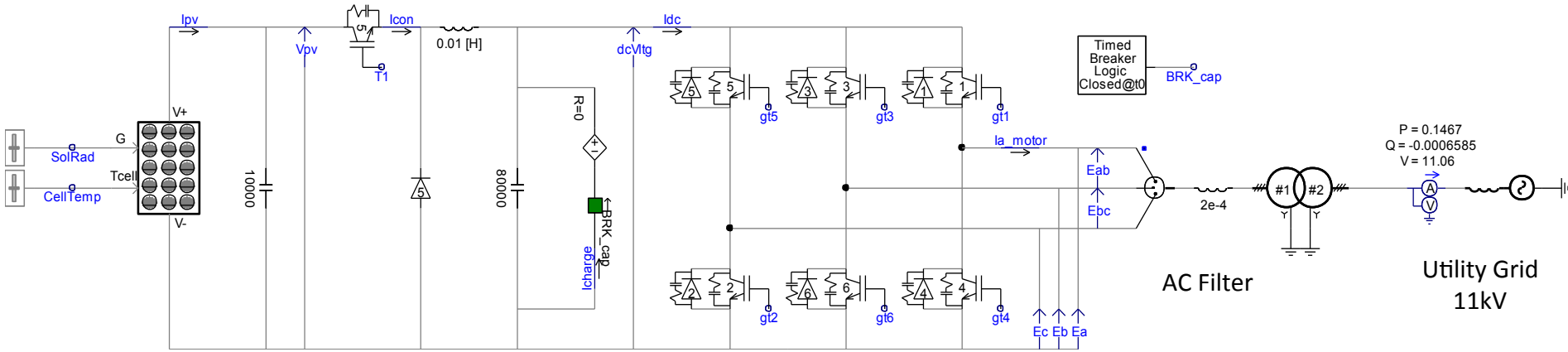
Output Capacitor




Solar Radiation
+
Cell Temperature
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DC-DC Converter
for MPP Tracking

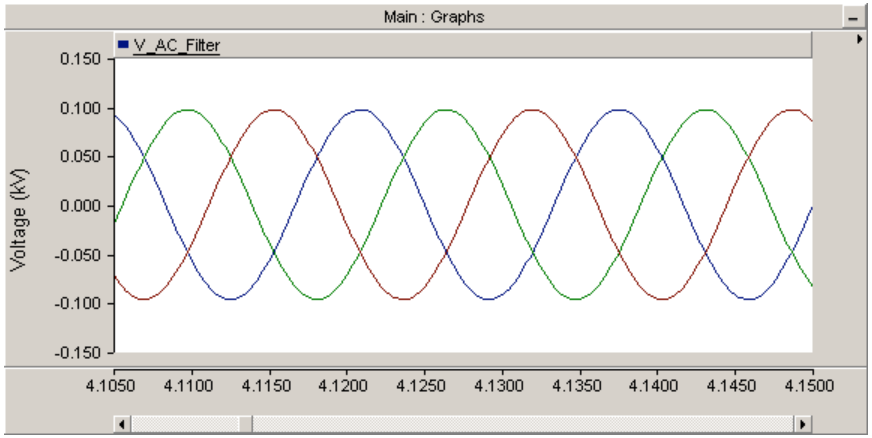
**3-phase Inverter Bridge**

AC Filter

Utility Grid
11kV

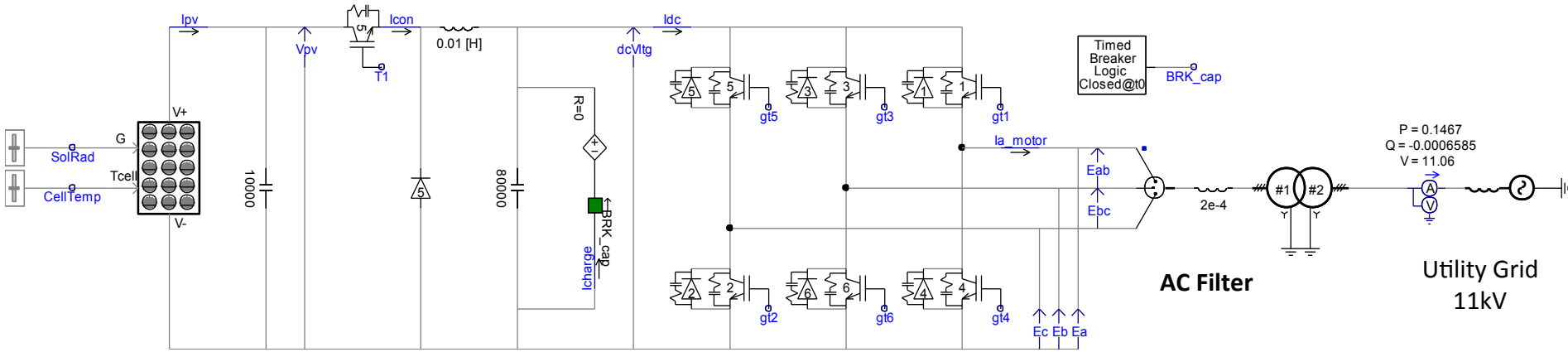
# Pscad Model Of Grid-Tied Photovoltaic System

**Smoothing the inverter output**




PV Array
+
Output Capacitor

Transformer
230V/11kV




**AC Filter**

Utility Grid
11kV

Solar Radiation
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Cell Temperature
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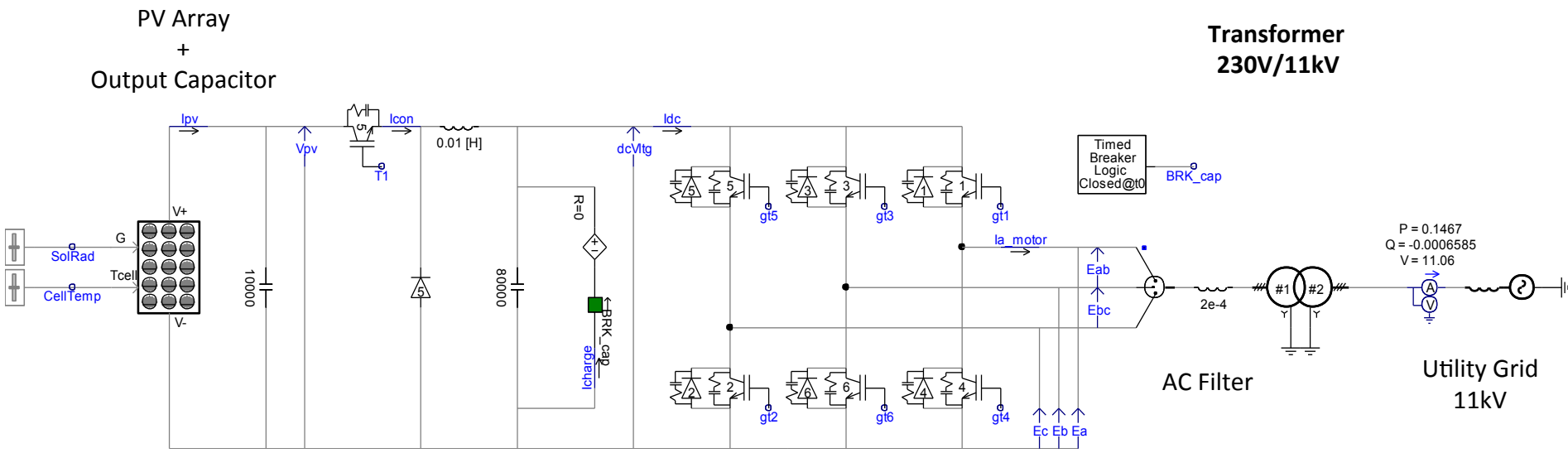
DC-DC Converter
for MPP Tracking

3-phase Inverter Bridge

# Pscad Model Of Grid-Tied Photovoltaic System

- **Voltage adjustment (step up or down)**
- **Galvanic insolation**



# Total Harmonic Distortion (THD) Analysis

# Total Harmonic Distortion (THD) Analysis

- Harmonics:
  - are sinusoidal components of a periodic wave having a frequency that is at multiples of the fundamental frequency
- Generated in PV systems by the converters that are using switching techniques that generate signals that are not perfect sinusoidal.
- Utility grid is already being injected with harmonics by the non-linear load
  - Connecting PV systems will add a stress on the power quality of the grid.

# IEEE Std 929- 2000

- "IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems"

  1. Total harmonic current distortion shall be less than 5% of the fundamental frequency current at rated inverter output.
  2. Each individual harmonic shall be limited as follows
     - If odd harmonic → limits in the table
     - If even harmonic → less than 25% of the odd harmonic limits listed

| Odd Harmonic | Distortion Limit |
|---|---|
| $3^{rd} - 9^{th}$ | $< 4.0\ \%$ |
| $11^{th} - 15^{th}$ | $< 2.0\ \%$ |
| $17^{th} - 21^{st}$ | $< 1.5\ \%$ |
| $23^{rd} - 33^{rd}$ | $< 0.6\ \%$ |
| $Above\ the\ 33^{rd}$ | $< 0.3\ \%$ |

# IEEE Std 929- 2000

- This standard is valid for medium and high voltage level electric utility
  - Simulated grid is 11 kV 60 Hz system (medium)

| **Voltage Class** | **Nominal Line-Line RMS Voltage** |
|---|---|
| Low Voltage | $< 600\ V$ |
| Medium Voltage | $600\ V - 69\ kV$ |
| High Voltage | $69\ kV - 230\ kV$ |
| Extra High Voltage | $230\ kV - 1100\ kV$ |
| Ultra High Voltage | $> 1100\ kV$ |

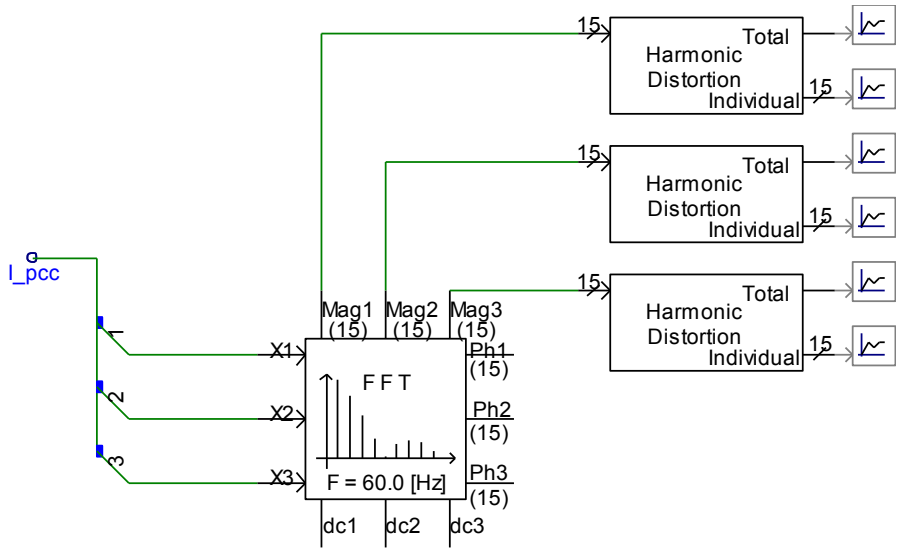
# THD Analysis using PSCAD

- Calculation of Total Harmonic Distortion

  1. Fast Fourier Transform (FFT) → Harmonic frequency components magnitude (each index)

  2. Using harmonic frequency components

     - Total Harmonic Distortion (%)
     - Individual Harmonic Distortion (%)



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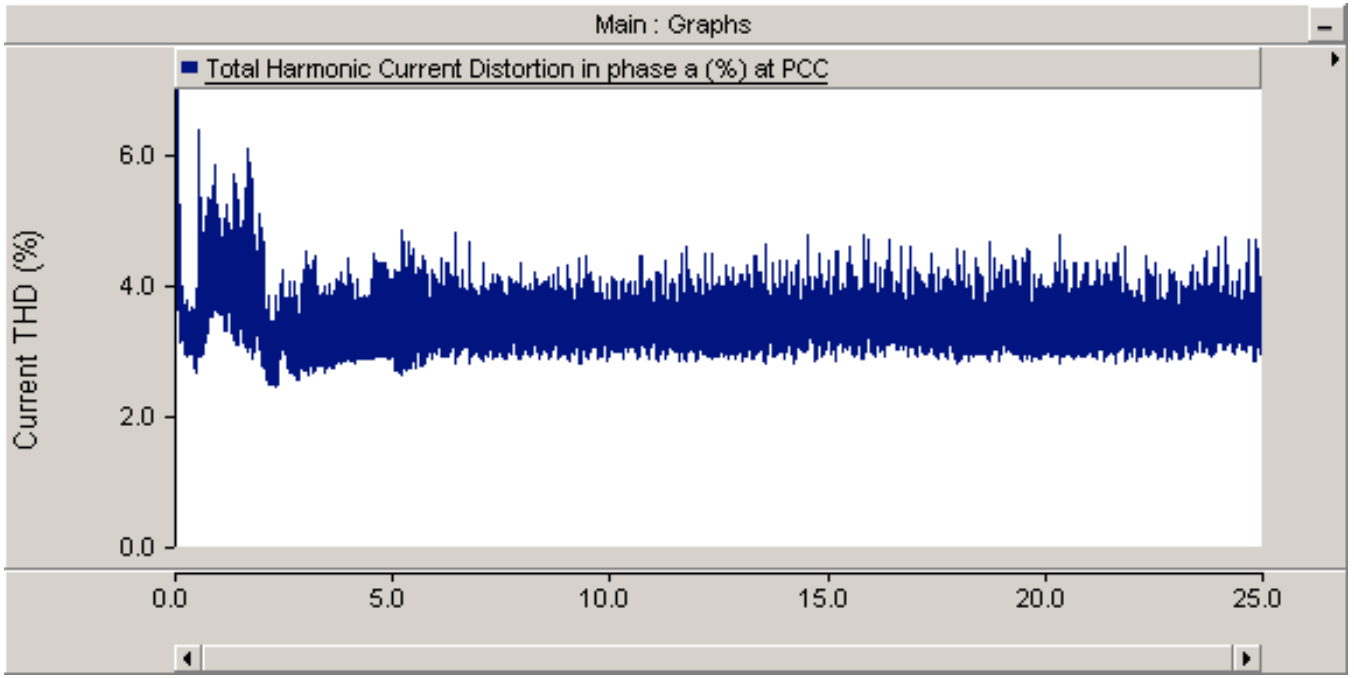

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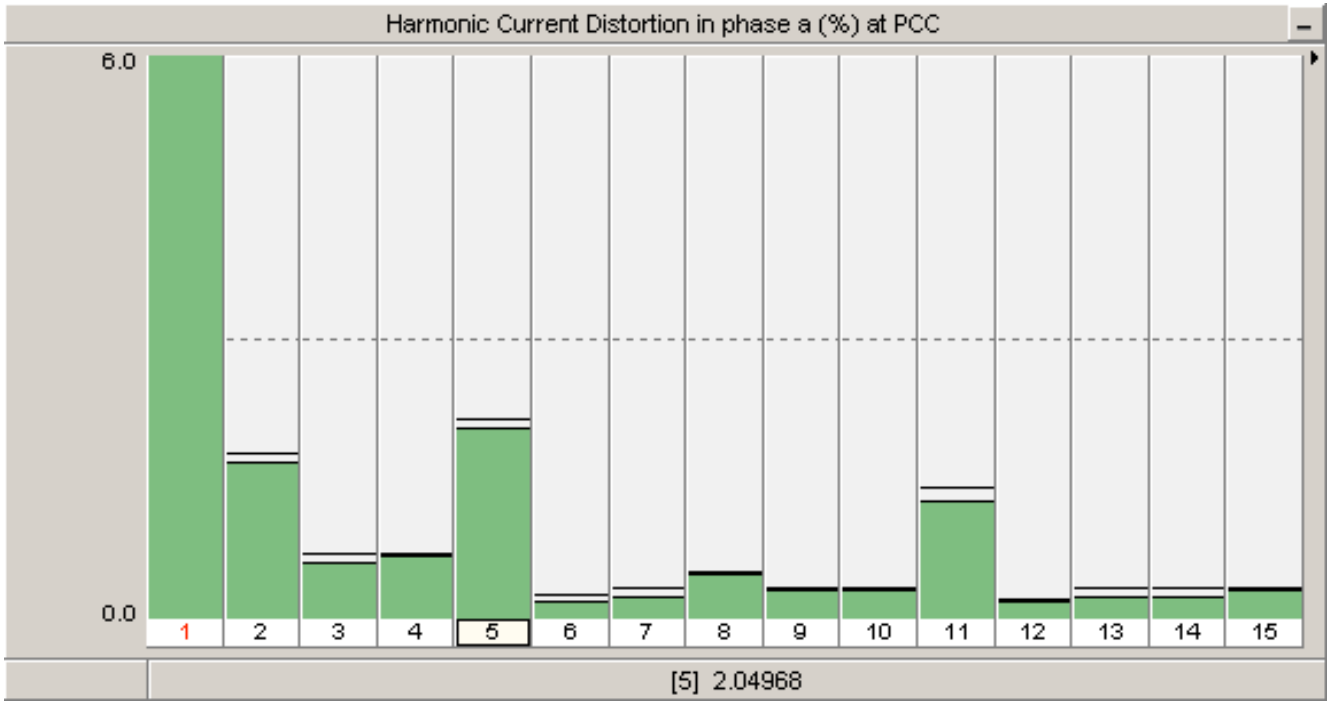
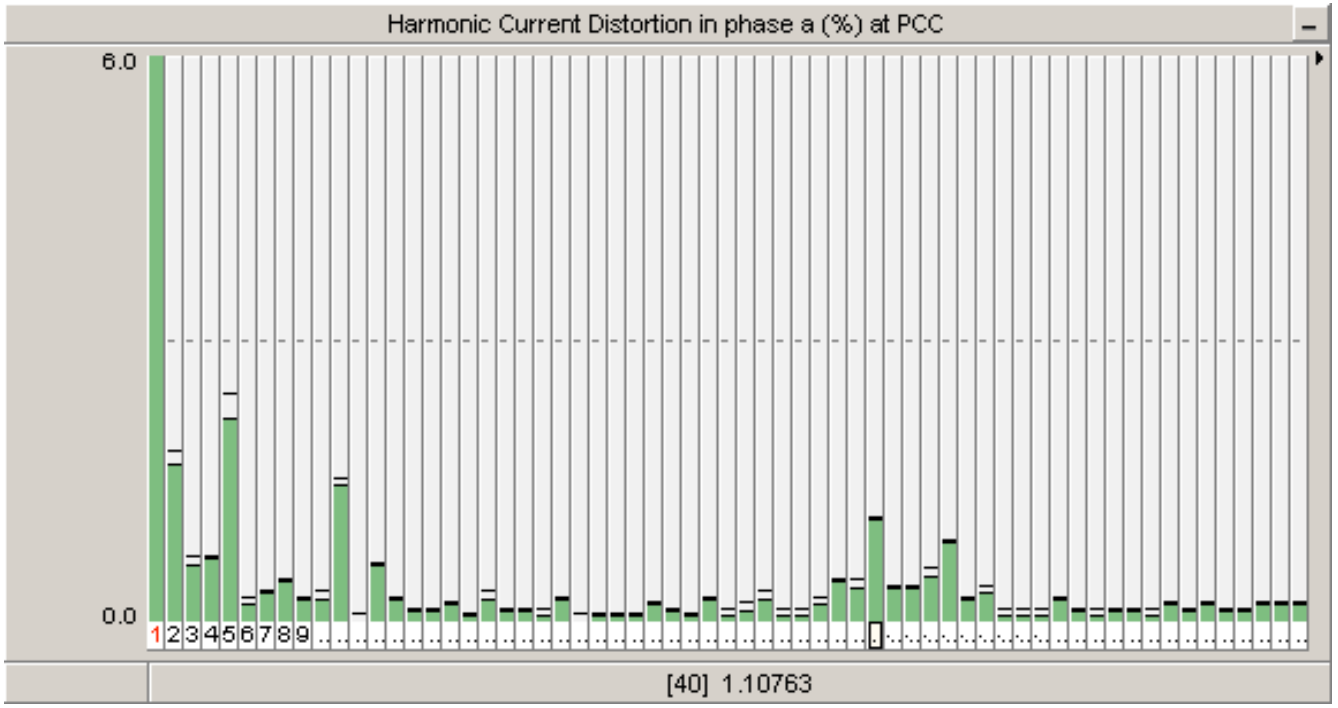


# THD Analysis using PSCAD

- Expanding the harmonic index to 63
  - The harmonics with indices from 38 to 46 are violating the distortion limits, which is 0.3%

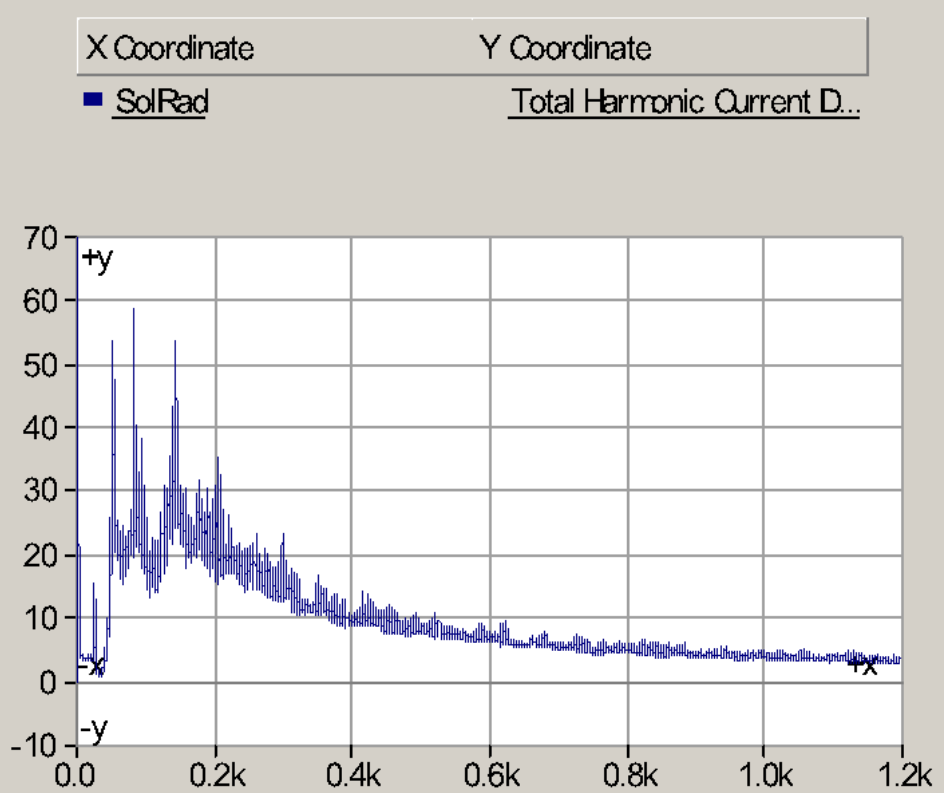


# Solar Irradiation Effects on Current and Voltage THD

- IEEE Std 929- 2000
  - Limits were established for THD of the current at PCC
- It is a common practice, especially in the case of grid-tied PVs, to pay more attention to current THD analysis.
- WHY?

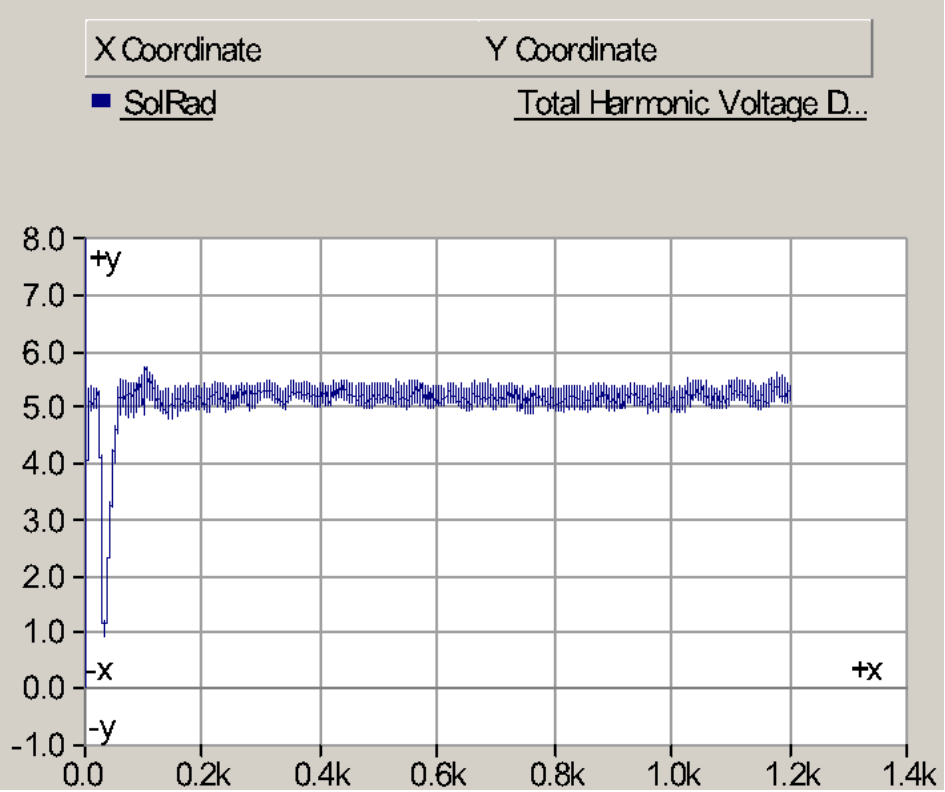
# Solar Irradiation Effects on Current and Voltage THD

- Current THD Vs. Solar Irradiation
  - Current THD decreases as the Solar Irradiation increases



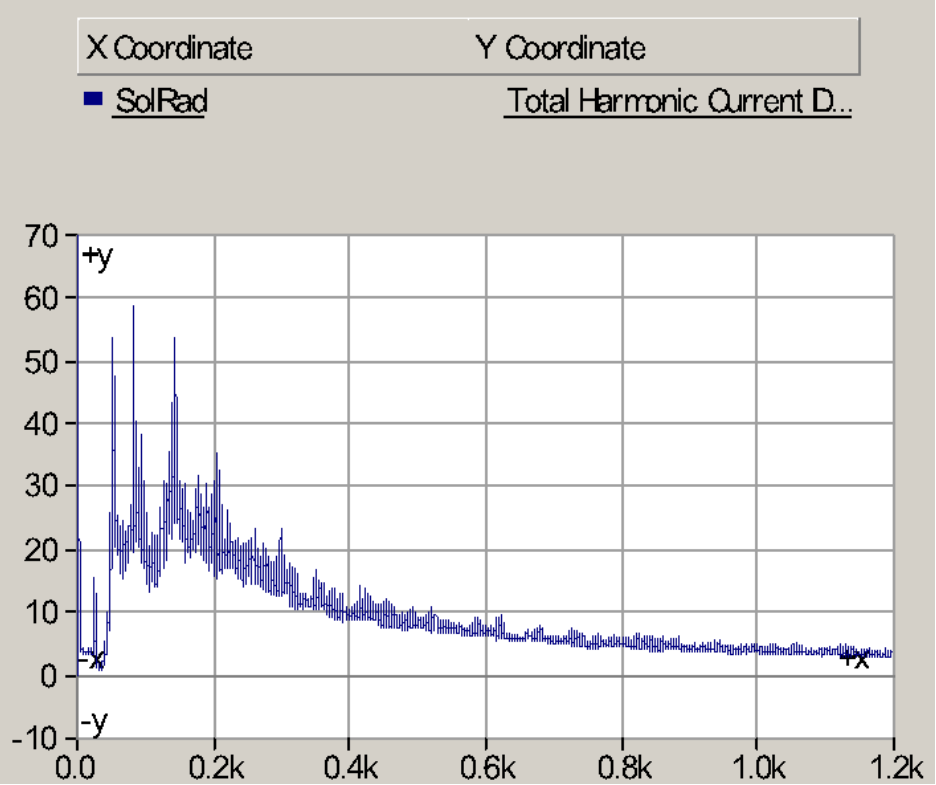
# Solar Irradiation Effects on Current and Voltage THD

- Voltage THD Vs. Solar Irradiation
  - Voltage THD is not affected by the varying Solar Irradiation



# Solar Irradiation Effects on Current and Voltage THD

- Current THD Vs. Solar Irradiation
  - PV systems operating under low solar irradiation values inject more current harmonics into the utility grid than at high irradiation values.



# Solar Irradiation Effects on Current and Voltage THD

- This problem might force PV system operators to
  - Disconnect the PV system from the grid to avoid paying the high THD levels penalty specified by the utility operator.
  - Use better filtering techniques
    - Passive filters (RLC)
    - Shunt Active Power Filters (used for harmonic compensation)

# Thank You

## Contact Information

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