Dynamic Modeling and Analysis of Inverter-Based Resources (IBR)

challenges from grid and device perspectives

Lingling Fan

University of South Florida

May 17, 2019

Outline

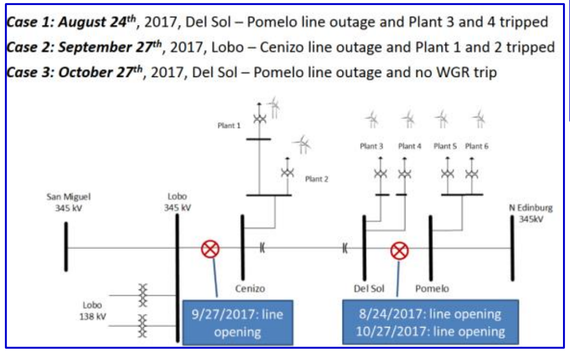
- Events relevant to wind and solar grid integration challenges
  - Example 1: type-3 wind SSR in South Texas
  - Example 2: 4 Hz oscillations in Texas Panhandler
  - Example 3: 7 Hz oscillations observed in a First Solar PV farm
  - Example 4: solar PV tripping events in California
- Challenges: unprecedented dynamic phenomena
  - converter control design
  - modeling and understanding
- Future research trend

Example 1: RLC + induction machine + converter

- In Aug- Oct 2017, South Texas experienced three type-3 wind farm SSR events[1].
  - ~25 Hz oscillations were observed due to transmission line tripping which left type-3 wind farms radially connected to series compensated 345 kV lines.
  - Two events left wind plant tripped.
- Similar oscillations have been experience in 2009[2-3].
- Northern Minnesota reported sub-harmonic oscillations for 150-MW type-3 wind farm in 2008[4].

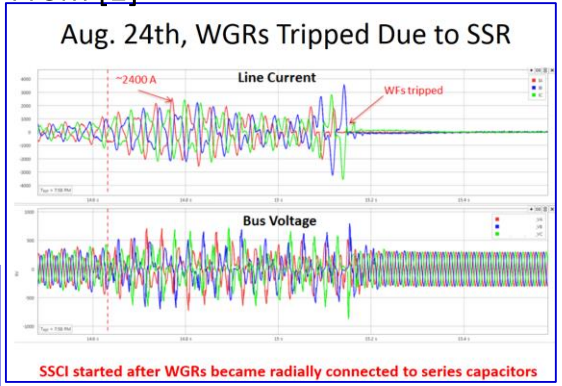
[1] ERCOT ROS Meeting presentation: South Texas SSR
url:
http://www.ercot.com/content/wcm/key_documents_lists/139265/10._South_Texas_SSR_ERCOT_ROS_May_2018_rev1.pdf

[2] L. C. Gross, "Sub-synchronous grid conditions: New event, newproblem, and new solutions," inProc. Western Protective Relay Conf.,2010, pp. 1–5.
[3] J.Adams,C.Carter,andS.-H.Huang, "ERCOT experience with sub-synchronous control interaction and proposed remediation," inProc.IEEE PES Transm. Distrib. Conf. Expo., 2012, pp. 1–5.
[4] K. Narendra, D. Fedirchuk, R. Midence, N. Zhang, A. Mulawarman, P.Mysore, and V. Sood, "New microprocessor based relay to monitor andprotect power systems against sub-harmonics," inProc. IEEE Elect.Power and Energy Conf. (EPEC'11), 2011, pp. 438–443

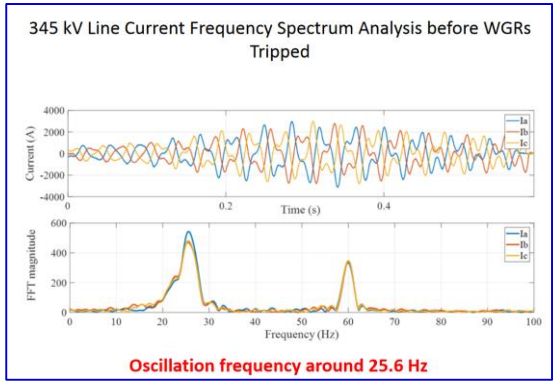


From [1]

From [1]



From [1]



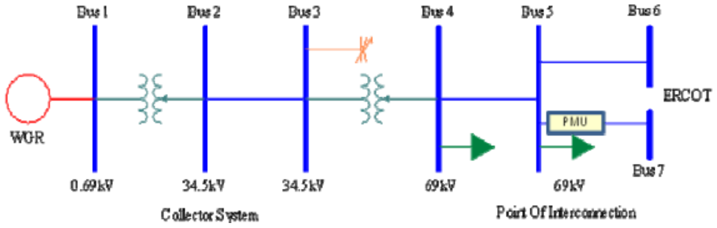
Challenge in modeling

- According to ERCOT ROS presentation in May 2018, replicating real-world events poses difficulty to wind turbine manufacturers.
- Replicating real-world events requires not only detailed wind farm models, but also grid representation.
- Putting entire ERCOT system into PSCAD is an option, but not realistic.
  - PSCAD will not run if the system is too large.

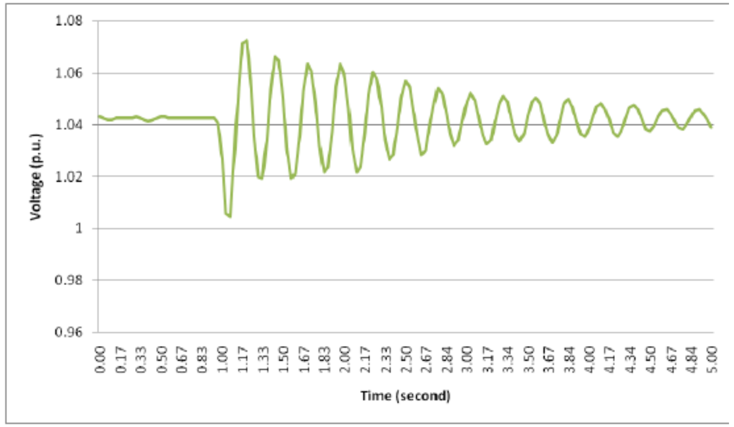
Example 2: 4 Hz oscillations (converter in weak grid)

From [5]:

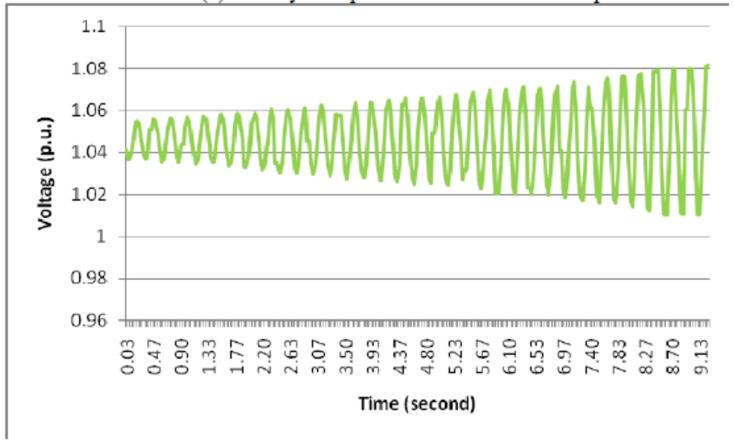
Fig. 1. CREZ transmission system.



A wind power plant connected to ERCOT CREZ zone with SCR =4. When Bus 5-Bus 6 trips, SCR = 2 or less. PMU captures poorly damped oscillations at lower output and undamped oscillations at high output.



(a) Poorly-damped oscillation at low output



(b) Un-damped oscillations at high output

Fig. 8. Recorded voltage oscillations at the WPP's POI

[5] S.-H. Huang, J. Schmall, J. Conto, J. Adams, Y. Zhang, and C. Carter, "Voltage control challenges on weak grids with high penetration of wind generation: Ercot experience," in Power and Energy Society General Meeting, 2012 IEEE. IEEE, 2012, pp. 1–7.

Example 2: 4 Hz oscillations (VSC in weak grid)

Letters

An Explanation of Oscillations Due to Wind Power Plants Weak Grid Interconnection

Lingling Fan, *Senior Member, IEEE*, and Zhixin Miao, *Senior Member, IEEE*

***Abstract*—An existing wind power plant at ERCOT experienced poorly damped and undamped voltage oscillations under weak grid conditions. The oscillations became worse during high power outputs. This letter aims to find the root cause of such oscillations. Our research provides a linearized system model by combining the vector control of wind power plants and the weak grid interconnection. Using this model, this letter succeeds in explaining that the weak grid condition introduces a zero in right half plane for the open-loop system, which can lead to poorly damped or undamped oscillations.**

***Index Terms*—Voltage oscillations, weak grids, wind power plants.**

I. INTRODUCTION

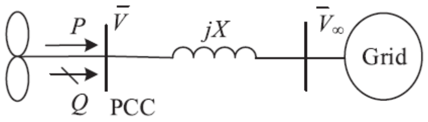


Fig. 1. The study system.

A. The Control Block

In power system dynamic studies, a WPP is assumed to be a current source [2]. This assumption is also used in this letter. Further, the vector control of a WPP is based on a *dq*-reference frame, where the *d*-axis is aligned with the point of

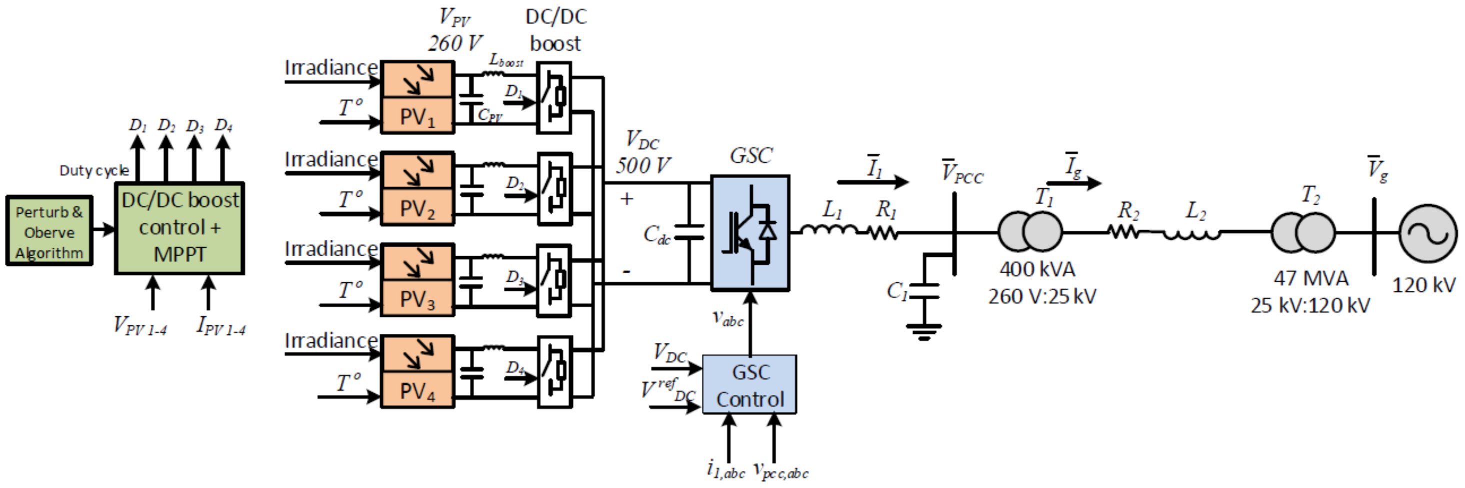
- The root cause identified as converter vector control based on PCC voltage introduces an instability mechanism.
- More power to grid, the PCC voltage will be lower.
- Some call it "dynamic voltage stability" issue.

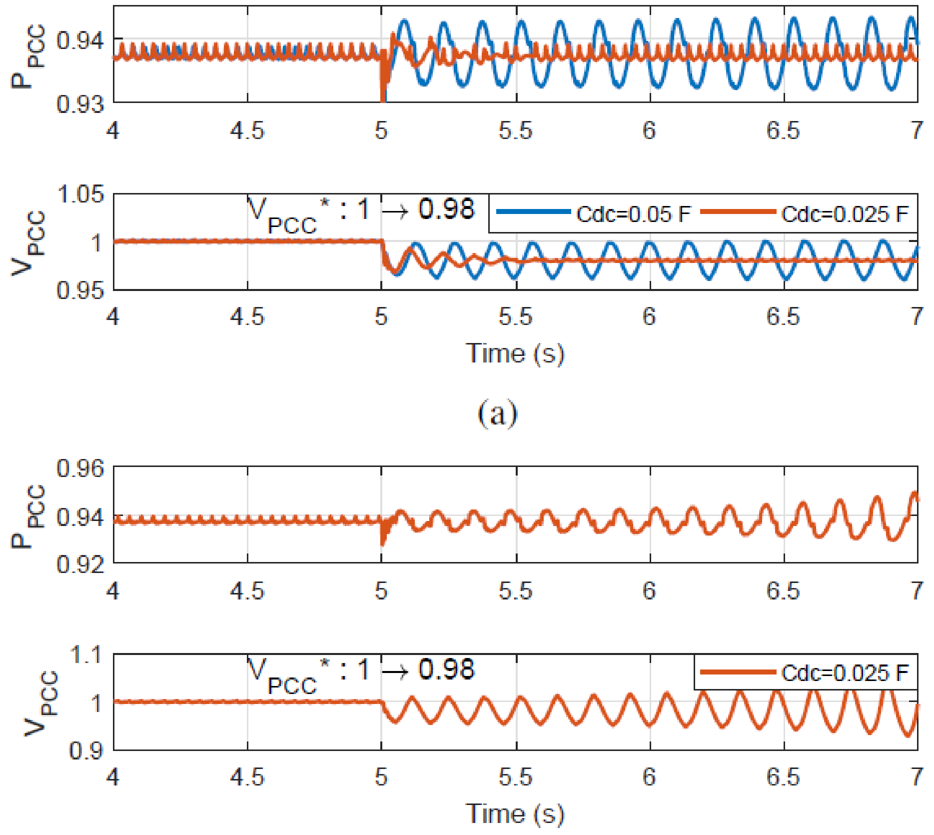
Challenge in converter control

Example 3: 7 Hz oscillations in solar PV farm (VSC in weak grid)

First Solar, "Deploying utility-scale PV power plants in weak grids," IEEE PESGM July 2017 panel presentation.

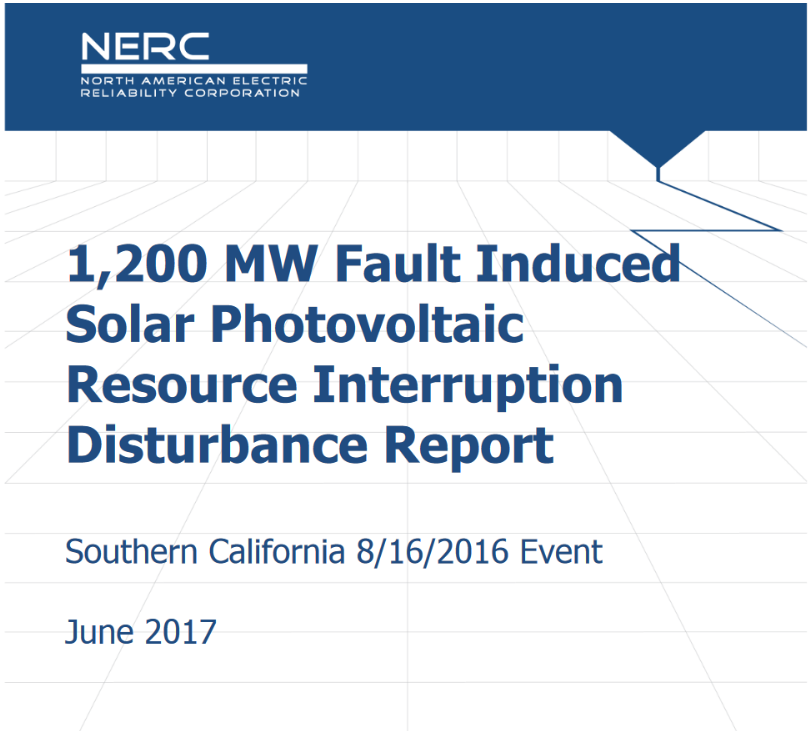
Replicating 7 Hz oscillations by USF SPS:





Challenge in converter control

Example 4: Solar PV tripping events documented by NERC reports



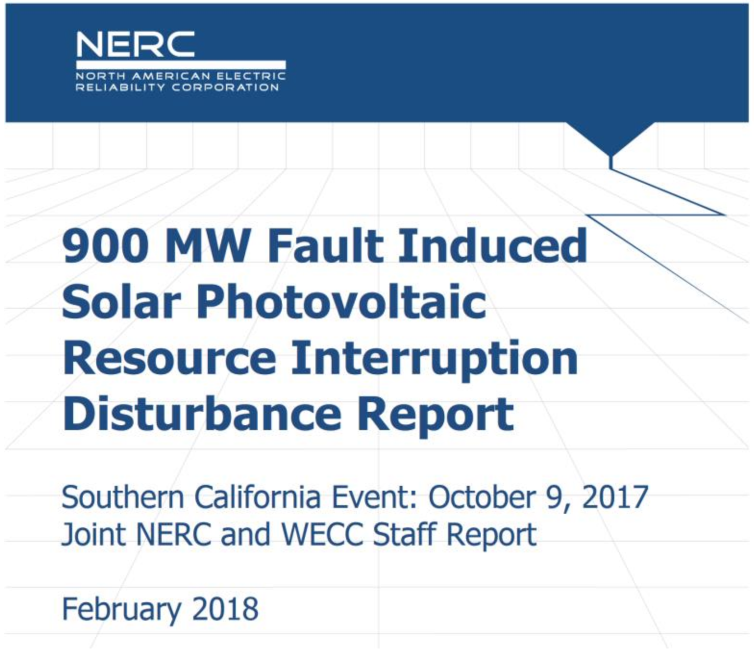
NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report

Southern California 8/16/2016 Event

June 2017

2016 Blue Cut Fire event



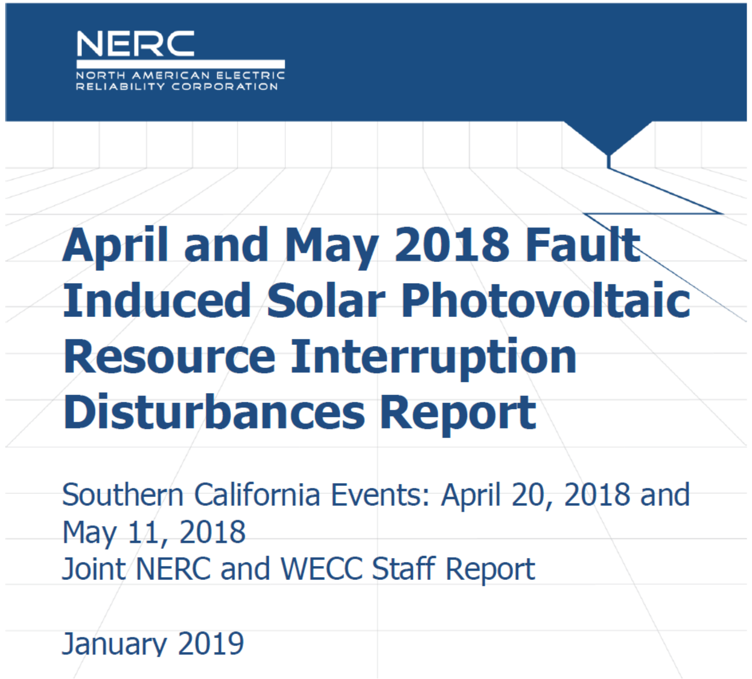
NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

900 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report

Southern California Event: October 9, 2017
Joint NERC and WECC Staff Report

February 2018

2017 Canyon 2 Fire event



NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

April and May 2018 Fault Induced Solar Photovoltaic Resource Interruption Disturbances Report

Southern California Events: April 20, 2018 and May 11, 2018
Joint NERC and WECC Staff Report

January 2019

Source: NERC Inverter-based resource disturbance analysis webinar slides.
https://www.nerc.com/comm/PC/IRPTF_Webinars_DL/Inverter-Based_Resource_Disturbance_Analysis_Webinar_2018-02-15.pdf

2016 Blue Cut Fire Event:

Erroneous frequency estimation by inverters

~700 MW PV tripped due to under-frequency (<57 Hz) sensed by inverters

Transmission grid transmission line phase-phase fault causes distortion on voltage waveforms.

Challenge of converter control design:

Synchronizing unit (PLL) performance during transients.

2017 Canyon 2 Event: PV inverter overvoltage

NERC report Key Finding #8: *Interactions between momentary cessation, in-plant shunt capacitors, transient voltages, harmonics, etc., that are not sufficient understood; EMT studies required.*

Challenge from grid perspective: dynamics not fully understood.

Challenges

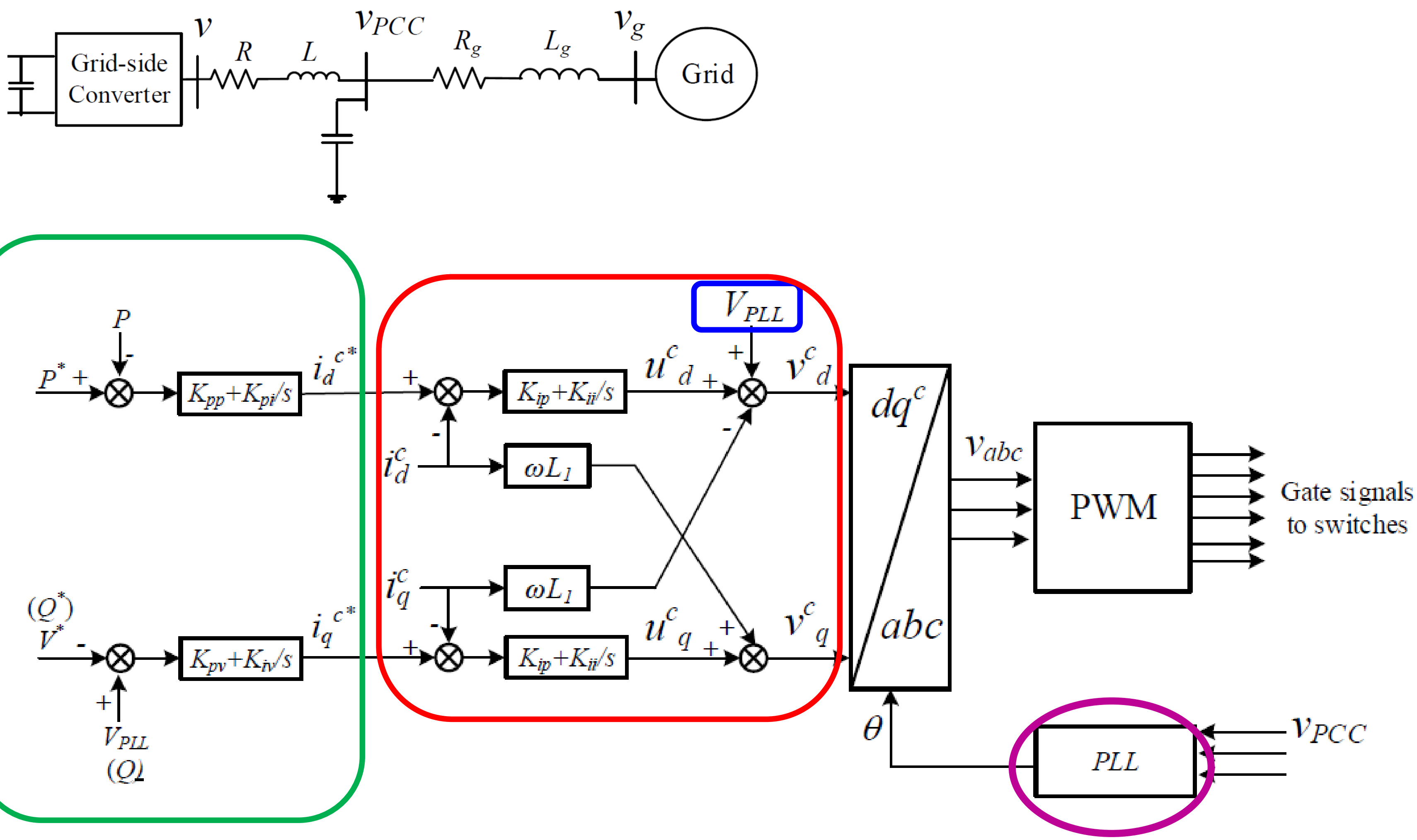
- There are/will be many unprecedented dynamic phenomena due to high penetration of inverter-based resources (IBR).
- Many questions to be answered, e.g.,
  - Will there be SSR if Texas grid (with many series caps) has high penetration of solar PV?
  - What will happen if solar PV converter design is changed?
- Investigation ahead of time is necessary.
- Next several slides offer more detailed overview of state-of-the-art and limitations.

Challenges from device (converter design) perspective

Voltage source converter control design has considered the following aspects:

- converter current limit (very fast current control)
- decoupling from grid (voltage feedforward)
- decoupled real power and reactive power control **(vector control)**

Textbook on VSC:
A. Yazdani, R. Iravani, Voltage-Sourced Converters in Power Systems, IEEE Wiley 2010



Challenges from vendor (device) perspective

- Converter control design assumes a stiff grid.
- How to take into grid effect into consideration in both modeling and control is a challenge
  - So far we've seen
    - Grid following converter control weak grid issue
    - PLL performance issue during transient
    - Inverter overvoltage issues

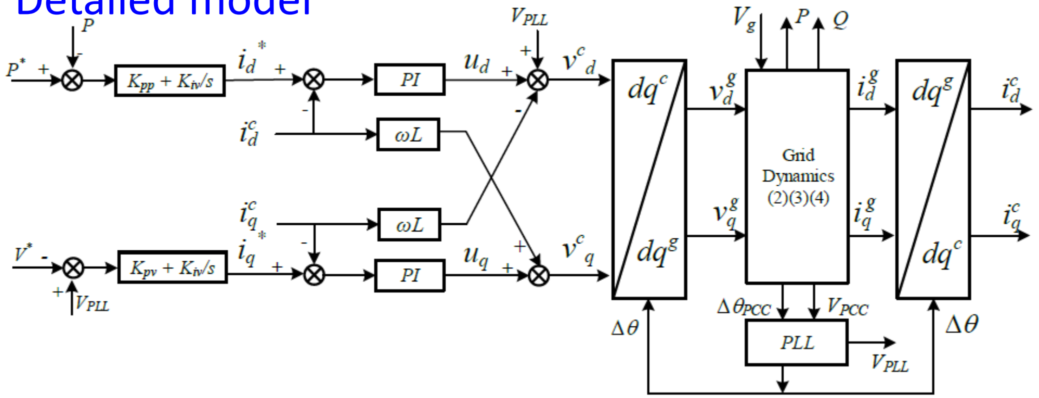
Challenges from grid perspective

- From grid perspective, how many details of converter control and PV/wind characteristic to be included in grid studies is a challenge.
  - Overvoltage not understood
  - Weak grid phenomena cannot be replicated.
- Other challenges:
  - Generic models do not match vendor provided models
  - Vendor models are “black boxes”

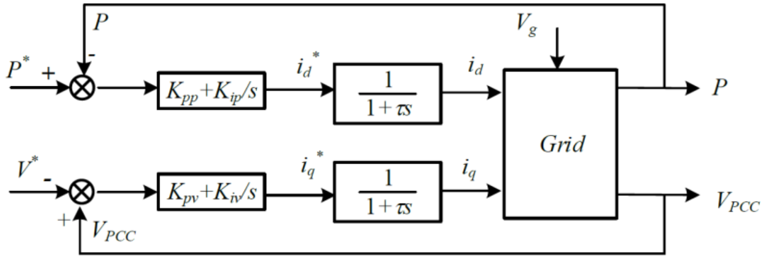
Challenges from grid perspective

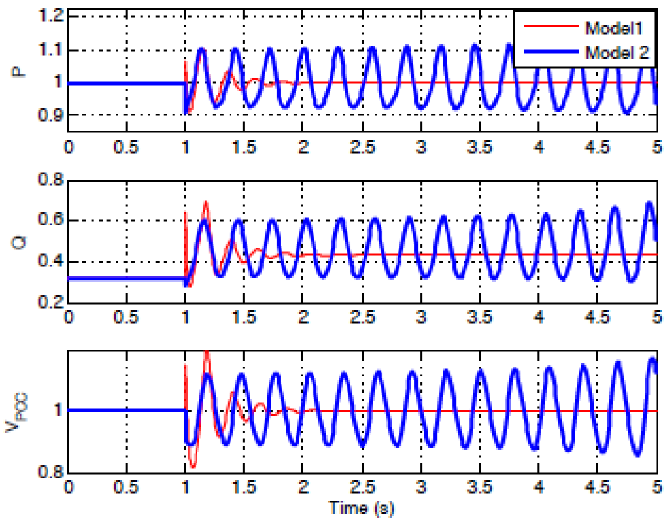
- Current grid-study **generic** model assumptions
  - PLL ignored
  - Network algebraic phasor model
  - Current control/feedforward/ simplified into a first-order delay unit

Detailed model



Simplified model





Very different performance if grid is weak.

L. Fan, "Modeling Type-4 Wind in Weak Grids," IEEE trans. Sustainable Energy 2018.

Future research trend

Power Electronics:

Study methods:
Hardware experiments;
Close-to-reality modeling;
Impedance-measurement-based two portal analysis

Power Grids:

Study methods:
Simplification;
Aggregation;
Large-scale network handling;
Computing efficient analytical tools

PSCAD

PSS/E, PSLF, SSAT

Future research trend

- Integration of domain knowledge and study methods of both power grids and power electronics
  - Analytical models/tools with proof of validation
  - Converter control design with grid consideration
    - *DE-EE0008771: Modeling and Control of Solar PVs for Large Grid Disturbances and Weak Grids*
- "Reverse engineering" to build models from "black boxes" and/or real-world event records
  - *Y. Li, L. Fan, Z. Miao, "Replicating Real-World Type-3 Wind SSR Events," R1 revision under review, TPWRD.*

Q&A

- Thank you!

- Lingling Fan
- University of South Florida
- linglingfan@usf.edu