Solar Power Plant Design and Interconnection

Wind & Solar Super Session

July 27, 2011

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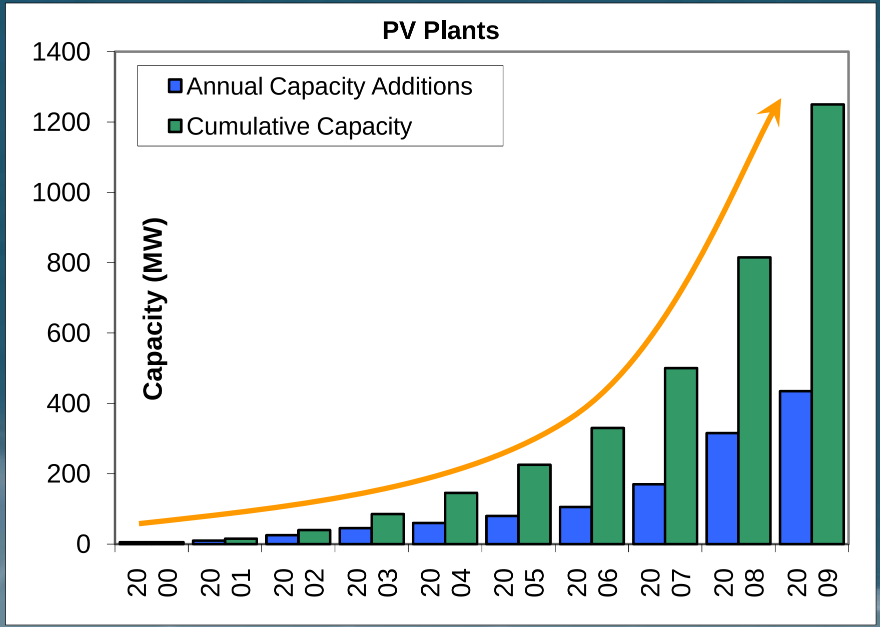
Outline

- Introduction
- Utility-scale PV power plant
  - Grounding
  - Reactive Power and Voltage Control
  - Low Voltage Ride-Through and System Stability
  - Short-Circuit Contributions
- Utility-scale CSP power plant

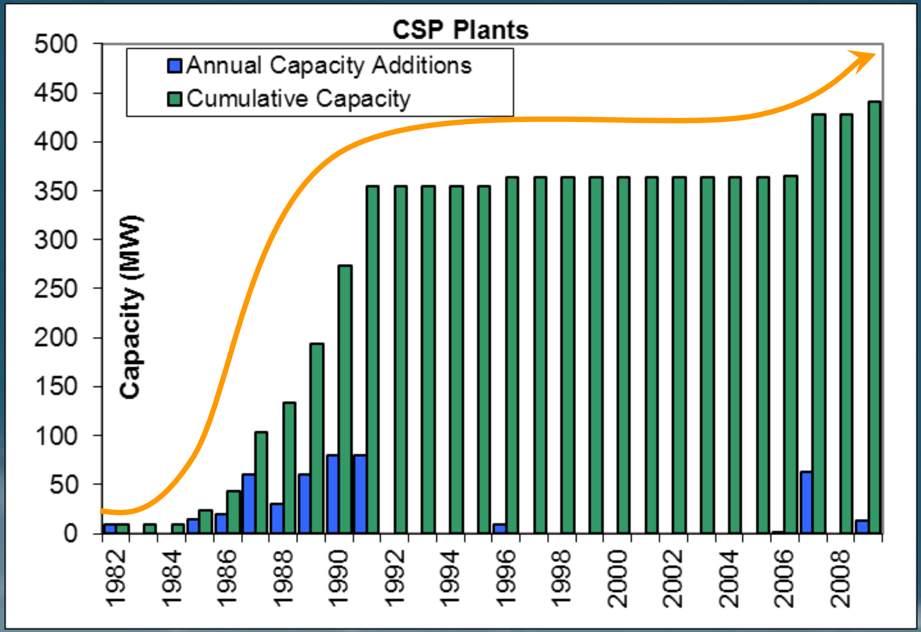
Introduction

- Solar Power Development in the US
  - Photovoltaic (PV) power plants
    - Steady growth in residential, commercial PV installations
    - Utility-scale installations emerging in 2008



Introduction

- Concentrating solar power (CSP) power plants
  - 9 CSP plants totaling 354 MW constructed from 1984 to 1990
  - 60 MW Solar One plant installed in Nevada in 2007
  - New CSP technology developments in 2010: dish Stirling systems



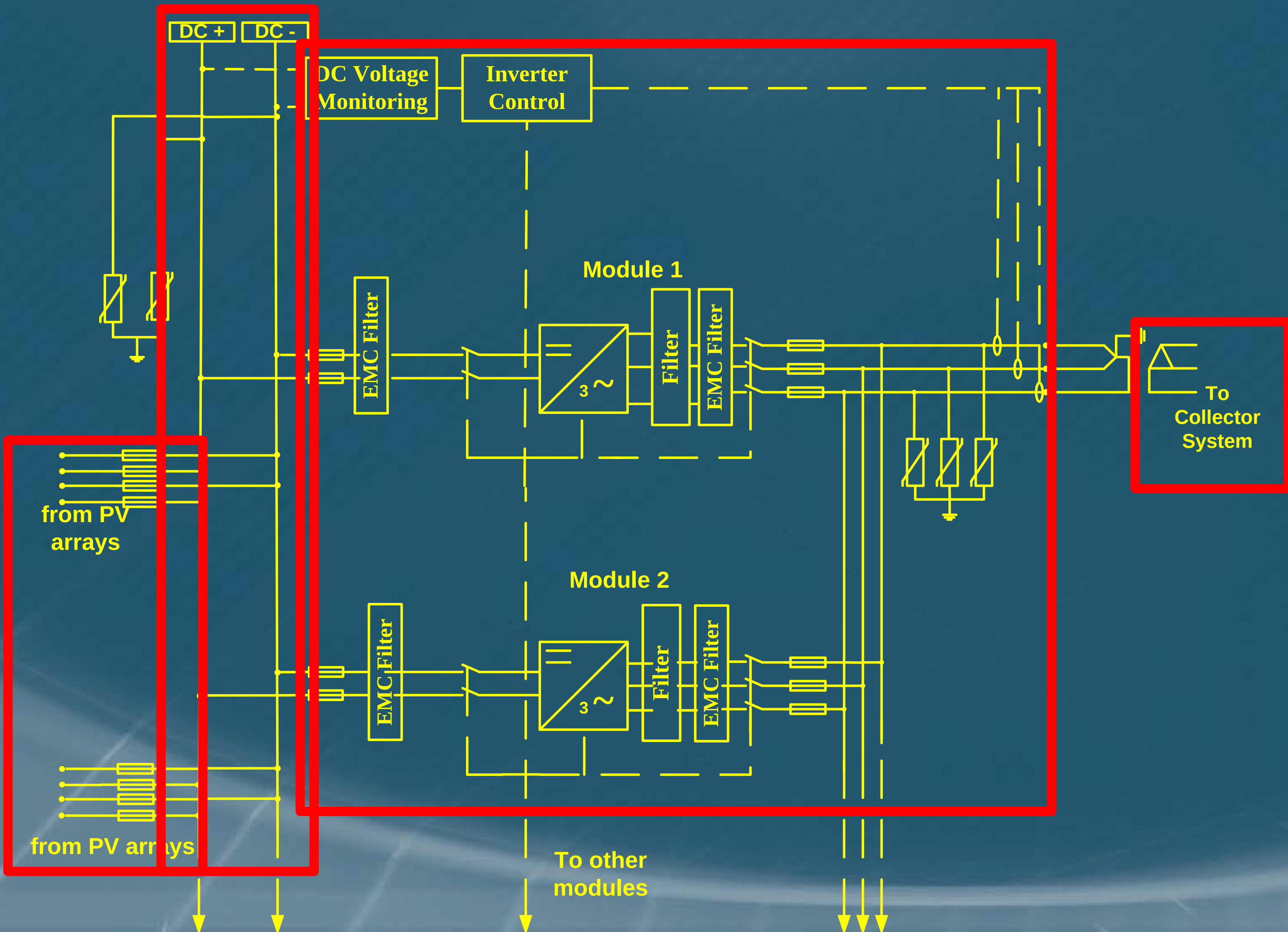
Introduction

- Most recent developments include large utility-scale PV plants
  - 80 MW Sarnia Plant in Ontario, Canada
  - 3 Large projects in CA just received conditional loan guarantees

Introduction

- Large utility-scale PV plant developments are driving changes in inverter design
- Distributed generation (DG) applications:
  - no reactive power capability for voltage control
  - fast disconnection from the utility system in the event of a disturbance
  - anti-islanding protection
- Rules for large transmission-connect plants require this performance and are leading to changes in PV plant design practices

Utility-Scale PV Power Plant Design



Utility-Scale PV Power Plant

- Design issues
  - Grounding
  - Reactive power and voltage control
  - Low voltage ride-through and system stability
  - Short-circuit contributions


Photo from the U.S. Department of Energy

Utility-Scale PV Power Plant

- Grounding
  - Grounding in LV system in accordance with the applicable articles of NEC
    - PV array grounding at a single point
    - Equipment grounding
  - Grounding on the MV system in accordance with applicable NEC and NESC requirements

Utility-Scale PV Power Plant

- Requirements for grounding transformers on the MV feeders dependent on inverter design
  - IEEE Std 1547/UL 1741 compliant inverters: no need for a grounding transformer or other means of feeder grounding once the feeder is isolated
  - Changes in inverter designs will require grounding transformer or other means of feeder grounding to limit temporary overvoltages on the feeder to within acceptable levels

Utility-Scale PV Power Plant

- Reactive power and voltage control
  - IEEE Std 1547/UL 1741 compliant inverters will typically not have reactive power capability & operate with a unity power factor
  - To meet transmission interconnection requirements for reactive power and voltage control, substation-based reactive power compensation systems (RCS) will typically be applied

Utility-Scale PV Power Plant

- RCS typically consist of a STATCOM with dynamic reactive power capability and switched capacitor and reactor banks

Utility-Scale PV Power Plant

- Low Voltage Ride-Through (LVRT) and System Stability
  - PV plants using inverters that are IEEE Std 1547/UL 1741 compliant do not have LVRT
  - Large penetration levels of PV plants using these types of inverters at distribution voltage level can affect the grid stability
  - New inverter designs with reactive power and LVRT capability and other “grid friendly” features are expected to be required in new plant designs

Utility-Scale PV Power Plant

- Short-Circuit Contributions
  - PV plants using inverters that are IEEE Std 1547/UL 1741 compliant contribute fault current for a few cycles
    - A fault on the line will typically trigger an “instantaneous AC undervoltage” trip of the inverter
    - Inverter gating will stop immediately, followed by the opening of the AC contactor after a few cycles
  - New inverter design expected to have short-circuit contribution limited by the inverter apparent power (kVA) rating and similar to that of a Type 4 (full converter) type wind turbine generator

Utility-Scale CSP Plant

- Utility-scale CSP power plants have been predominantly solar thermal plants using parabolic trough technology
- Since these plants use conventional synchronous generators with or without thermal energy storage
  - electrical characteristics of the plant does not differ appreciable from that of a conventional power plant
- Development of newer technologies in CSP plants, particularly dish Stirling systems, is creating new challenges in the design of the low- and medium-voltage collector systems for large solar power plants

Utility-Scale CSP Plant

- New dish Stirling systems use 10 to 25 kW solar concentrator in a dish structure
  - Mirrors collect and concentrate solar energy into a power conversion unit
  - Includes a reciprocating Stirling engine
  - The Sterling engine uses an internal working fluid, typically hydrogen or helium

Utility-Scale CSP Plant

- Stirling engine drives a squirrel-cage induction generator
- Multiple 10 to 25 kW units are connected at low voltage into groups & connected to a step-up transformer
- The thermal, electrical, and control systems of the dish-Stirling system, along with a method for simulation are presented in "Modeling of Dish-Stirling Solar Thermal Power Generation" by Dustin Howard and Ronald G. Harley, in Proc. 2010 IEEE Power & Energy Society General Meeting, Minneapols, Minnesota, USA, July 25-29, 2010

Utility-Scale CSP Plant

- Reactive power and voltage control requirements of new dish Stirling CSP plant: STATCOM and switched capacitors
- Induction generators and Stirling engines in dish Stirling systems have minimal rotational inertia
  - Need for additional internal speed control measures to avoid overspeeding during a grid fault
  - Speed-control measures allow the units to ride through up to a few seconds of grid or in-plant faults prior to eventual disconnection

Utility-Scale CSP Plant

- The induction generators in dish Stirling systems will respond similarly to small induction machines to contribute to faults
  - Peak fault current contribution will be approximately 5 to 6 per unit
  - Decaying to nominal current in less than 6 cycles

Utility-Scale CSP Plant

- Rapid power fluctuations in dish Stirling system plants will be mitigated by the thermal inertia of the Stirling engine
- The composite effect of a large number of units will also mitigate power ramp rates
- During plant start-up, a large number of units must be brought on-line in a relatively short time period to maximize plant productivity
  - Start-up sequences must be controlled to limit the power ramp rates to within specified limits