



PV System Models For System Planning and Interconnection Studies

Abraham Ellis

Sandia National Laboratories

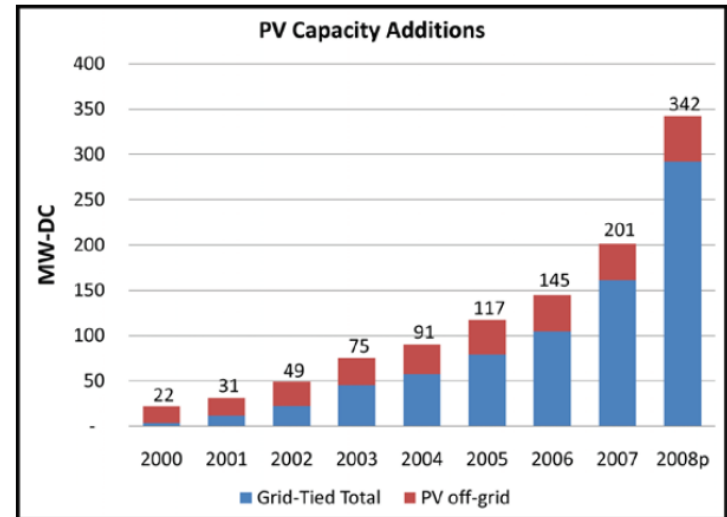
aellis@sandia.gov

Cedar Rapids, IA – October 2009



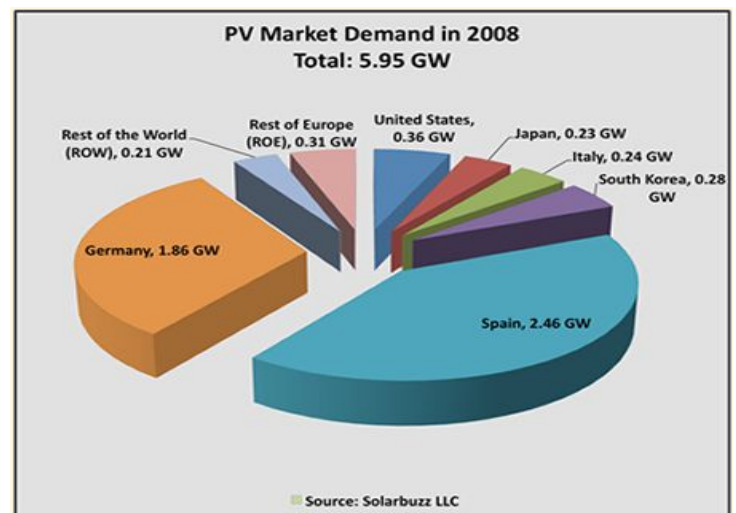
Growth in Grid-Tied PV Systems

- Grid-tied PV as of as of 2008
 - 791 MW total (most in CA)
 - ~1,500 MW “under development”
 - Tendency toward larger systems

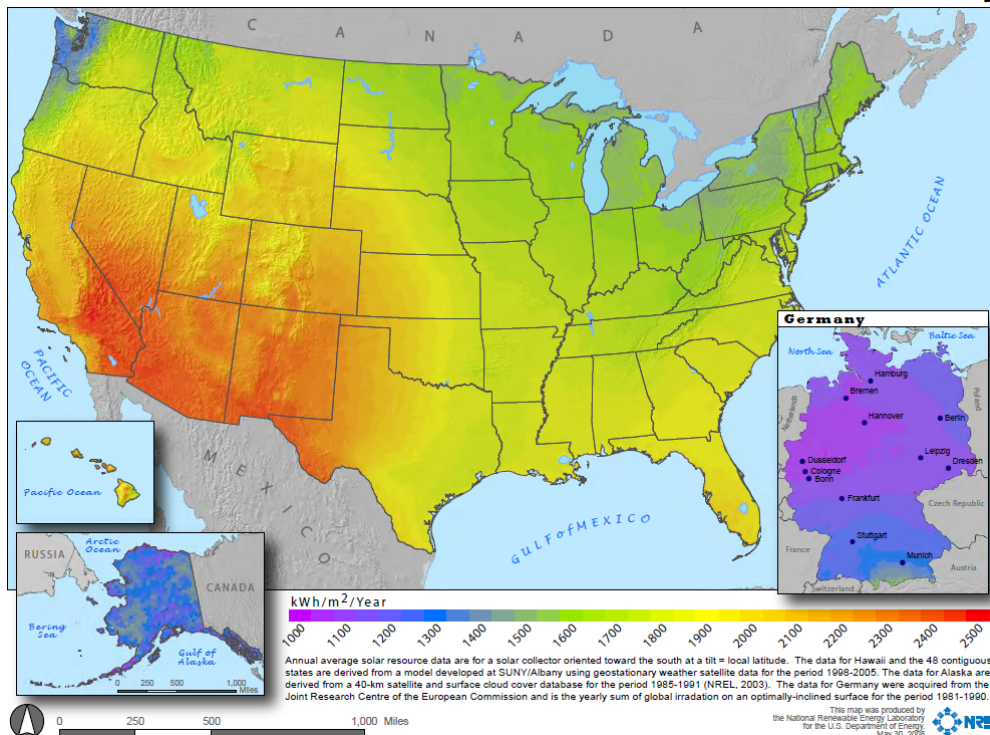


p = preliminary

Source: Larry Sherwood (IREC), SEIA



Source: Solarbuzz LLC





Utility Industry Modeling Needs

- The not-so-distant future

Proposed PV Capacity (MW) Based on LGIP Queue				
Utility	2010	2011	2012	2013
SCE	1350	2822	1540	2180
NV Energy South	469	776	484	980

- Reasonable concerns emerging
 - Within a few years, inverter-based PV generation will displace a non-trivial amount of conventional generation
 - Some areas likely to see higher penetration, larger projects
 - NERC reliability criteria are not likely to ease
 - How do we plan for it?



Utility Industry Modeling Needs

- Utility planners need models of these facilities to assess planning and operating impacts
 - Steady-state power flow (thermal, voltage)
 - Dynamic (transient stability)
 - Short circuit (interrupting capacity, system protection)
- With very few exceptions, utility simulation tools don't have standard-library models for PV systems
 - At best, project developers provide insufficiently validated, manufacturer-specific, proprietary, user-created models
 - Worse yet, modeling short cuts (e.g., load netting) are used without adequate technical basis



Utility Industry Modeling Needs

- NERC Intermittent and Variable Generation Task Force has identified the lack of industry-standard validated models as major barrier to renewable energy development

“Validated, generic, non-confidential, and public standard power flow and stability (positive-sequence) models for variable generation technologies are needed. Such models should be readily validated and publicly available to power utilities and all other industry stakeholders. Model parameters should be provided by variable generation manufacturers and a common model validation standard across all technologies should be adopted. The NERC Planning Committee should undertake a review of the appropriate Modeling, Data and Analysis (MOD) Standards to ensure high levels of variable generation can be simulated.”

*Source: NERC Special Report, Accommodating High Levels of Variable Generation,
http://www.nerc.com/files/IVGTF_Report_041609.pdf*



Type of Planning Models

Type	Main Application	Example of Commercial Platforms
Power flow, unbalanced	Power flow (static) simulation of distribution networks. Software also does motor start, protection coord., etc.	FeederALL, SynerGEE, EasyPower
Power flow, positive sequence	Large-scale power flow simulations of bulk transmission systems	PSS/E, PSLF, ETAP, Power World
Dynamic, positive sequence	Large-scale dynamic simulations of bulk transmission systems	PSS/E, PSLF, ETAP
Transient, three phase	Detailed analysis of power system electromagnetic/mechanical and control interaction and performance	PSCAD, Matlab, EMTP-RV
Short Circuit	Fault analysis protection coordination	Aspen, SynerGEE,



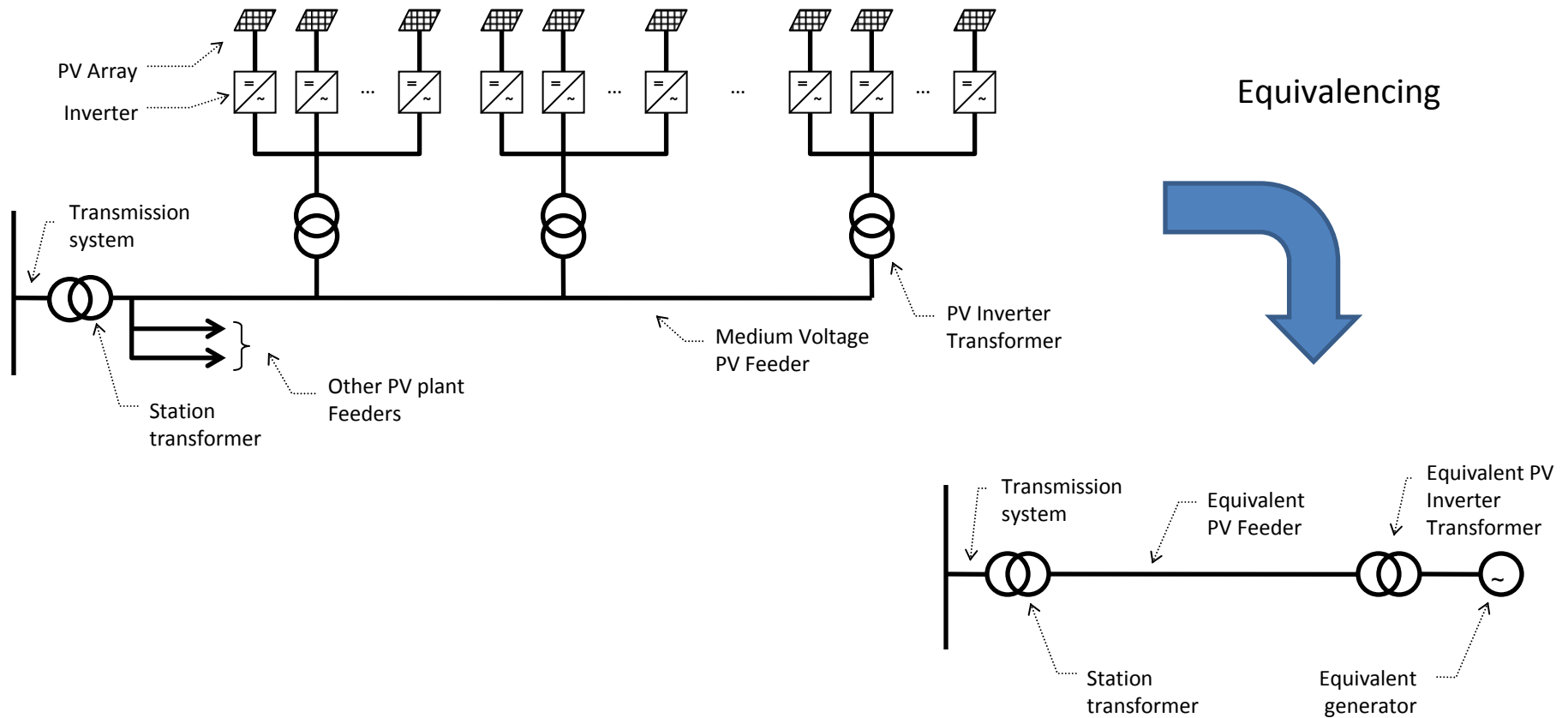
PV System Power Flow Models

- PV inverters may be modeled as conventional generators in the steady state
- Over and under excitation limits must be set with cognizance of inverter reactive capabilities and modes:
 - Constant power factor
 - Constant reactive power
 - Voltage regulation
- For large-scale simulations, power flow modeling data requirements must be reduced through “equivalencing”, similar to wind plants
 - Refer to existing WECC Wind Power Plant Power Flow Modeling Guide (www.wecc.biz)



PV System Power Flow Models

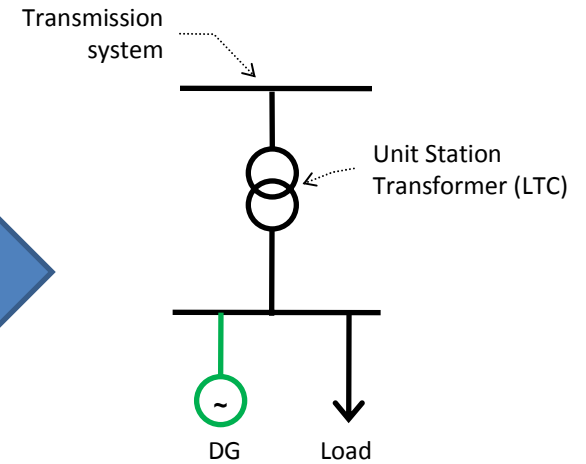
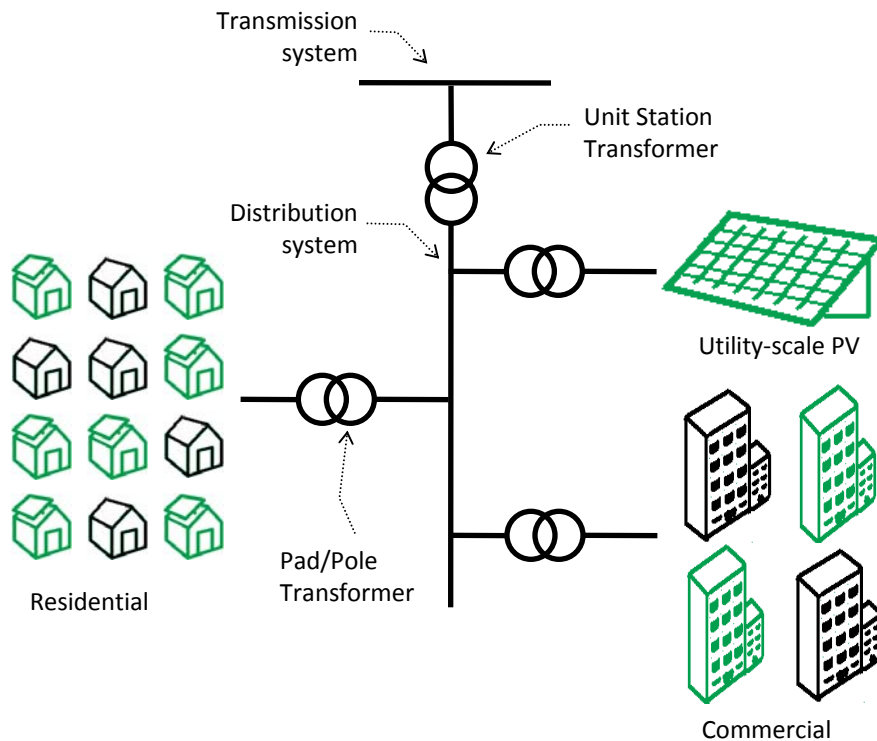
- For utility-scale PV





PV System Power Flow Models

- For distributed PV



Model feeder impedance for dynamics
(e.g., WECC Composite Load Model)



PV System Dynamic Models

- Vendor-specific, user-written models have a role, but don't meet critical needs
- Generic models have multiple advantages
 - Provide viable alternative to meet utility requirements
 - Allow interconnection studies to proceed before inverter and PV module manufacturers are selected
 - Reduce manufacturer confidentiality concerns with respect to proprietary aspects of user-created models
 - Provide improvements in:
 - Quality (thoroughly tested for compatibility with core software)
 - Portability (across different simulation platforms)
 - Usability (similar to familiar look and feel of conventional generator/turbine/exciter standard library models)



PV System Dynamic Models

- A user-friendly generic PV system dynamic model would:
 - Approximate the aggregate dynamic response of a large number of inverters at a common point of interconnection
 - Be suitable for simulating plant response of the plant to grid disturbances, typically 3-phase faults up to 200 ms in duration and ground faults up to one second in duration
 - Allow for simulation of the post transient response of the plant for periods of 20 to 30 seconds
 - Allow for simulation of the response of the plant to cloud-induced irradiance transients
 - Allow for simulation time steps as high as $\frac{1}{2}$ cycle (8.3 ms)
 - Provide for user-settable gains, time constants, and feature on/off switches (e.g., for voltage control, droop response, etc.) that would be specified by the manufacturers for their specific hardware
 - Validated against field data, higher order (EMTP-type) models, or both



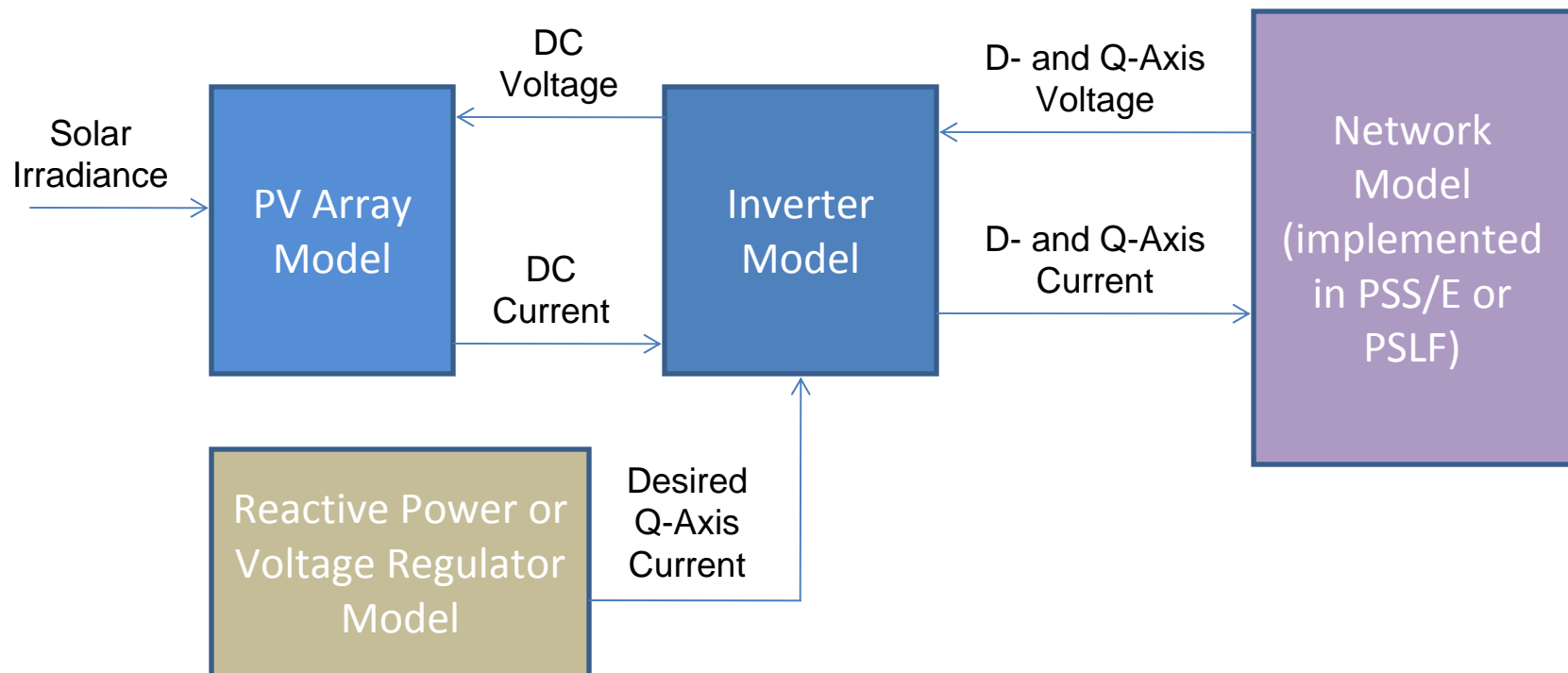
PV System Dynamic Models

- Generic models pose challenges that can be overcome
 - Evolving technology and performance standards
 - Models need to include existing as well as future capabilities
 - Grid codes activities can guide model development
 - Access to detailed technical information from manufacturers for model development and validation
- Timing is right
 - Numerous user-written models have been developed
 - Industry interest is very high
 - Have opportunity to build on technical work and industry connections laid out by WECC/IEEE generic wind generator modeling effort



A Potential Implementation

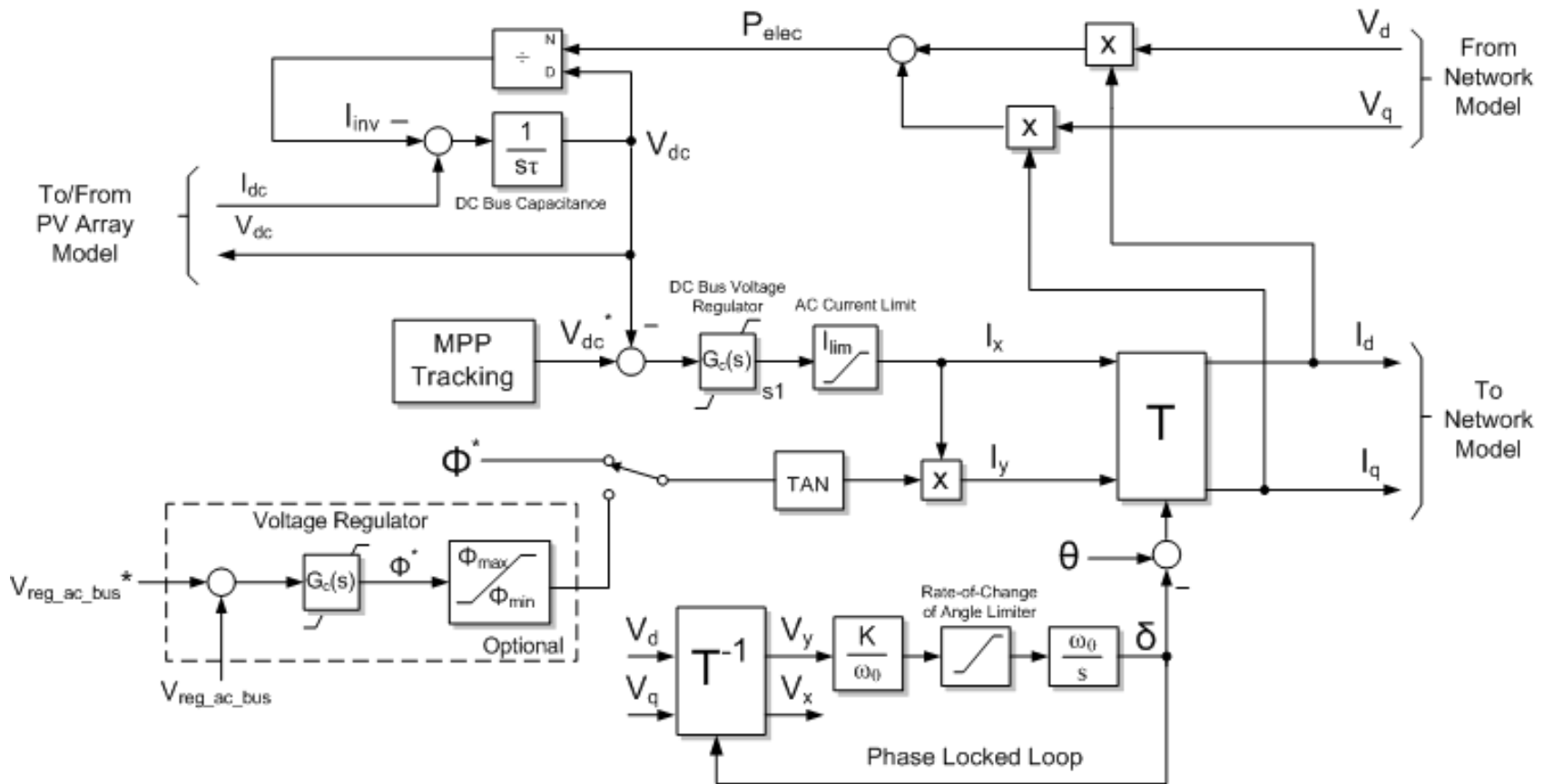
- Model connectivity





A Potential Implementation

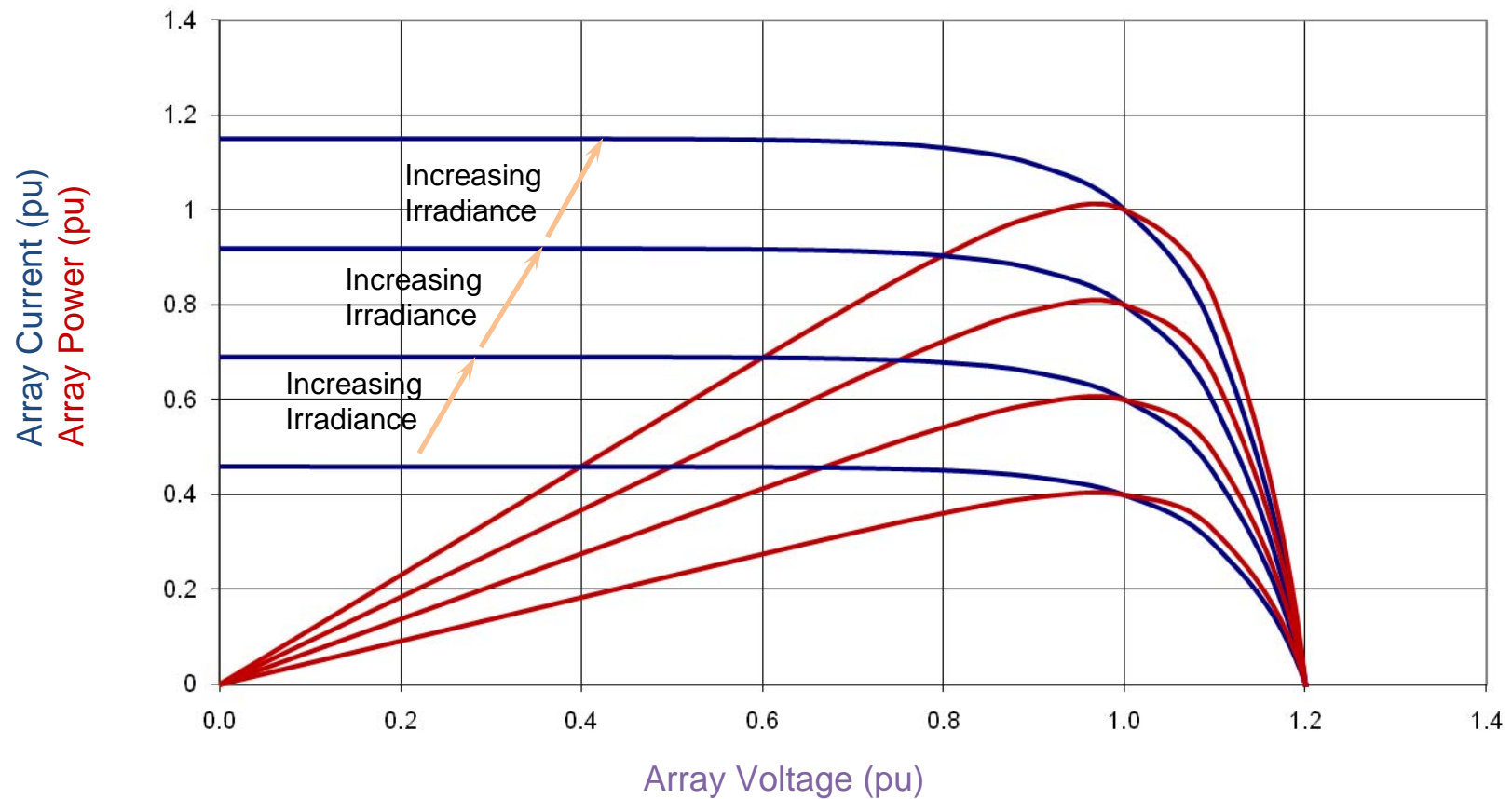
- Inverter model





A Potential Implementation

- PV array model





A Potential Implementation

- Basic Assumptions
 - PV array is voltage- and irradiance-dependent current source
 - Temperature impacts can be neglected in simulation frames of interest for transient stability
 - Current response to voltage or irradiance transient is instantaneous (algebraic)
 - Inverters are high-frequency, pulse-width-modulated, ac current-regulated, voltage-source type
 - With $\frac{1}{2}$ cycle time step, current regulator and modulator dynamics may be neglected... perhaps
 - Primary dynamics are due to inverter dc capacitor bank, dc voltage regulator and ac phase lock algorithms
 - Additional dynamics may be introduced to influence real and reactive power ramp rates



Activities Already Underway

- PV modeling initiative already started under the auspices of the WECC Modeling and Validation Work Group (MVWG)
 - Development, implementation & dissemination to be conducted openly
 - Similar in character to the generic wind modeling, also championed by WECC
- WECC group has broad industry representation
 - National Laboratories (Sandia coordinating effort)
 - Utilities
 - Equipment manufacturers
 - Project developers and systems integrators
 - Software developers
 - Consultants
- Initial focus is on positive-sequence power flow and dynamic models
- Models to be introduced to broader audience via technical coordination and outreach (WECC, NERC, IEEE)



Conclusions

- PV generation proposed and under development is becoming too large to ignore in the planning process
- The lack of access to user-friendly, validated models is a barrier to rapid deployment of PV
 - User written models have a role, but don't meet critical utility requirements
 - Need to make progress on standardized, validated PV system models for use in traditional transmission planning
- Generic models pose technical and institutional challenges that can be overcome
- Industry efforts already underway... Stay Tuned!



Questions and Discussion

