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PV Power System Testing, Monitoring and Certification

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Outline

- System Testing Concept
- MW Plant Performance Parameters
- Performance Ratio (PR) Monitoring
- Functional, Acceptance and Performance Testing
- System Test Standards
- Plant Quality Certification

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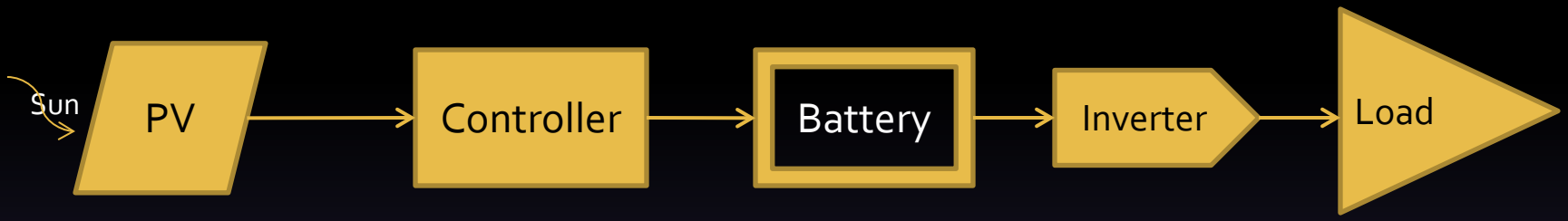
PV System Concept



- System Performance: How much energy is delivered to load at operating conditions compared to PV Energy produced at standard conditions?
- System performance depends on insolation, weather, PV modules, batteries, power conditioning components, load and their sizing/integration.
- System Testing , Certification and Warranty is paramount!

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PV System Monitoring

- Off-grid system: PV output, Battery input/output and Load output are tested.
- Monitor battery input Wh to full charge and output Wh to cutoff level and evaluate battery efficiency.
- Battery SOC needs to be monitored for given load current and battery temperature.
- Energy delivered to load can be compared to rated PV energy for one battery cycle to determine system efficiency

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PV System Optimization

- System performance depends on maximum utilization of PV.
- PV charge current needs to be optimized for given battery State of Charge (SOC) and load profile for improved system performance.
- Adaptive Control- Number of hours of load operation needs to be optimized for a given PSH.

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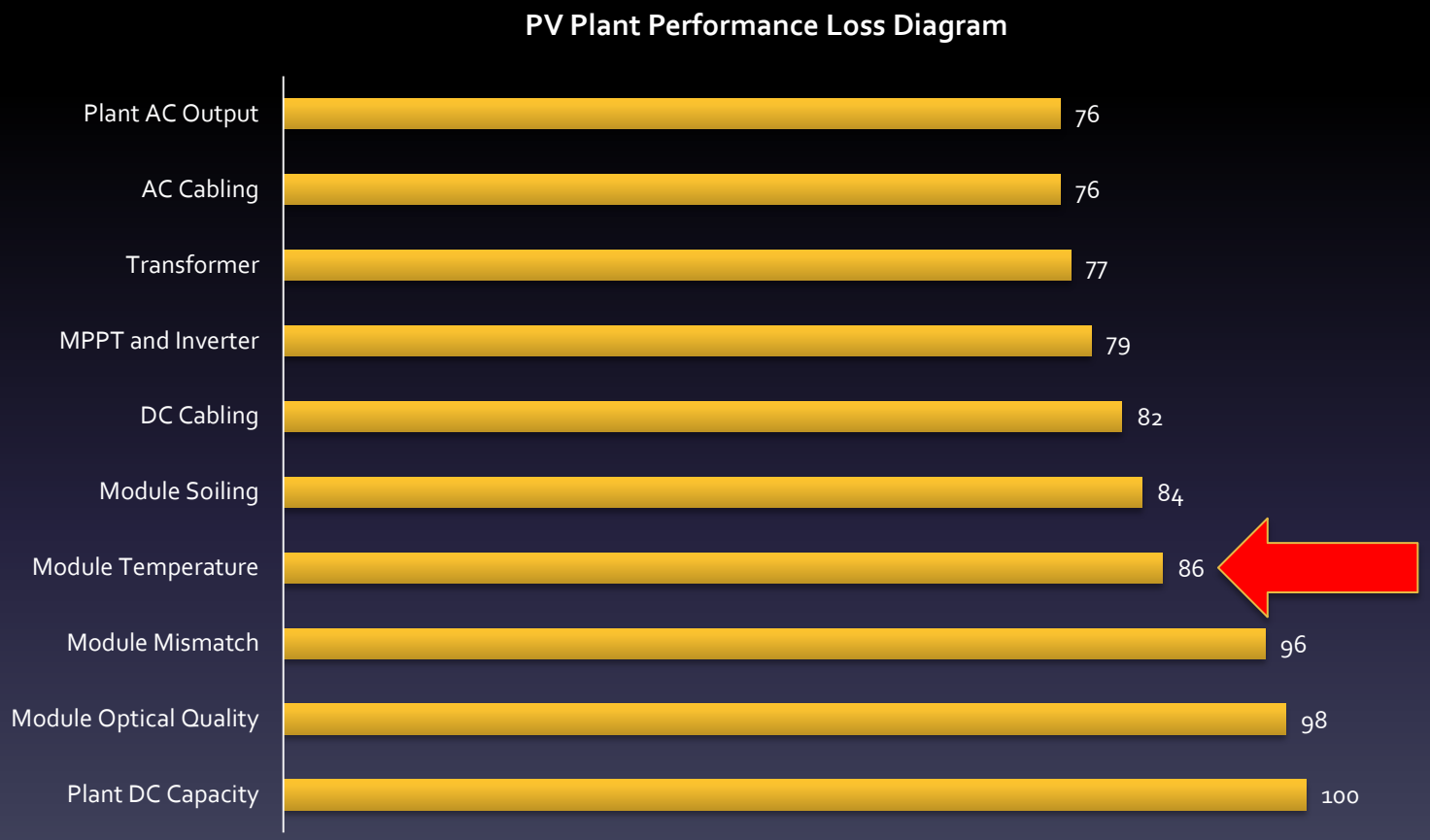
MW PV Plant Performance

- **Governing Factors-Solar Insolation, Weather, System Loss Factors, O&M, Module Degradation and Grid Conditions.**
- **Plant performance ratio (PR)**
  Measured Energy (kWh)/Modeled or Rated Energy (kWh)
- Modeled Energy = POA Irradiation (kWh/m²)*Active Area of PV Array (m²)*module efficiency = Rated Array kWp x POA PSH
- **Capacity utilization factor (CUF) or Plant Load Factor (PLF)**
  Measured Energy (kWh) / Potential Energy (kWh)
- Potential Energy = Installed Capacity (kWp) x (24 x 365) h
- Generation
  - **Dependent on PR, Solar radiation, module degradation and plant availability.**
  - Calibrated **POA global radiation** monitor to co-relate generation with incidence

System Loss Diagram



Performance Ratio

- Depends on sum total of system loss factors.
- Dependent on PV Technology (c-Si/TF):
  HOCT efficiency, Tempco, response to low/diffuse light etc.
- Dependent on MPPT and Inverter efficiency, DC and AC Cabling losses, Transformer efficiency etc.
- Independent of amount of Solar Insolation (first order).
- External factors-Quality of solar insolation, Angle of Incidence, Ambient temperature, Dust and other Weather parameters.
- Simulated, Design, Installed and operation PR.

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PR Monitoring

- Monitor sum total of DC input power to inveters and AC output power evacuated.
- Ratio of inverter DC input power to DC rated power of array is the DC PR of plant.
- Ratio of AC output power evacuated to inverter DC input power is the AC PR of plant.
- Daily, Weekly, Monthly and Yearly PR evaluation based on SCADA data.
- Irradiation sensor installed in no-shadow zone and cleaned on daily basis is a must for accurate PR evaluation.

Performance Monitoring Method

(IEA PVPS Task 5)

- AC system output under Performance Test Conditions (PTC).
- Parameters recorded over measurement period: Psys-AC system power output, Irr-POA insolation, Tamb, WS- wind speed
- $Psys = Irr*A + Irr^2*B + Irr*Tamb*C + Irr*WS*D$
- Regression analysis using measured data to determine coefficients A,B,C,D.
- Derived coefficients and PTC values used to calculate system power output

Standards based Performance Monitoring

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- IEC 61724 recommends procedures for the monitoring of energy-related PV system characteristics such as in-plane irradiance, array output, storage input and output and load voltage & current.
- Specified parameters that must be measured in real time by the data acquisition system.
- Other parameters that shall be calculated from the measured data.
- KPIs and Alarms-Tolerance of rated power, aging of modules, reflection losses, soiling, shadowing, thermal losses, wiring losses, inverter and transformer efficiencies, MPP tracking performance.

Weather corrected PR

- PR varies with cell temp, wind, insolation, incidence angle and spectrum.
- Monthly PR tested in winter is high and poor performing plant can pass PR test. Corrected PR test is valid in any season.
- When PR calculations are corrected for annual weather variations, corrected PR can be used to predict annual energy generation for the given system design and annual weather file.

Temp. Corrected PR Testing

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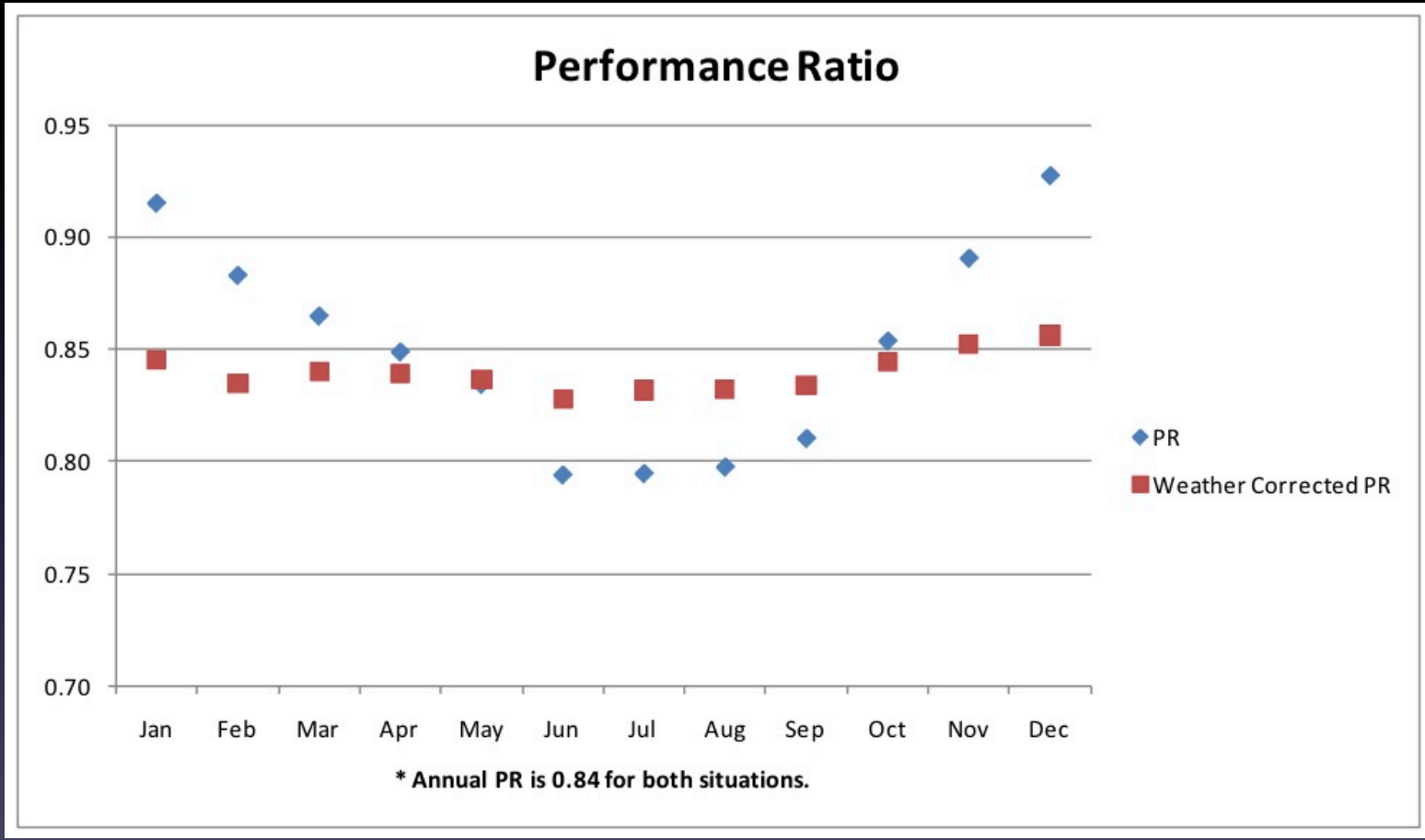
- Simple PR = AC kWh/[kWp*(POA PSH)], as per IEC 61724.
- Temp. Correction Factor (TC)
  = 1-Tc(Avg. cell temp-Operating cell temp)
- Corrected PR = AC kWh/[kWp*(POA PSH)*TC], as per NREL using Sandia model.
- Operating cell temp accounts for Amb. Temp, wind and heating due to insolation.
- Month to month Corrected PR differs from Simple PR
- Annual average Simple PR and Corrected PR are the same nos.

Simulated PR



Plant Performance Guarantee

- Annual energy generation is the product of POA insolation, kWp rating and average annual PR.
- Higher radiation implies more generation when PR guarantee is offered unlike generation guarantee.
- Higher PR also implies more generation for a given solar resource.
- Generation guarantee undermines plant performance.
- PR guarantee is more beneficial to customer than CUF or generation guarantee.
- As PR is both a function of system efficiency and weather, measure of PR is an insufficient metric for performance guarantee with precise confidence intervals.
- Weather Corrected PR is a better choice for contract guarantee.

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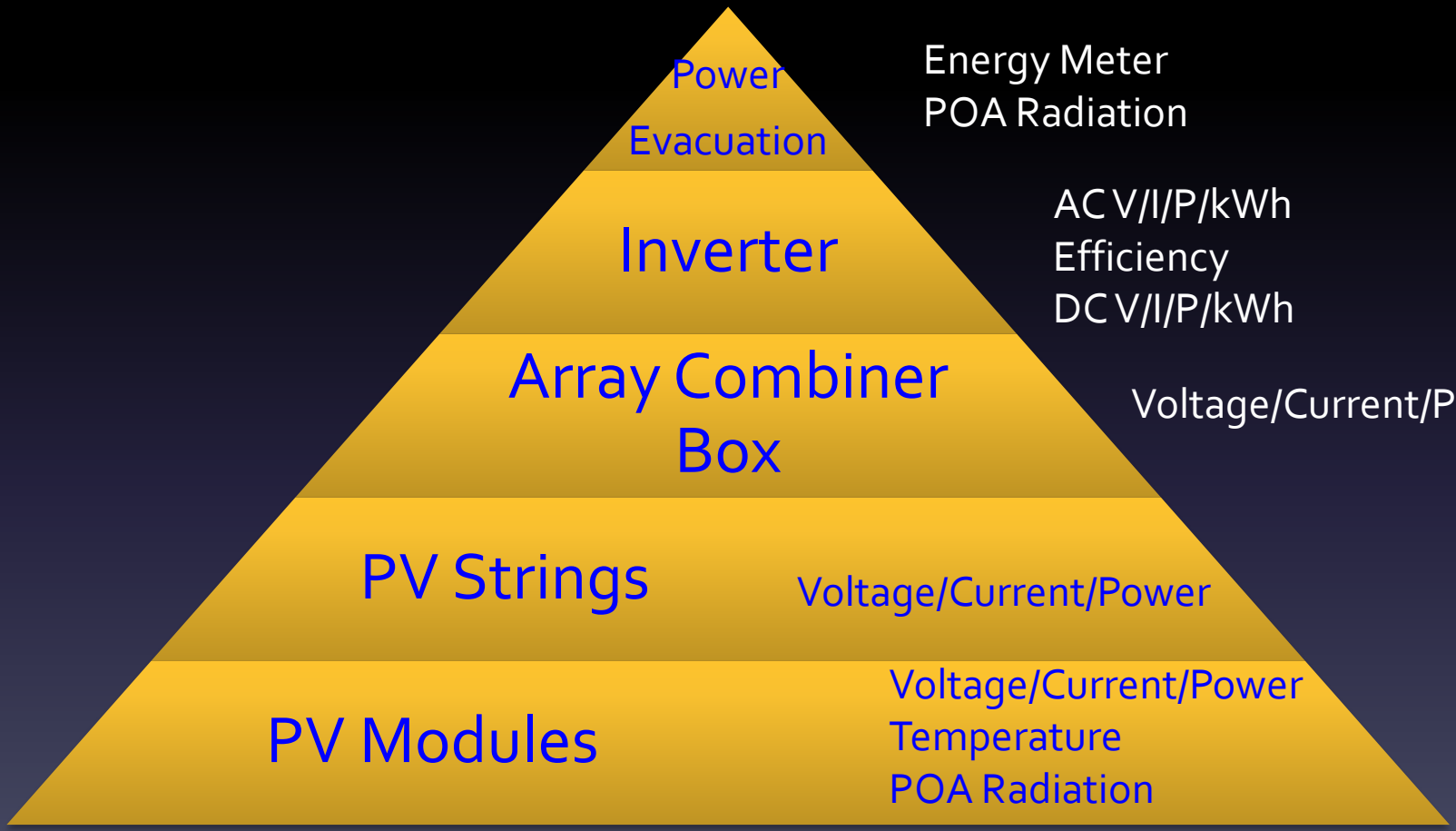
Plant Functional Tests



Plant Acceptance Tests

- Runtime Operational Tests-5 to 10 days
- **Capacity** tests to measure plant size-need reference irradiance and weather conditions.
- **Integrated PR** at Effective Temp. adjusted irradiance levels.
- **Weighted PR**: Temp. adjusted PR Tests within different irradiance bins.
- Sensitivity to Seasonality: Monthly tests to distinguish **seasonal effects and PR issues.**

Plant Performance Tests

- **Monthly/Quarterly/Annual Performance Ratio.**
- Seasonal Variation in PR.
- Year-to-year performance test to understand **plant degradation rates.**
- Performance normalized for irradiance and ambient temperature.
- Co-relate predicted and actual performance.
- **Compare plant performance between locations and technologies.**
- Demonstrate plant equipment and grid availability.
- **DC and AC PR Test to isolate Module/Inverter underperformance.**
- **Identify BoS and Power Evacuation Issues**

Stakeholders and Testing

- EPC requires a DC capacity test under a range of insolation conditions.
- Off-taker requires max. installed AC capacity tests.
- O&M Contractor requires long term energy tests.

Test and Monitoring Equipment

- Digital Insulation Tester
- Digital Earth Resistance Meter
- Digital Temp. Monitor
- Digital Clamp DC/AC Multi-meter
- Power Analyzer.
- **DC/AC Energy Meters**
- Tilt/Sun-path/Shading-Solmetric SunEye
- Radiation, **I/V**-Solmetric PV Analyzer/Daystar
- Ground continuity, insulation resistance, OC voltage, SC current , Operational test-Seaward PV Installation Test Kit PV100-meets IEC 62446 test requirements
- PV Module Fault Detectors-String Tracer & Cell Line Checker-Togami
- **Thermo-graphic Camera-Fluke**
- Plant SCADA
- Radiation and Weather Monitor

MW Plant Field Performance

Field Issues	Possible Solutions
Inter-table heights differ by few cms-shadows in morning and evening	Increase spacing between tables/Better alignment
Generation in best month (Feb) dropped in 1 year for similar POA radiation	Evaluate LID/PID effects
Array cleaning trigger @ 2% loss	Needs normalization for thermal loss
Weather station validated data not available	Pyranometer needs daily cleaning and yearly recalibration for valid data
Single axis tracker not calibrated and is misaligned	Needs frequent calibration checks and realignment
Inverter not feeding into 11kV grid for 0.5 hrs per day	Consider evacuation into >= 33kV grid
Strings grouped together and ungrouped before connecting to string inverters	Better cable management

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MNRE System Test Guidelines

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- PV Lighting System Specs
  - Individual component specs and certifications.
  - Dust to dawn operation @ 5.5 PSH is specified.
  - No system level tests (5 years system warranty) are specified.
- JNNSM phase 2 batch 2 guidelines: Test Specifications
  - Certifications required for PV modules, inverters and BoS components.
  - Remote monitoring of solar radiation, weather parameters, plant DC and AC power.
- System testing guidelines are required.
  - Co-relate power and energy output with solar radiation and weather.
  - DC and AC performance analysis.
  - System level design, installation and test standards.

System level Standards

- IEC 62548- Design (safety) requirements for photovoltaic (PV) arrays including d.c. array wiring, electrical protection devices, switching and earthing provisions. (off-grid and on-grid systems)
- IEC 62446: 2009 - Grid connected PV systems – minimum requirements for system documentation, commissioning tests, and inspection.
- IEC 61724 - Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis.
- IEC 62124- PV standalone systems design verification- Check functionality, autonomy and ability to recover after periods of low state of charge of the battery.

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PV GAP and Certification

- PV Global Acceptance Program (GAP)-1998.
- PV Quality Mark for PV components and PV Quality Seal for systems.
- IEC International Standards for safety, quality and performance.
- Aging and impact resistance, endurance, and energy efficiency testing ensures long term reliability.
- New Owners- IECEE (CB-FCS Program) and Electrosuisse in Switzerland.
- EPIA/SEIA award PV GAP mark/seal based on VDE Certifications.

VDE Quality Mark for PV plants

- Verification of system design, planning and engineering
- Proofing of selected system components
- Checking of installation work package planning
- Verification of documentation in construction phase
- Lab testing of module performance based on rep samples-Max. power, EL, temperature and irradiance dependance
- Extensive on-site inspection-safety and functionality, PV generator power output, PV array thermography
- PR and yield calculation based on lab tests

First Quality Test Certified PV Plant

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- First Solar 50MW AC Macho Springs, New Mexico Plant.
- VDE and Fraunhofer ISE QT certified.
- Not only IEC certification of components.
- 300 test points in four areas-electrical and mechanical safety, system performance, operation and independent verification of investors.
- Field and Lab. testing
- Quality and Reliability assurance.
- System level risk reduction and technical bankability.

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Conclusion

- System level testing and monitoring is vital for both off-grid and on-grid systems.
- System performance evaluation and optimization is key to long term success.
- Weather corrected performance ratio can be used to provide contract guarantee.
- Plant functional, acceptance and performance tests are required in various stages for system level certification.
- System level IEC standards is a first step to PV GAP certification.

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References

- Weather corrected PR-NREL/TP-5200-57991, April 2013.
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- Complete PV plant certification for technical bankability-VDE Institute and Fraunhofer ISE

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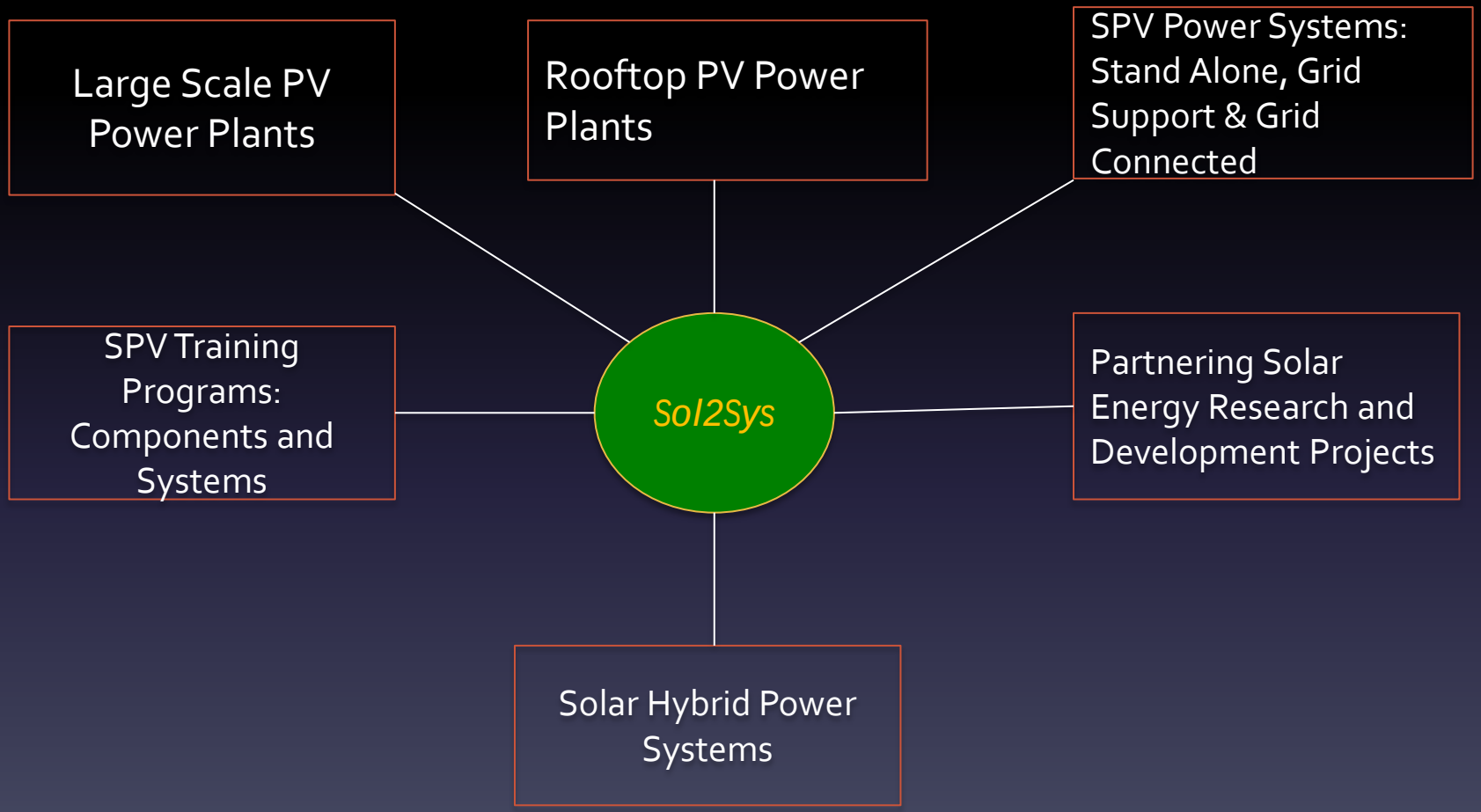
What We Do?



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Services We Offer

- Feasibility Study
- Solar Potential Estimation
- Technology Selection
- Systems Design
- Systems Integration
- Detailed Engineering
- Component Selection
- Due Diligence in EPC
- Oversight in O&M
- Testing and Monitoring
- Performance Evaluation and Improvement
- Training and Documentation

Thank You!