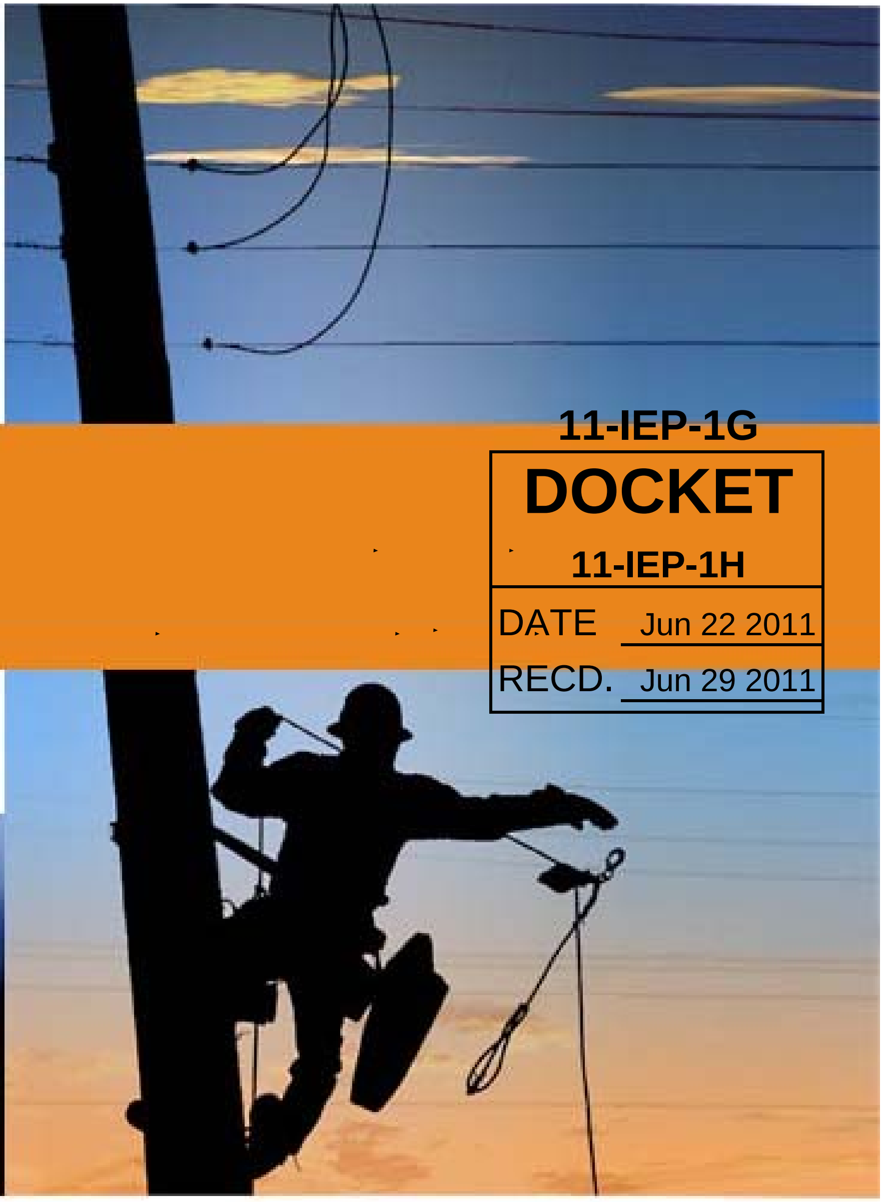

IEPR Committee Workshop
Sacramento, California
June 22, 2011

- **Operational Concerns (PV Power Variability)**
  - Monitoring and ensuring resource adequacy
  - Frequency regulation
  - Voltage regulation
  - Impact is highly location dependent (urban vs rural)
  - O&M impacts
- **Engineering / Planning**
  - Capacity planning (size, location, time, guaranteed production)
  - Volt/ VAr planning
  - Conservation Voltage Reduction impacts
  - Electrical models
  - Transient analysis tools
- **Regulatory**
  - Rule 21
  - Rule 2
  - Cost causation

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- **Voltage**
  - Overvoltage
  - Voltage fluctuations
  - LTC/regulator/cap bank impact
  - Unbalance
- **Protection**
  - Unintentional islanding “potential”
    - Load mismatch
    - Interconnect transformer connection
  - load rejection overvoltage
  - Reverse power (directional relaying)
  - Voltage events
  - Frequency events
- **Operational**
  - Intermittency/Variability
  - Observability/ Monitoring
  - Forecasting PV levels
  - Off Peak production
- **Demand/Energy**
  - PV impact on peak demand/load growth
  - Annual losses
  - Annual energy consumption
  - Impact on CVR
- **Thermal overloads**
- **Power Quality**
  - Harmonics
  - Flicker
  - CEBMA Violations
- **Utility Safety Practices**
  - Lineman practices
  - Hotline/deadline work
  - Improved mapping and tracking of PV to ensure safety

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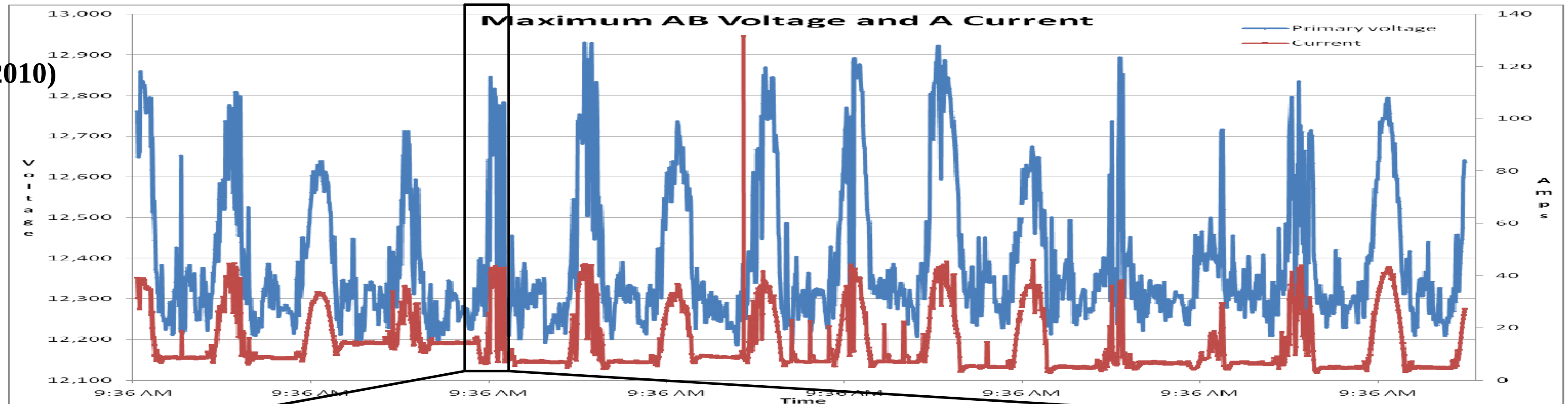
3

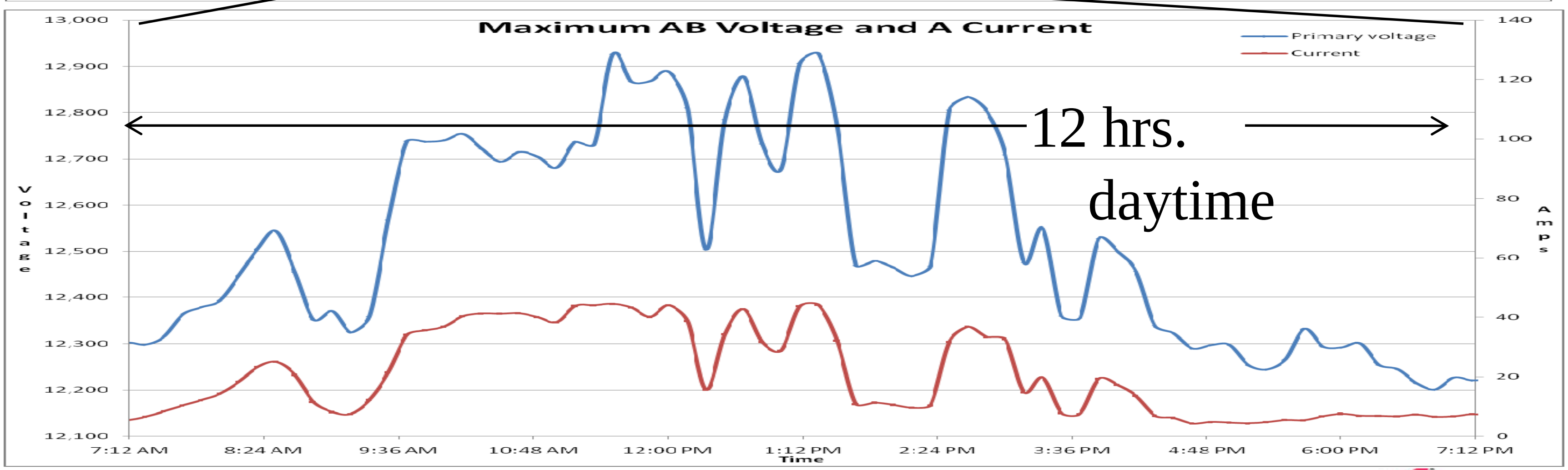
- Technical Studies simulating high levels of distributed generation
  - EPRI High PV Penetration Study –
    - Evaluates increasingly high levels of PV Penetration
    - Includes monitoring of PV generation along actual distribution circuits and simulation of actual intermittency
    - Models customer load and generation for all hours of the year
    - Includes evaluation and optimization of energy storage to mitigate impacts of high PV concentration
    - Evaluate benefits of using Smart Inverters for PV
  - Quanta Technologies Study – Evaluates Transient and Dynamic Impacts of distributed generation (high PV concentrations)
    - PSCADD – Detailed modeling of inverters
  - High PV Penetration study with DOE and UCSD
    - Simulates SDG&E distribution circuits
    - Conducted by EDSA

ntermittency xample –

Daily PV Generation (2/23 – 3/10,2010)



Variability within a typical day (2/28/10)



Each data point recorded at 10 min intervals

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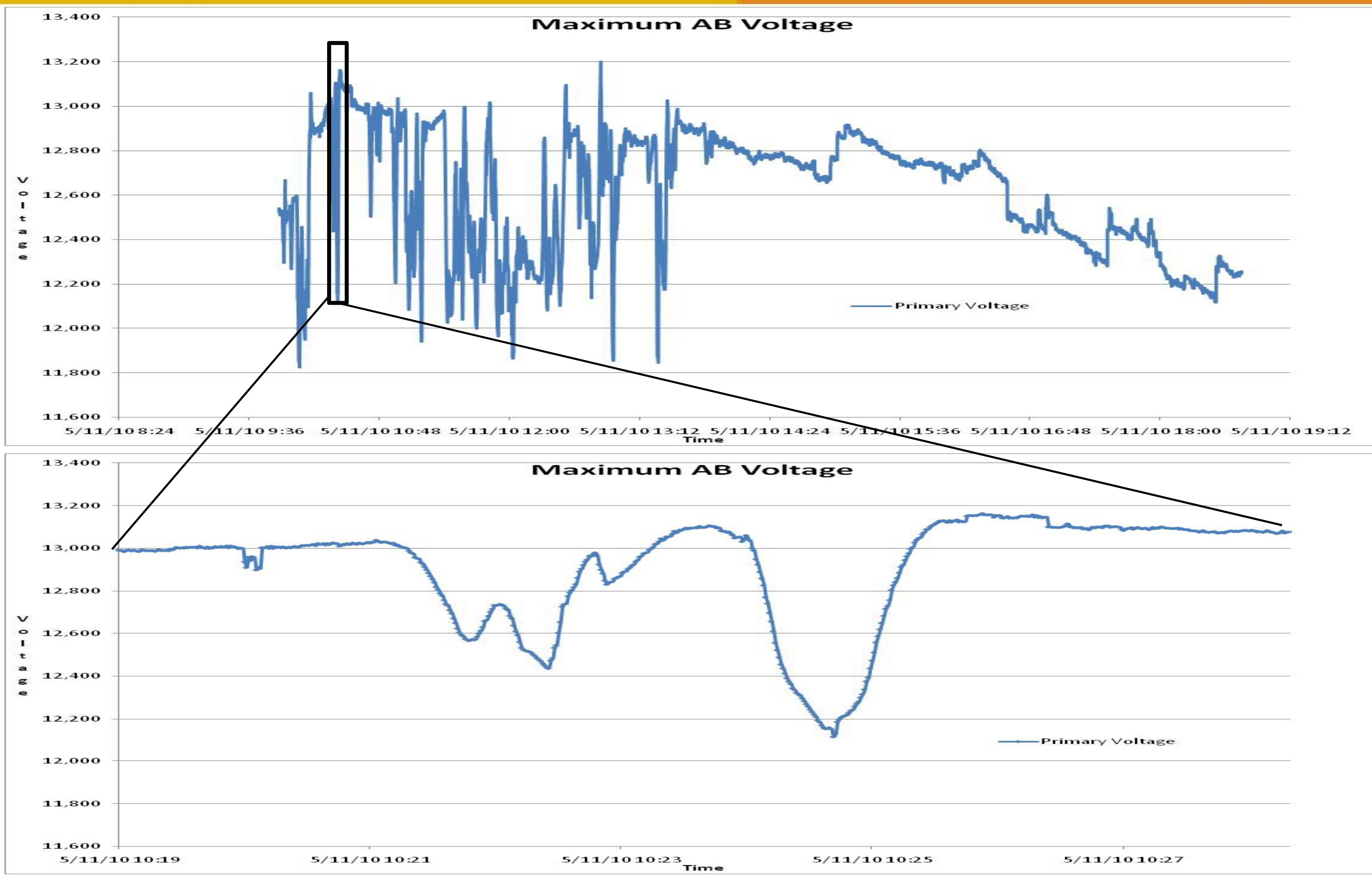

Maximum AB Voltage
Voltage
13,400
13,200
13,000
12,800
12,600
12,400
12,200
12,000
11,800
11,600
5/11/10 8:24
5/11/10 9:36
5/11/10 10:48
5/11/10 12:00
5/11/10 13:12
5/11/10 14:24
5/11/10 15:36
5/11/10 16:48
5/11/10 18:00
5/11/10 19:12
Time
Primary Voltage
Maximum AB Voltage
Voltage
13,400
13,200
13,000
12,800
12,600
12,400
12,200
12,000
11,800
11,600
5/11/10 10:19
5/11/10 10:21
5/11/10 10:23
5/11/10 10:25
5/11/10 10:27
Time
Primary Voltage

SDG&E Rule 21

Table D-1: Voltage Trip Settings

Voltage at Point of Common Coupling		Maximum Trip Time *[1]*	
Assuming 120 V Base	% of Nominal Voltage	# of Cycles (Assuming 60 Hz Nominal)	Seconds
Less than 60 Volts	Less than 50%	10 Cycles	0.16 Seconds
Greater than or equal to 60 Volts but less than 106 Volts	Greater than or equal to 50% but less than 88%	120 Cycles	2 Seconds
Greater than or equal to 106 Volts but less than or equal to 132 Volts	Greater than or equal to 88% but less than or equal to 110%	Normal Operation	
Greater than 132 Volts but less than or equal to 144 Volts	Greater than 110% but less than or equal to 120%	60 Cycles	1 Second
Greater than 144 Volts	Greater than 120%	10 Cycles	0.16 Seconds

[1] "Maximum Trip Time" refers to the time between the onset of the abnormal condition and the Generating Facility ceasing to energize SDG&E's Distribution System. Protective Function sensing equipment and circuits may remain connected to SDG&E's Distribution System to allow sensing of electrical conditions for use by the "reconnect" feature. The purpose of the allowed time delay is to allow a Generating Facility to "ride through" short-term disturbances to avoid nuisance tripping. Set points shall not be user adjustable (though they may be field adjustable by qualified personnel). For Generating Facilities with a Gross Nameplate Rating greater than of 30 kVA, set points shall be field adjustable and different voltage set points and trip times from those in Table D.1 may be negotiated with SDG&E.

(Continued)

SDG&E Rule 21

http://www.sdge.com/tm2/pdf/ELEC_ELEC-RULES_ERULE21.pdf - Microsoft Internet Explorer provided by Sempra Energy

INTERCONNECTION STANDARDS FOR NON-UTILITY OWNED GENERATION

D. GENERATING FACILITY DESIGN AND OPERATING REQUIREMENTS (Continued)

2. Prevention of Interference (Continued)

Table D.2: Frequency Trip Settings

Generating Facility Rating	Frequency Range (Assuming 60Hz Nominal)	Maximum Trip Time *[1]* (Assuming 60 Cycles per Second)
Less or equal to 30kW	Less than 59.3 Hz	10 Cycles
	Greater than 60.5 Hz	10 Cycles
Greater than 30kW	Less than 57 Hz	10 Cycles
	Less than an adjustable value between 59.8 Hz and 57 Hz but greater than 57 Hz *[2]*	Adjustable between 10 and 18,000 Cycles. *[2, 3]*
	Greater than 60.5 Hz	10 Cycles

[1} – "Maximum Trip Time" refers to the time between the onset of the abnormal condition and the Generating Facility ceasing to energize SDG&E's Distribution System. Protective Function sensing equipment and circuits may remain connected to SDG&E's Distribution System to allow sensing of electrical conditions for use by the "reconnect" feature. The purpose of the allowed time delay is to allow a Generating Facility to "ride through" short-term disturbances to avoid nuisance tripping. Set points shall not be user adjustable (though they may be field adjustable by qualified personnel). For Generating Facilities with a Gross Nameplate Rating greater than 30 kVA, set points shall be field adjustable and different voltage set points and trip times from those in Table D.2 may be negotiated with SDG&E.

[2} – Unless otherwise required by SDG&E, a trip frequency of 59.3 Hz and a maximum trip time of 10 cycles shall be used.

[3} –When a 10 cycle Maximum trip time is used, a second under frequency trip setting is not required.

- 3 phase, large capacity, large conductor primary voltage
  - 300-500 kVA service transformer
  - Large secondary network
- Obliged to provide a technically appropriate PCC for PV connection
  - 25% of cost on UDC
- Not measuring granular voltage and current data
- Voltage regulation issues on secondary network
  - Low load, high PV output
  - Solution network upgrades
- German Grid Code
  - Require PV systems to support the grid
  - Minimize network upgrade costs

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- German Grid Code
  - Minimize network upgrade costs
  - Dynamic grid support
    - Stay connected during faults
    - Support voltage by providing reactive power during faults
    - Consume same or less reactive power after faults
  - Active power control
    - Modify power output in response to frequency
  - Reactive power control
    - Adjust reactive power throughout the power factor range

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German Grid Code – Low Voltage Ride Through

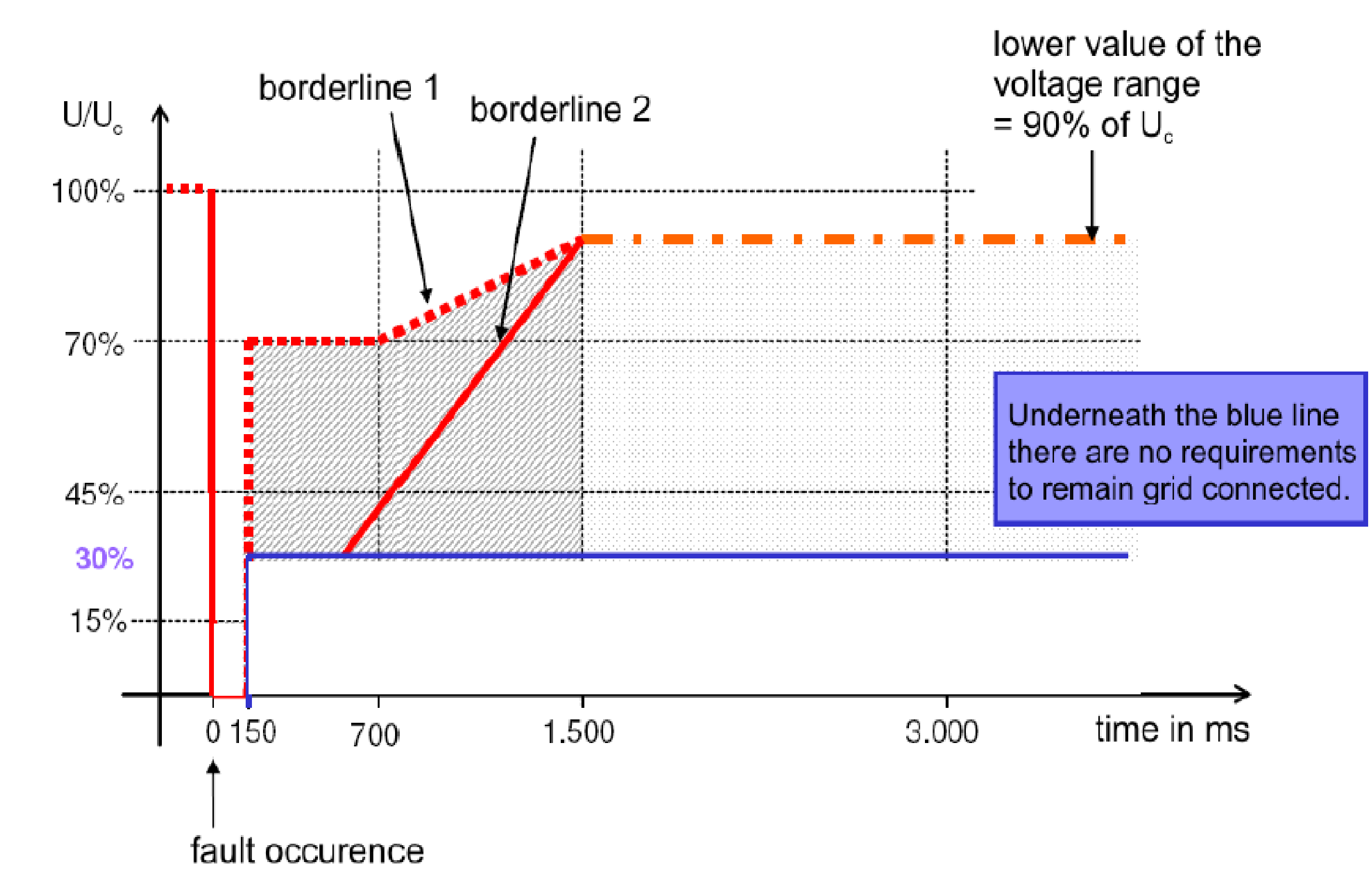


Fig. 1. Limiting curves of voltage at the grid connection point for a generating facility of type 2 in the event of a network fault [1]

E. Troester, "New German Grid Codes for Connecting PV Systems to the Medium Voltage Power Grid", 2nd International Workshop on Concentration Photovoltaic Power Plants: Optical Design, Production, Grid Connection

German Grid Code – Dynamic Grid Support

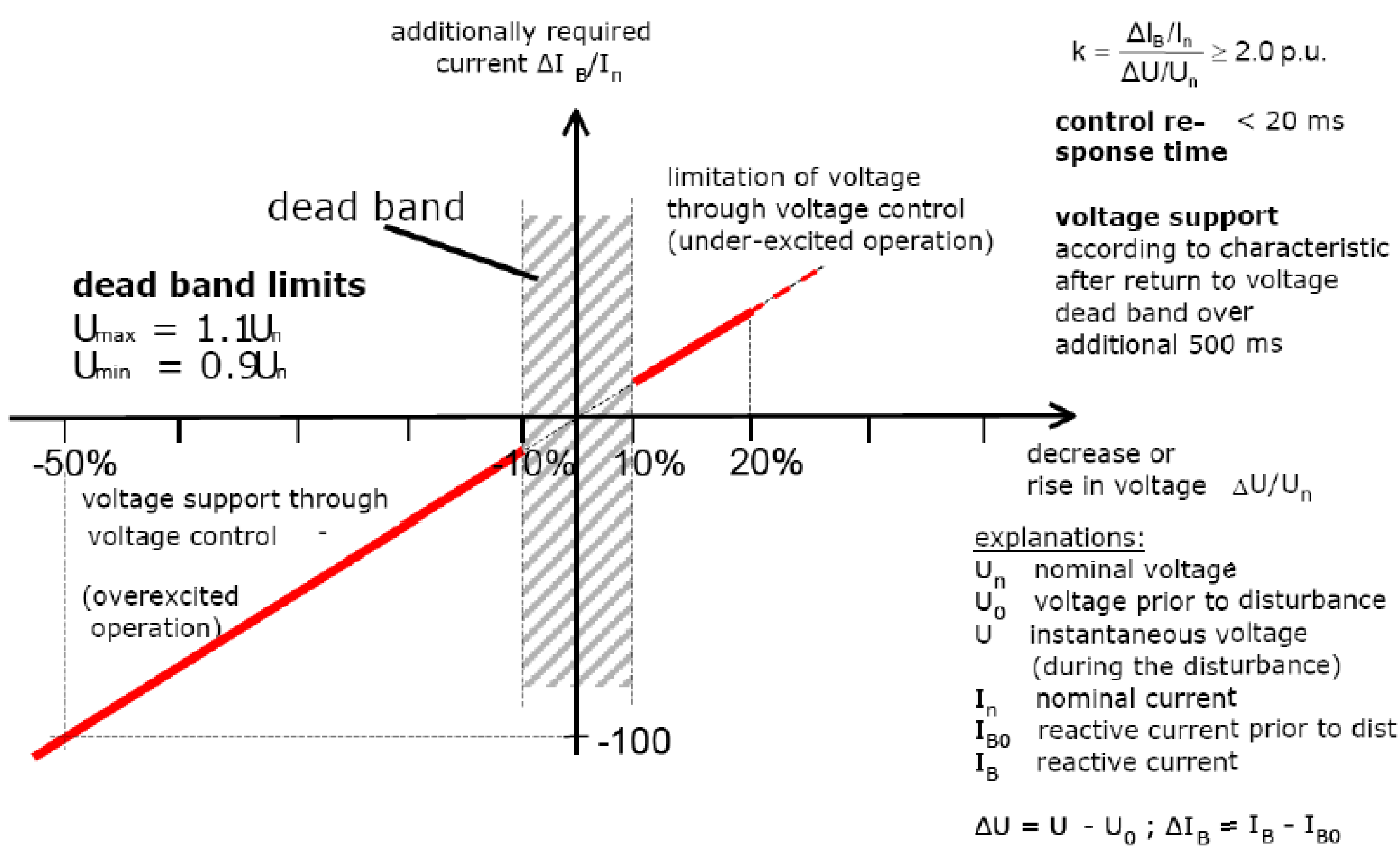
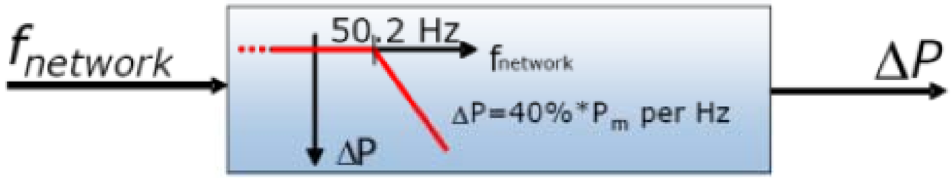


Fig. 2. Principle of voltage support in the event of network faults [2]

E. Troester, "New German Grid Codes for Connecting PV Systems to the Medium Voltage Power Grid", 2nd International Workshop on Concentration Photovoltaic Power Plants: Optical Design, Production, Grid Connection

German Grid Code– Active Power Support



$$\Delta P = 20\, P_m \frac{50.2\,Hz - f_{network}}{50\,Hz} \quad \text{at } 50.2\text{ Hz} < f_{network} < 51.5\text{ Hz}$$

P_m instantaneously available power

ΔP power reduction

$f_{network}$ network frequency

within the range of	47.5 Hz	<	$f_{network} \leq$	50.2 Hz		no limitation
at	$f_{network} \leq$ 47.5 Hz	and	$f_{network} \geq$	51.5 Hz		disconnection from the grid

Fig. 3. Active power reduction of generating units in the case of overfrequency [2]

E. Troester, "New German Grid Codes for Connecting PV Systems to the Medium Voltage Power Grid", 2nd International Workshop on Concentration Photovoltaic Power Plants: Optical Design, Production, Grid Connection

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German Grid Code – Reactive Power Support

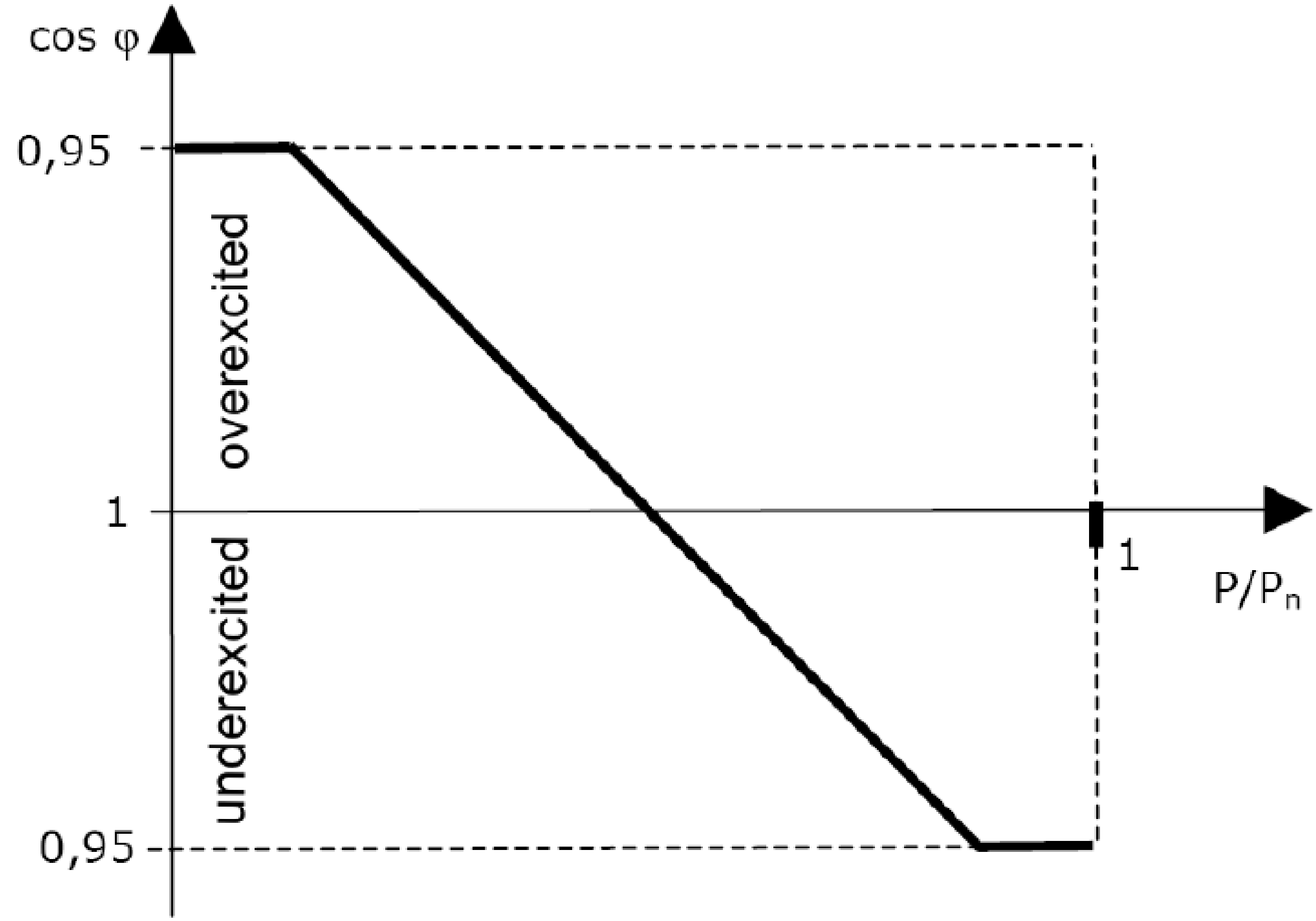
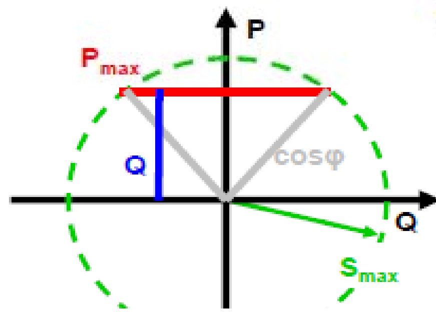


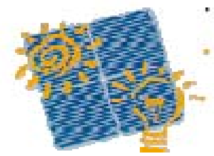
Fig. 4. Example of a cos φ (P)-characteristic [1]

E. Troester, "New German Grid Codes for Connecting PV Systems to the Medium Voltage Power Grid", 2nd International Workshop on Concentration Photovoltaic Power Plants: Optical Design, Production, Grid Connection

German Reactive Supply Approaches

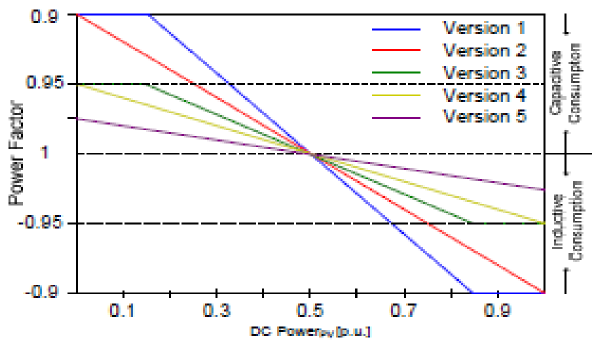
Reactive Power Supply Approaches

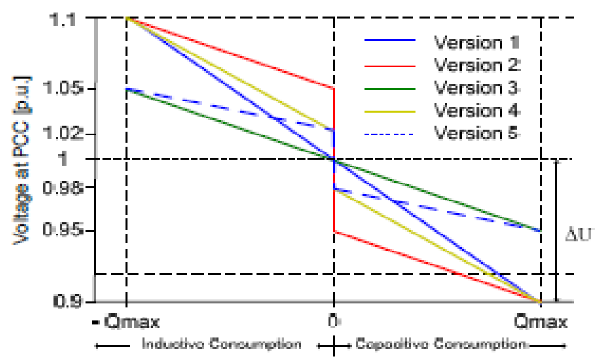




- fixed Q method
- fixed cosφ method
- cosφ(P) characteristic
- Q(U) droop function

	V 1	V 2	V 3	V 4
Fixed Cosφ	- 0.9	-0.95	-0.97	-0.98
Fixed Q [kvar]	- 2.24	- 1.64	- 1.25	- 1.02





- Central optimisation by distribution system operator → set values to PV

Source: T. Stetz (IWES)

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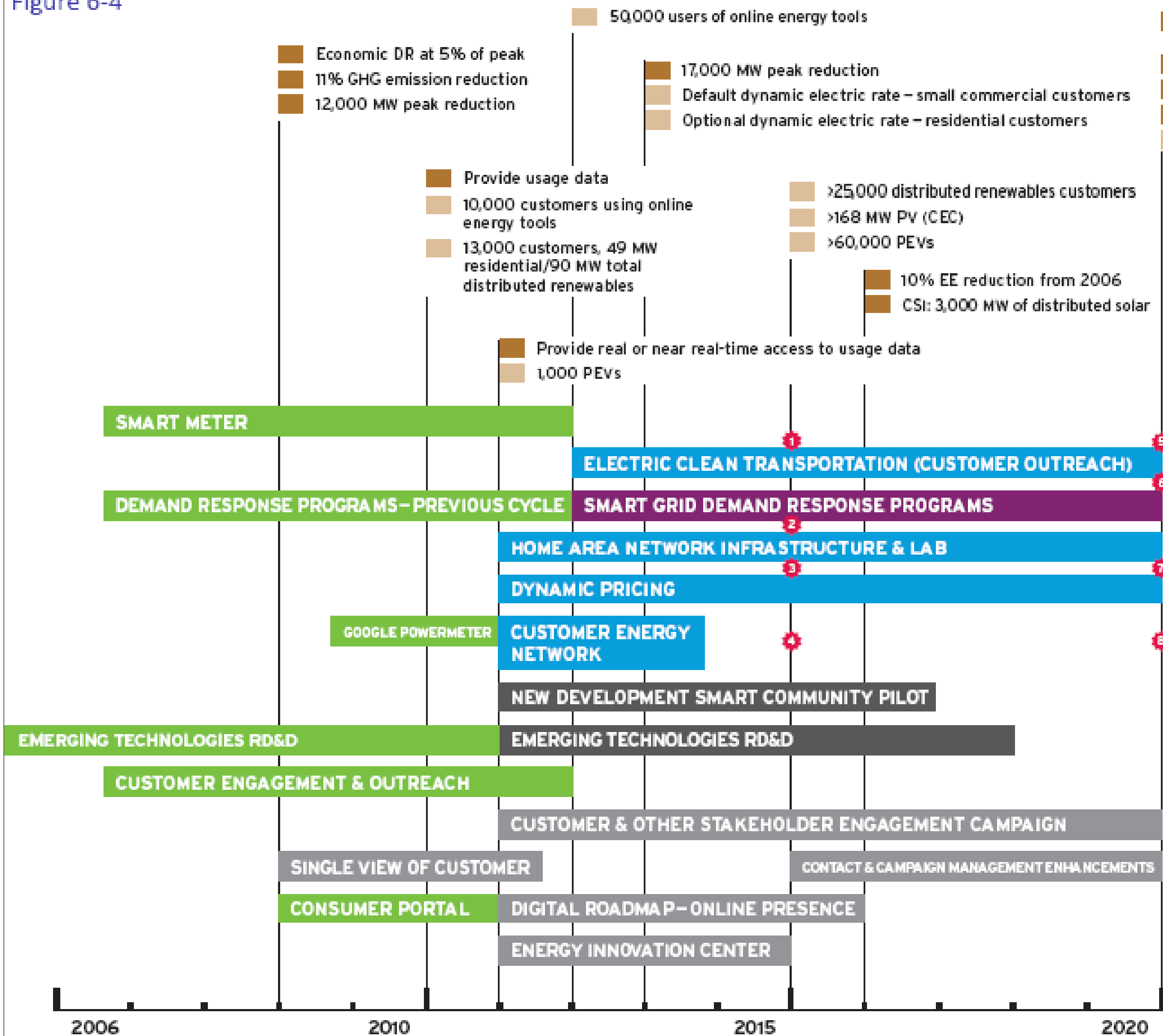
1 2 3 4 5 6 7 8 9 **2011 Smart Grid Roadmap**

CUSTOMER EMPOWERMENT

Key

- Policy Goal
- Forecast
- SDG&E Smart Grid Vision
- In Flight Project
- New Project - Policy
- New Project - Value
- New Project - Pilot
- Enterprise Project

Figure 6-4



SDG&E Smart Grid Vision: by 2015

1. Customer education and outreach programs are proactively engaging customers through multiple channels
2. SDG&E and third parties are providing HANs and other customer premise network capabilities, providing customers real time feedback on power consumption and energy pricing
3. Standardized/reliable customer specific interval usage information and time differentiated price signals are available, enabling customers to make informed and cost-based energy use decisions
4. Customers can choose among multiple energy information services and providers

SDG&E Smart Grid Vision: by 2020

5. Customers are provided near-real time signals via price and event triggers enabling a balance of supply and demand
6. Widely adopted standards create a ubiquitous market of plug-and-play network devices in businesses and homes, including multi-unit dwellings
7. SDG&E is providing options and tariffs for customers to sell generation using distributed energy resources, electric vehicle to grid, or energy storage discharge
8. Microgrid and other technologies give customers more reliability options

www.sdge.com/smartgrid

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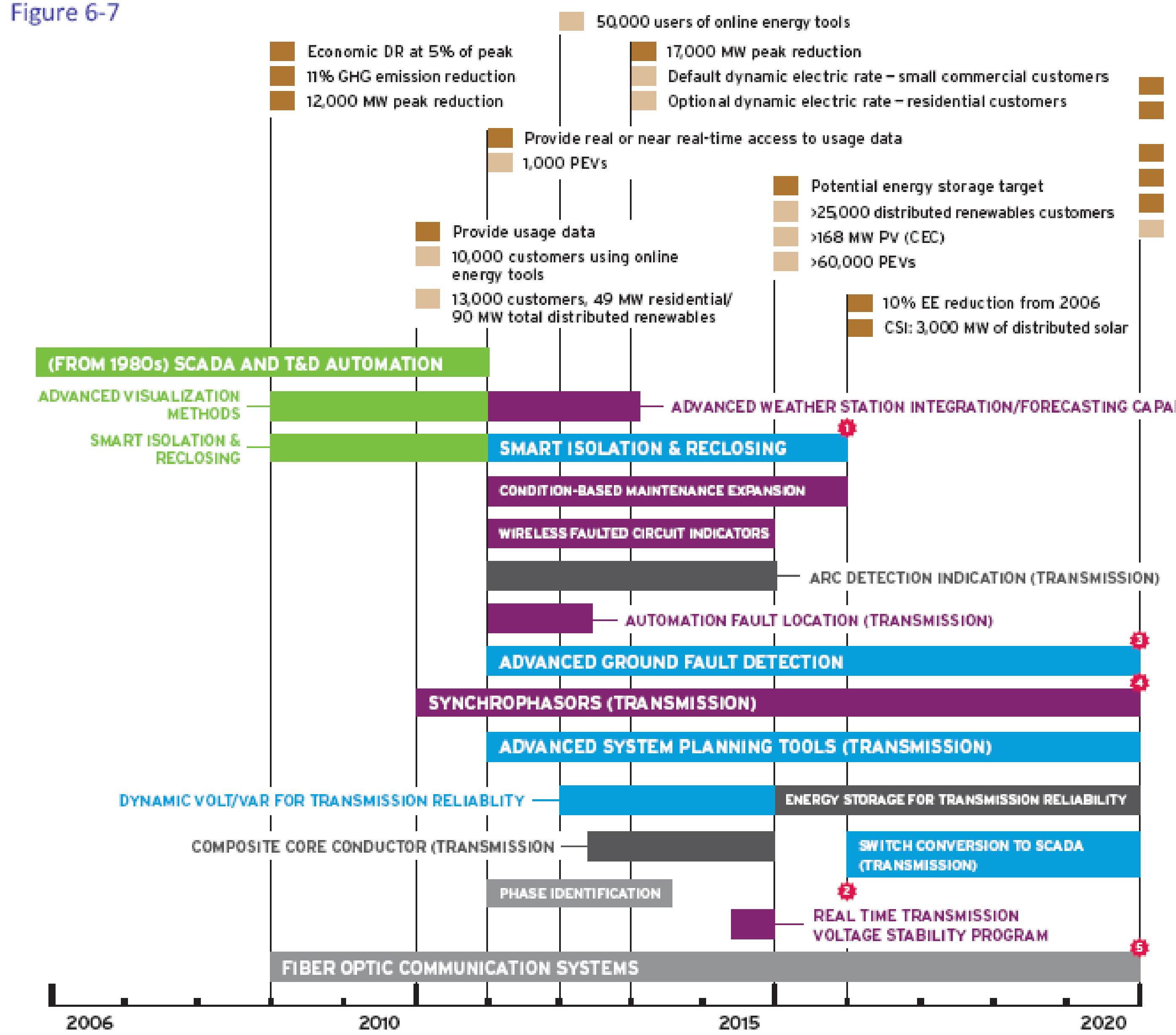
1 2 3 4 5 6 7 8 9 2011 Smart Grid Roadmap

RELIABILITY AND SAFETY

Key

- Policy Goal
- Forecast
- SDG&E Smart Grid Vision
- In Flight Project
- New Project - Policy
- New Project - Value
- New Project - Pilot
- Enterprise Project

Figure 6-7



SDG&E Smart Grid Vision: by 2015

1. Automatic fault detection, isolation, and service restoration capabilities are being enabled, requiring minimal human intervention and leading to improvement in outage restoration
2. Cost-effective energy storage—either utility, customer, or third party owned—is helping to resolve voltage regulation, voltage flicker, and intermittency of renewable resources

SDG&E Smart Grid Vision: by 2020

3. SDG&E is enabling differing levels of reliability, based on customer needs/preferences for self sufficiency (particularly for C&I customers)
4. Synchrophasor data is being used to assess the condition of the grid and respond to changes before they become problems
5. Highly reliable network services are deployed to targeted areas to ensure continued availability for mission critical applications

www.sdge.com/smartgrid

- **SDG&E Borrego Springs Microgrid Project**
  - Demonstrate controlled islanding and load/DG balancing
  - Real Time Optimization and control of DG and energy storage
  - Automatic Volt/VAr control, feeder automation
- **Power Quality Field Measurement and Analysis Project**
  - Field data collection of distribution steady state and transient voltages on distribution circuits with high levels of DG
  - Data analysis and evaluation of DG impact
- **Dynamic voltage support project on distribution circuit with known voltage regulation issues due to high levels of DG**
  - Contracted General Electric to conduct analysis to size and locate dynamic voltage support devices
  - GE to install dynamic Var device to evaluate feasibility and benefits
- **Energy Storage Projects to Mitigate Impacts of DG**
  - CEC funded Projects
  - EPRI demonstration of CESS
  - SDG&E Smart Grid Energy Storage projects

- **General Rate Case Smart Grid Projects ($ 54 Million* – Yr 2012)**
  - Distributed Energy Storage ($ 34 Million*)
  - Dynamic Line Ratings for distribution ($ 4 Million*)
  - Synchrophasors for distribution ($ 8 Million*)
  - Dynamic Voltage support ($ 3 Million*)
  - Distributed Energy Resource Management System ($ 5 Million*)
- **Smart Grid Deployment Plan**

* Costs shown in 2009 dollars, unloaded. Cost to mitigate 120 – 130 MW of PV on SDG&E system in yr 2012, does not include T&D costs of meeting 12,000 MW PV goal by 2020.

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- Existing Rules require modification to accommodate high PV penetration
- Draft IEEE 1547.8, IEC 61850 can be utilized today
  - Similar to German Grid Code
- Actual field measurements and modeling are important part of the solution
- Adopt lessons learned in European countries
- Need randomization of re-connect times

Thank you.

Thomas Bialek

Chief Engineer, Smart Grid

tbialek@semprautilities.com
www.sdge.com/smartgrid/

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