Climate Change and Global Warming -Do you believe in them?

First they came for the socialists, and I did not speak out—
Because I was not a socialist.

Then they came for the trade unionists, and I did not speak out—
Because I was not a trade unionist.

Then they came for the Jews, and I did not speak out—
Because I was not a Jew.

Then they came for me — and there was no one left to speak for me.

German Lutheran pastor Martin Niemöller (1892–1984).

So many are fighting against the renewable energy and running propaganda ads and so on

1) http://stopthesethings.com/2014/08/04/more-australian-wind-power-fails/
2) http://www.heraldsun.com.au/business/when-the-wind-doesnt-blow-the-power-doesnt-switch-on/story-fni0d8gi-1226998025051
3) https://wattsupwiththat.com/2018/12/21/germanys-green-transition-has-hit-a-brick-wall/
4) http://joannenova.com.au/2019/02/solar-subsidy-death-spiral-2-billion-in-australia-rising-50-pa-as-electricity-prices-go-crazy/
5) https://www.theaustralian.com.au/business/mining-energy/households-2bn-hit-for-solar-roof-panel-subsidies/news-story/54735ae55adf6de65ca8f63b31776f24

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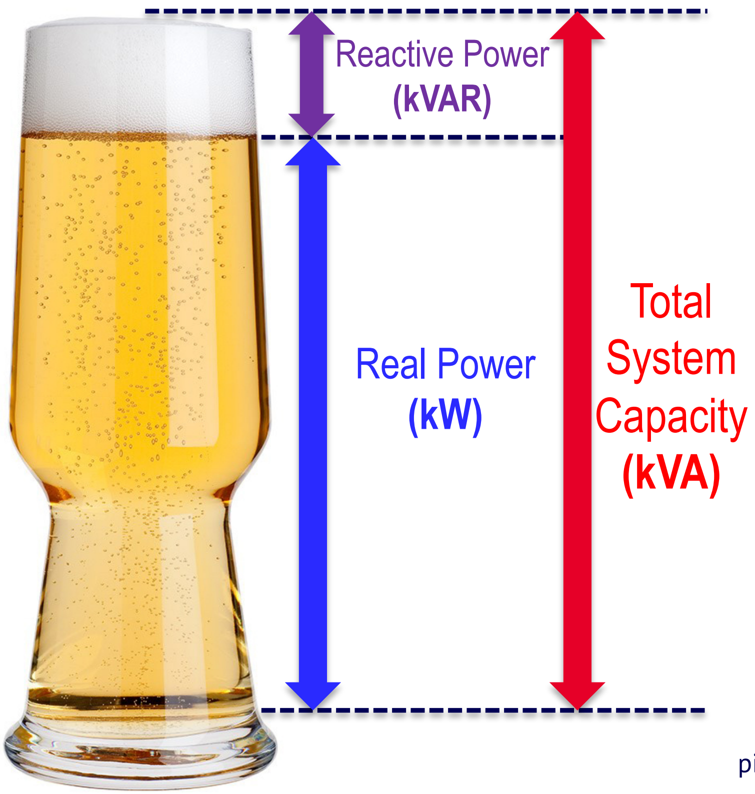
Smart Grid and Renewable Energy Integration: Challenges, Mitigation Strategies, and Associated Grid Codes

by

Dr. Manoj Datta, RMIT University

Power System Basics
Real and Reactive Powers

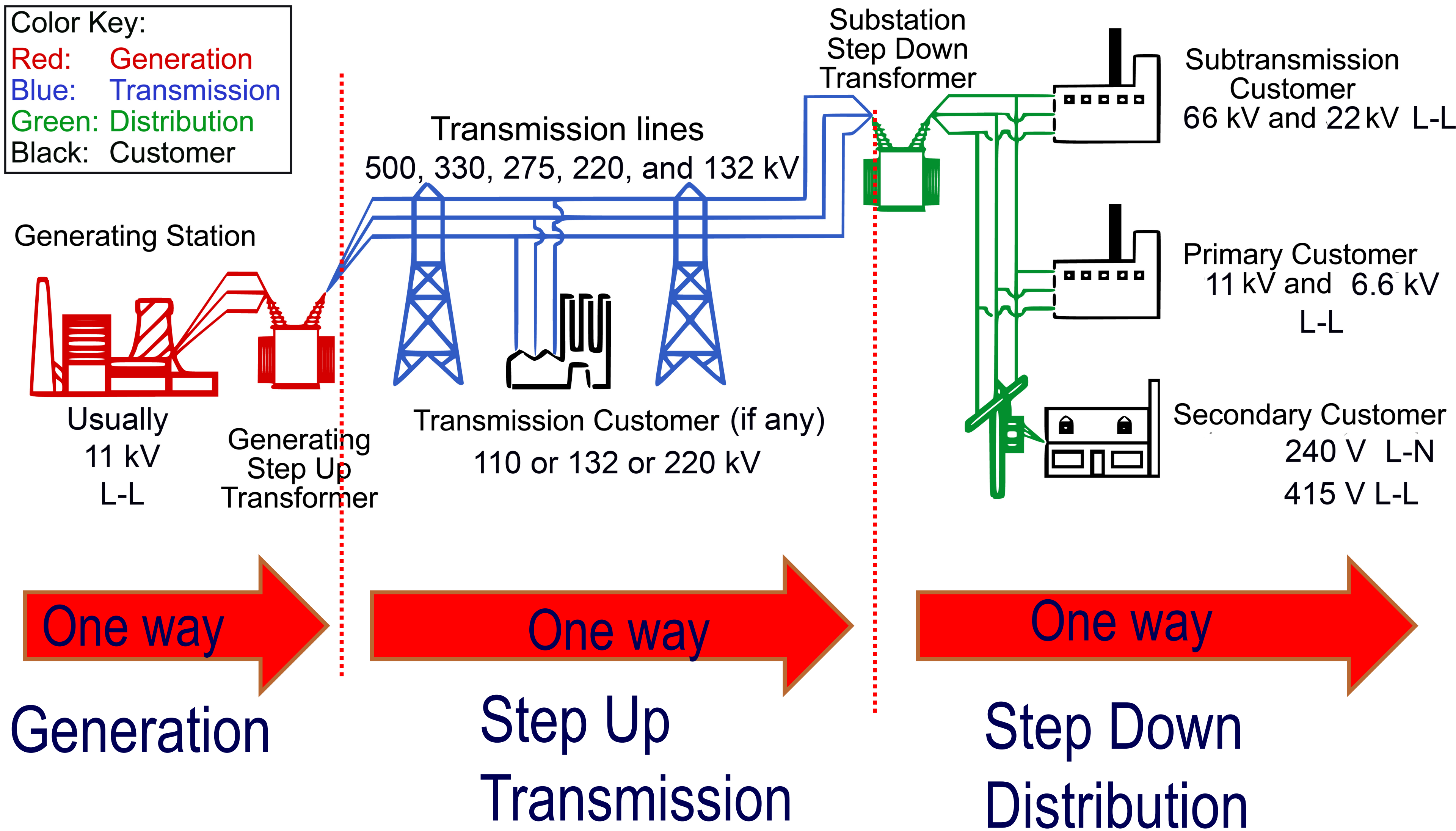
- Real power does the work
- Reactive power helps real power in doing the work
- A power system needs both or it will not work
- What is reactive power?



picture: Tim Carrafa. *Source:* news corp australia

- A full forward like Mr. Cyril Rioli can throw the footy ball, but not very far
- For long distances, he kicks the ball in an arc
- Real power is the footy ball
- Reactive power is the height of the arc
- Transmission lines are the directions

Conventional Power System: Australia
Creates Unidirectional power and current flows



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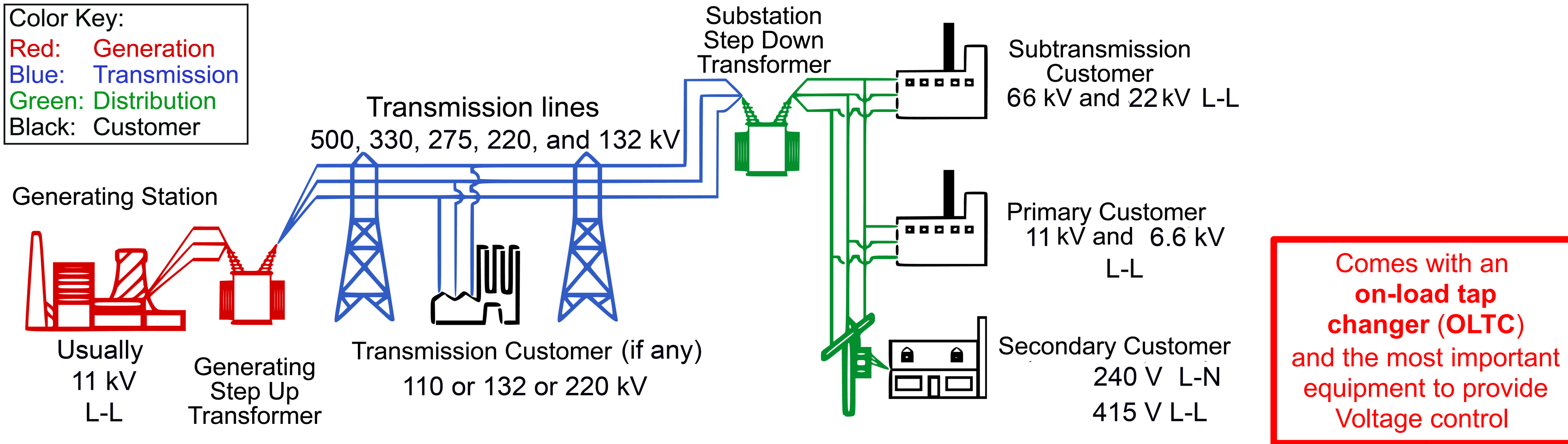
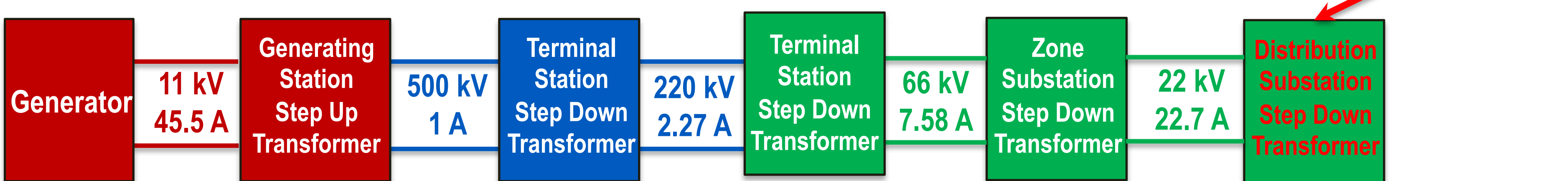
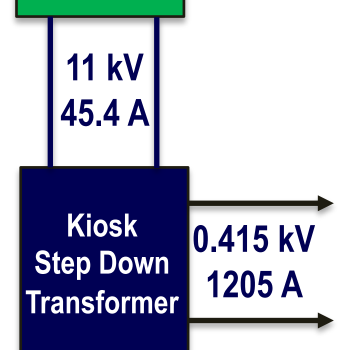
Conventional Power System: Australia
Unidirectional power flow transformation





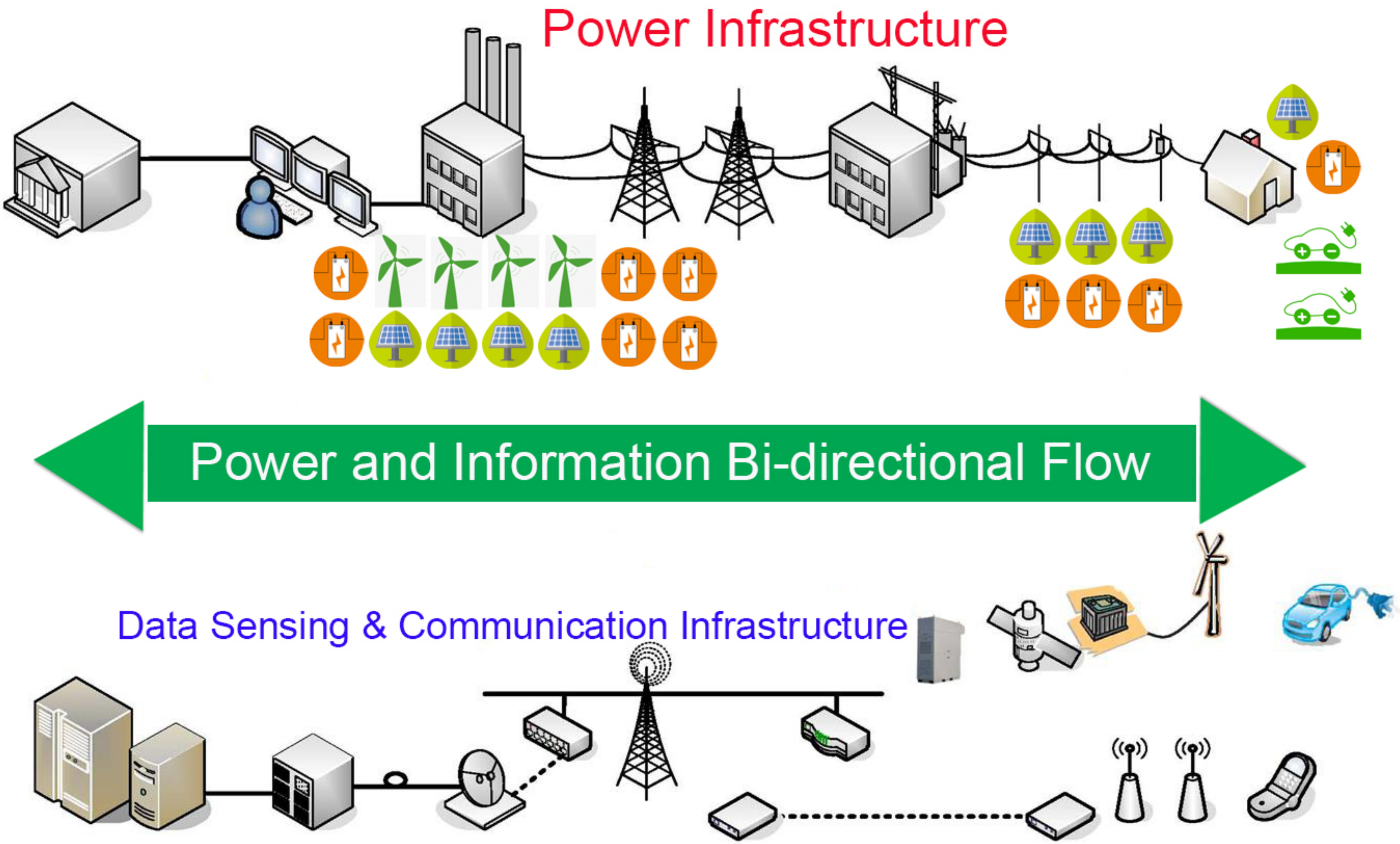


$$P_{in} = P_{out}$$

$$V_{in} \times I_{in} = V_{out} \times I_{out}$$

We transforms the current down to send long distances over transmission lines, then we transform the high voltage down to low voltage making it safer for the customers.

Smart Power Grid
Two way power and information flows
It's Bi-directional



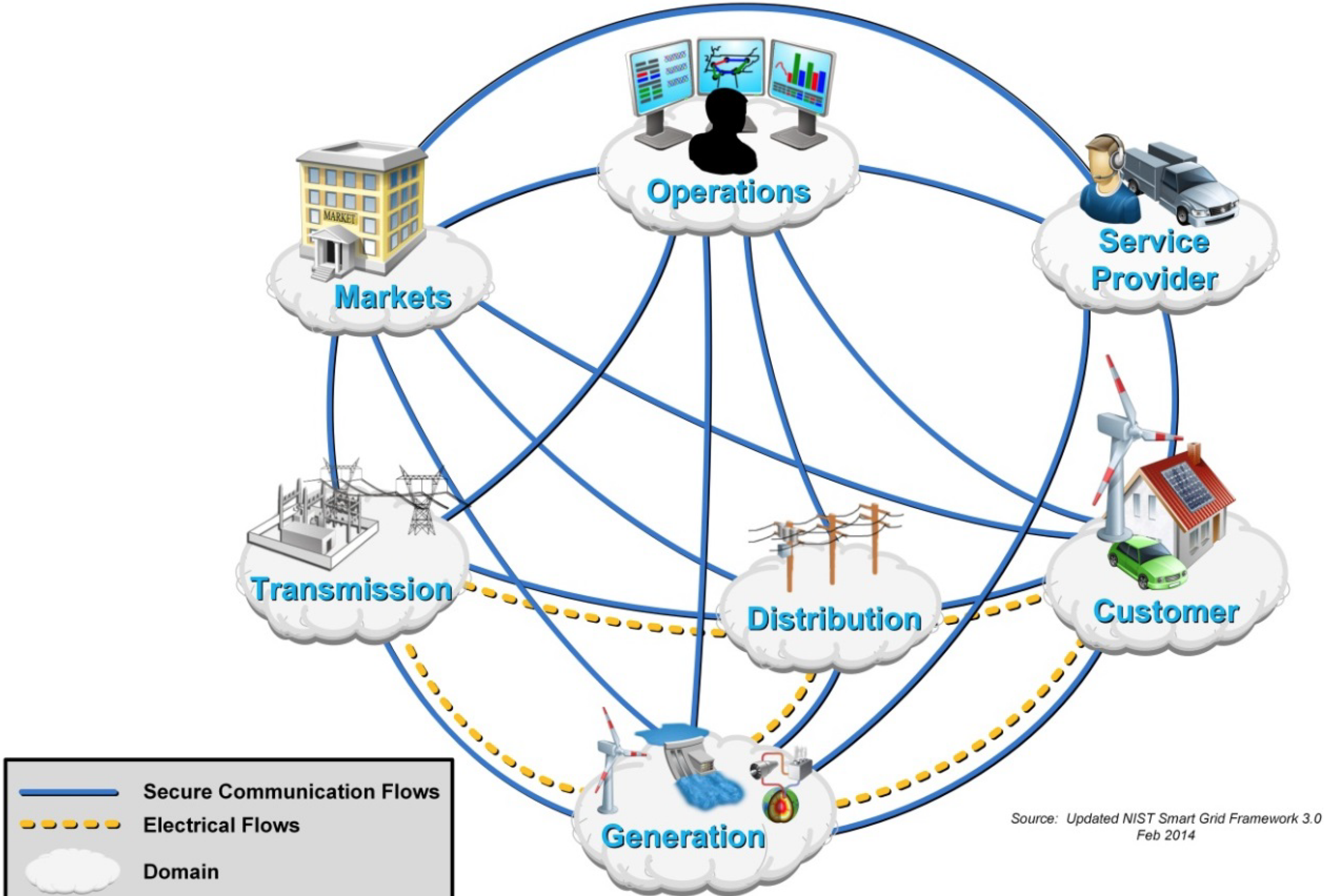
Smart Grid Definition

- A smart grid generates and distributes electricity more **effectively**, **economically**, **securely** and **sustainably**.

- It integrates **innovative tools and technologies**, products and service, from generation, transmission and distribution all the way to consumer appliances and equipment using **advanced sensing**, **communication**, and control technologies.

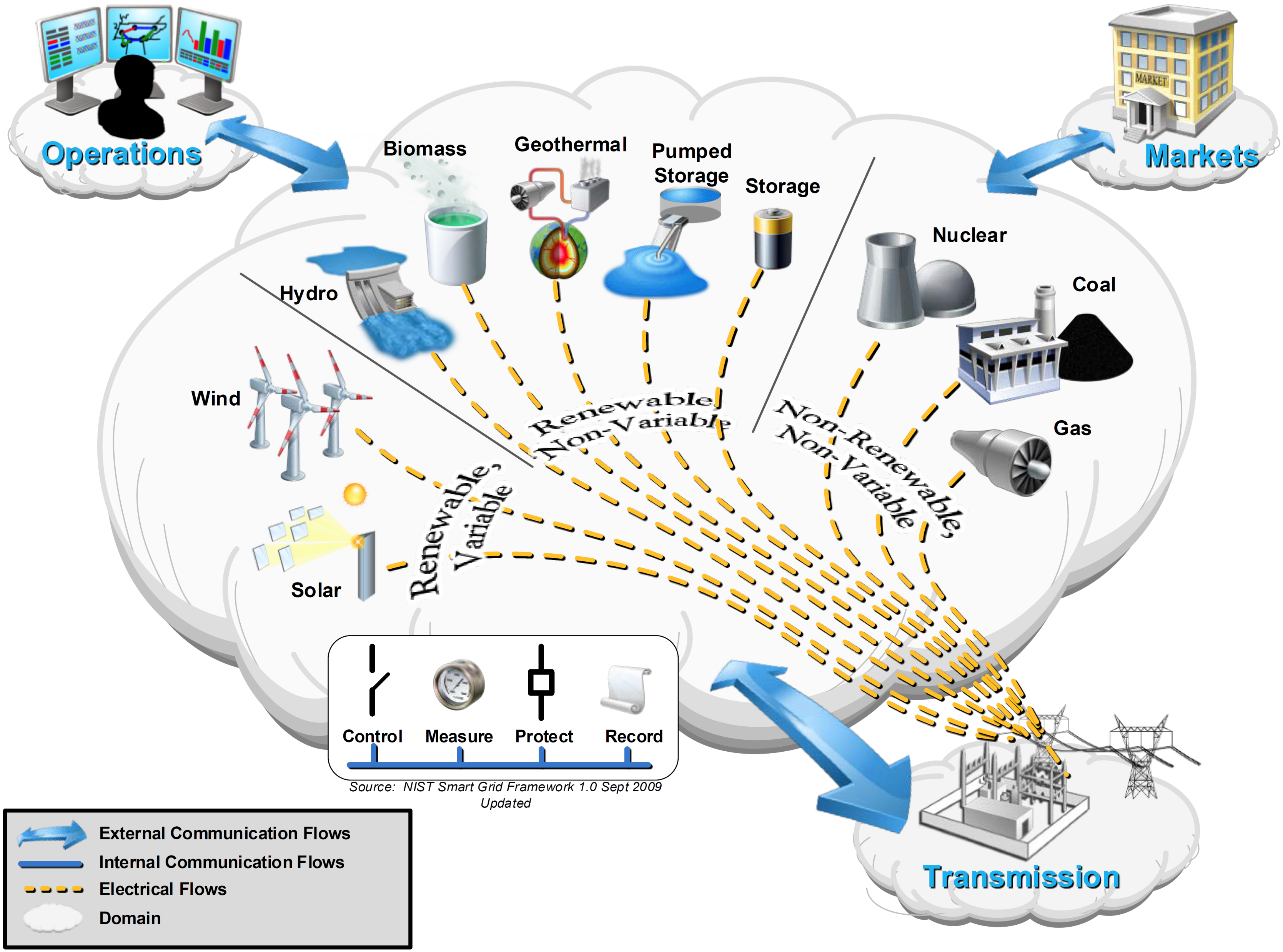
- It provides customers with **greater information and choice**, including power export to the network, demand participation and energy efficiency

Smart Grid Framework



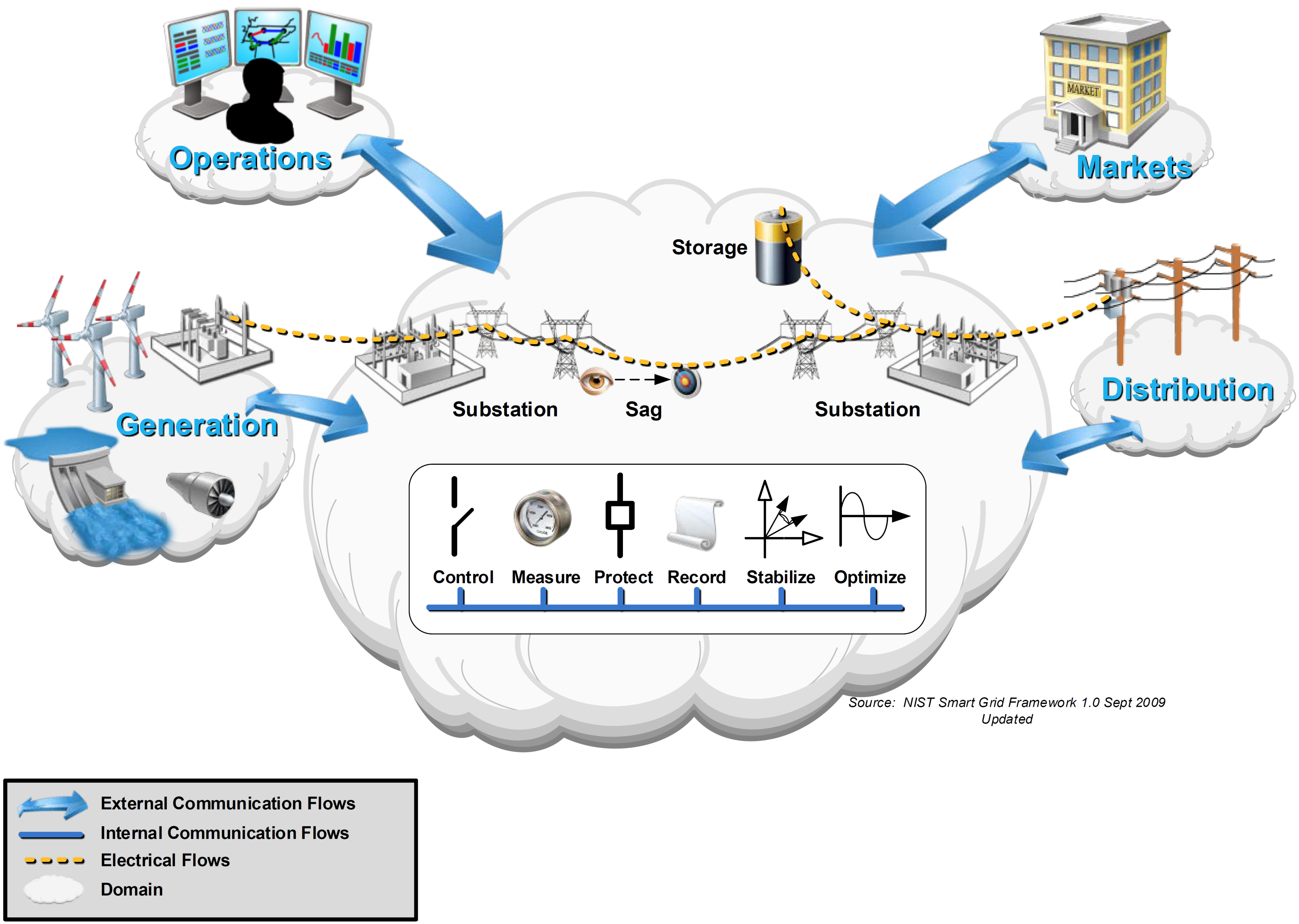
Source: NIST & IEEE, Smart Grid Conceptual Model

Power Generation Domain



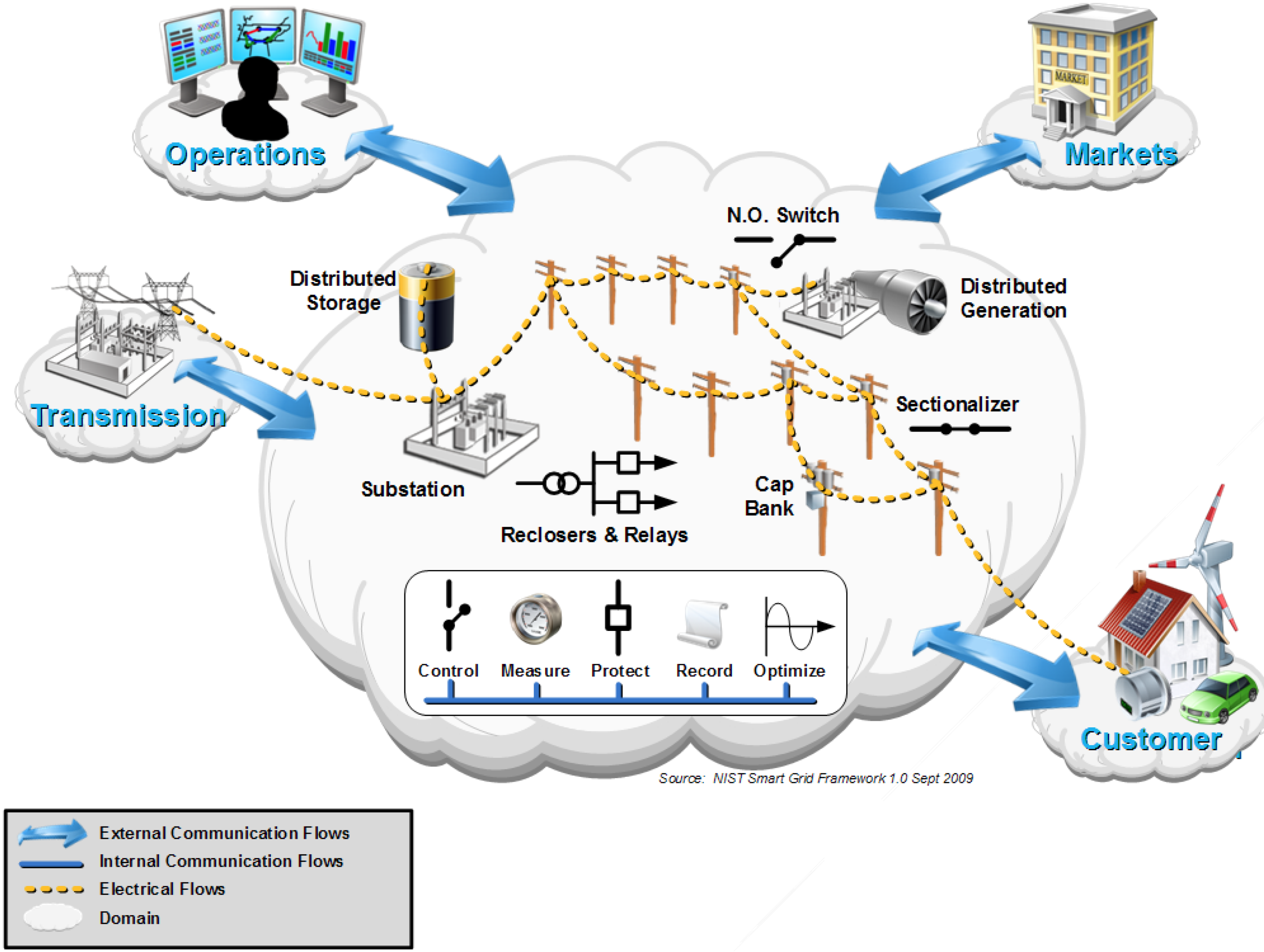
Source: NIST & IEEE, Smart Grid Conceptual Model

Power Transmission Domain



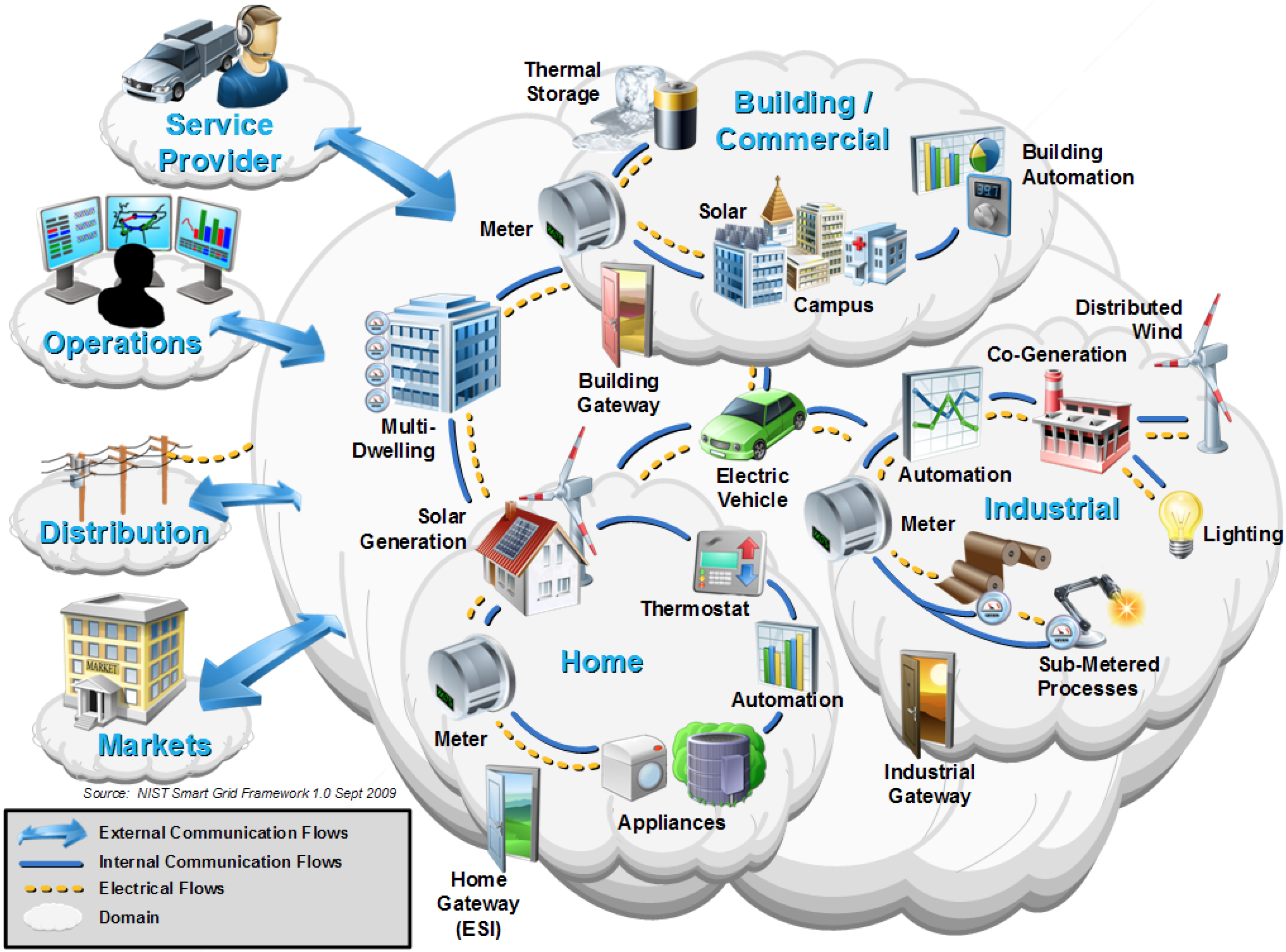
Source: NIST & IEEE, Smart Grid Conceptual Model

Power Distribution Domain



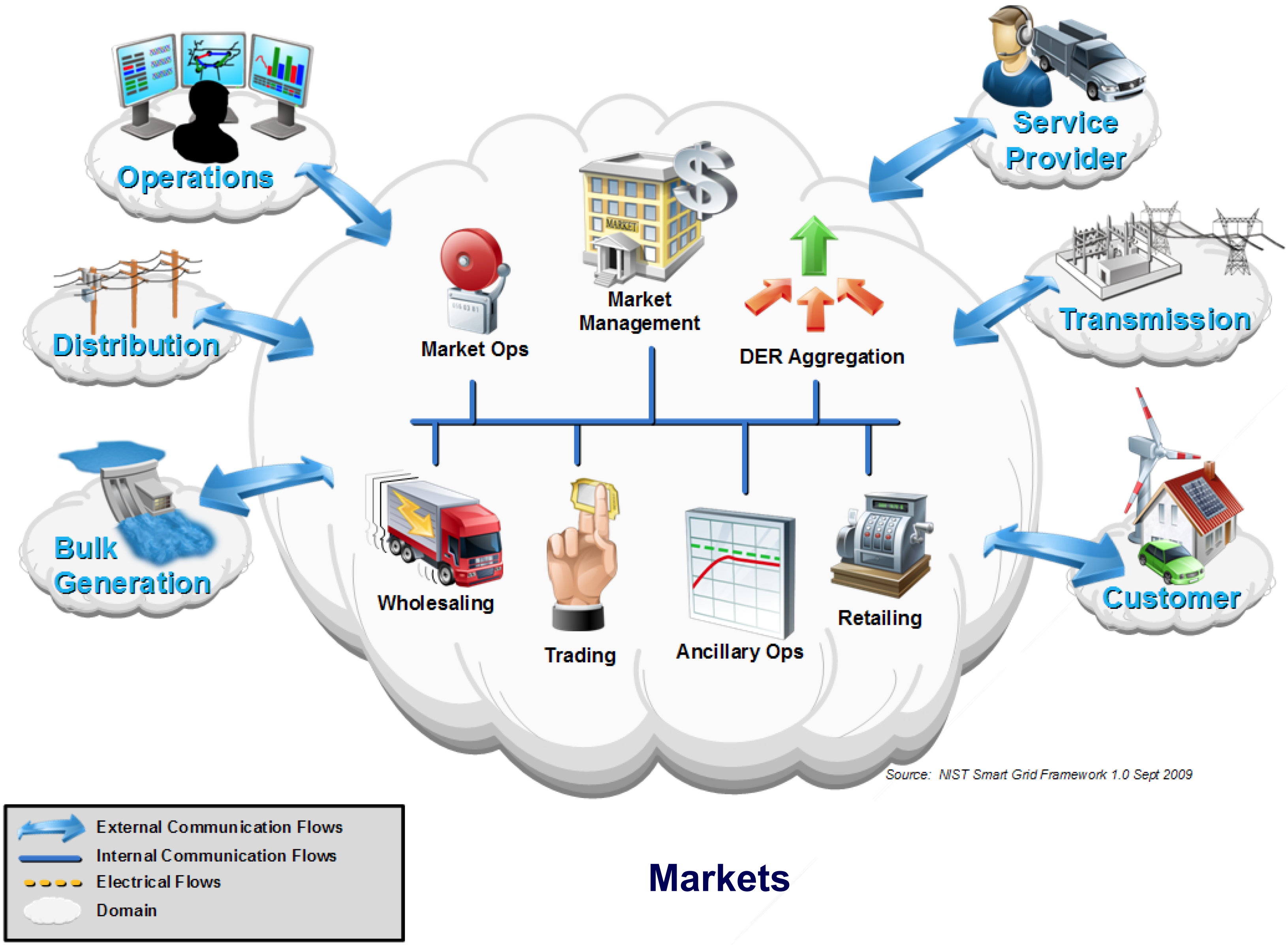
Source: NIST & IEEE, Smart Grid Conceptual Model

Power Consumer Domain



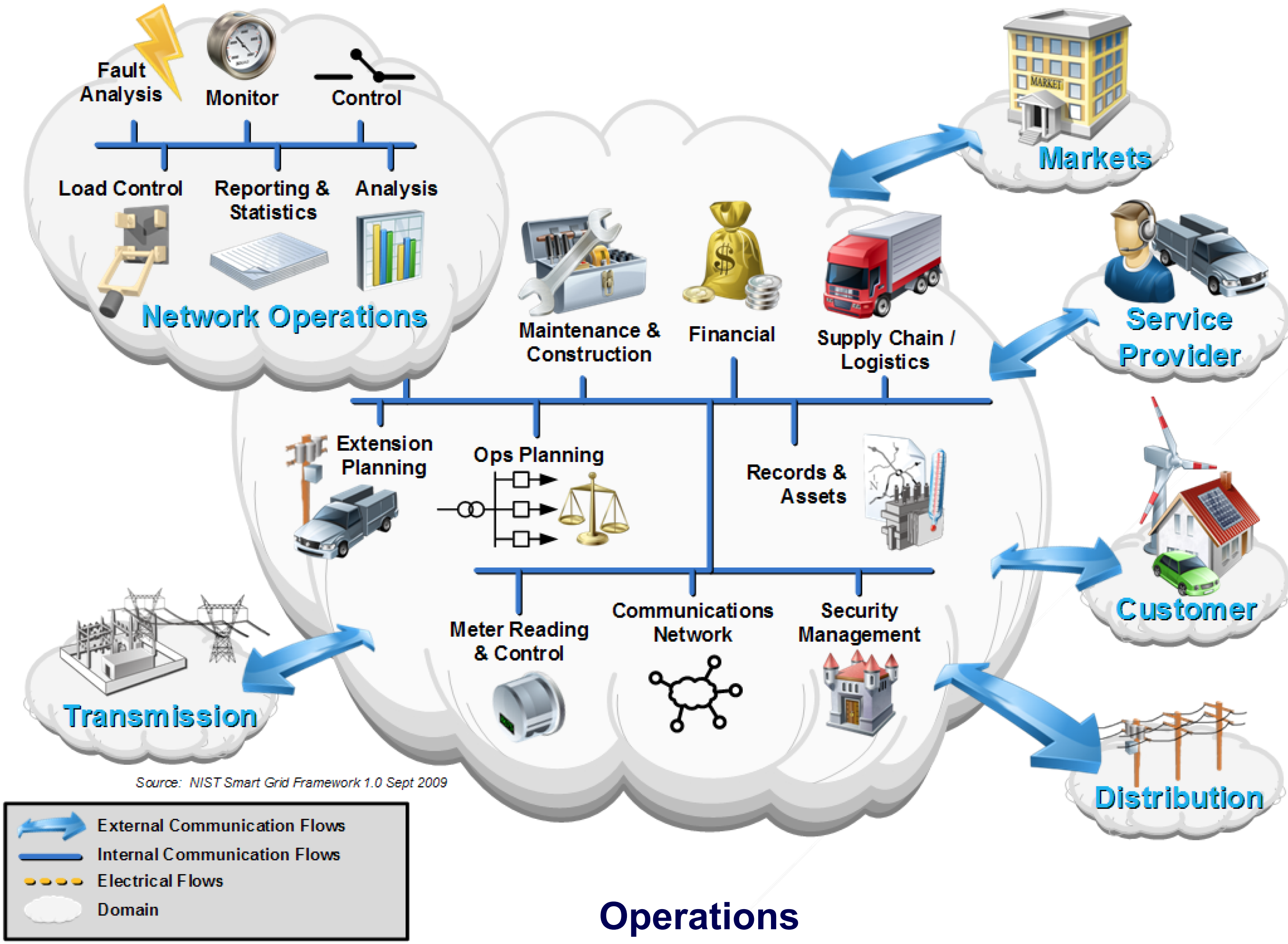
Source: NIST & IEEE, Smart Grid Conceptual Model

Energy Markets, Operation, & Service Providers Domains



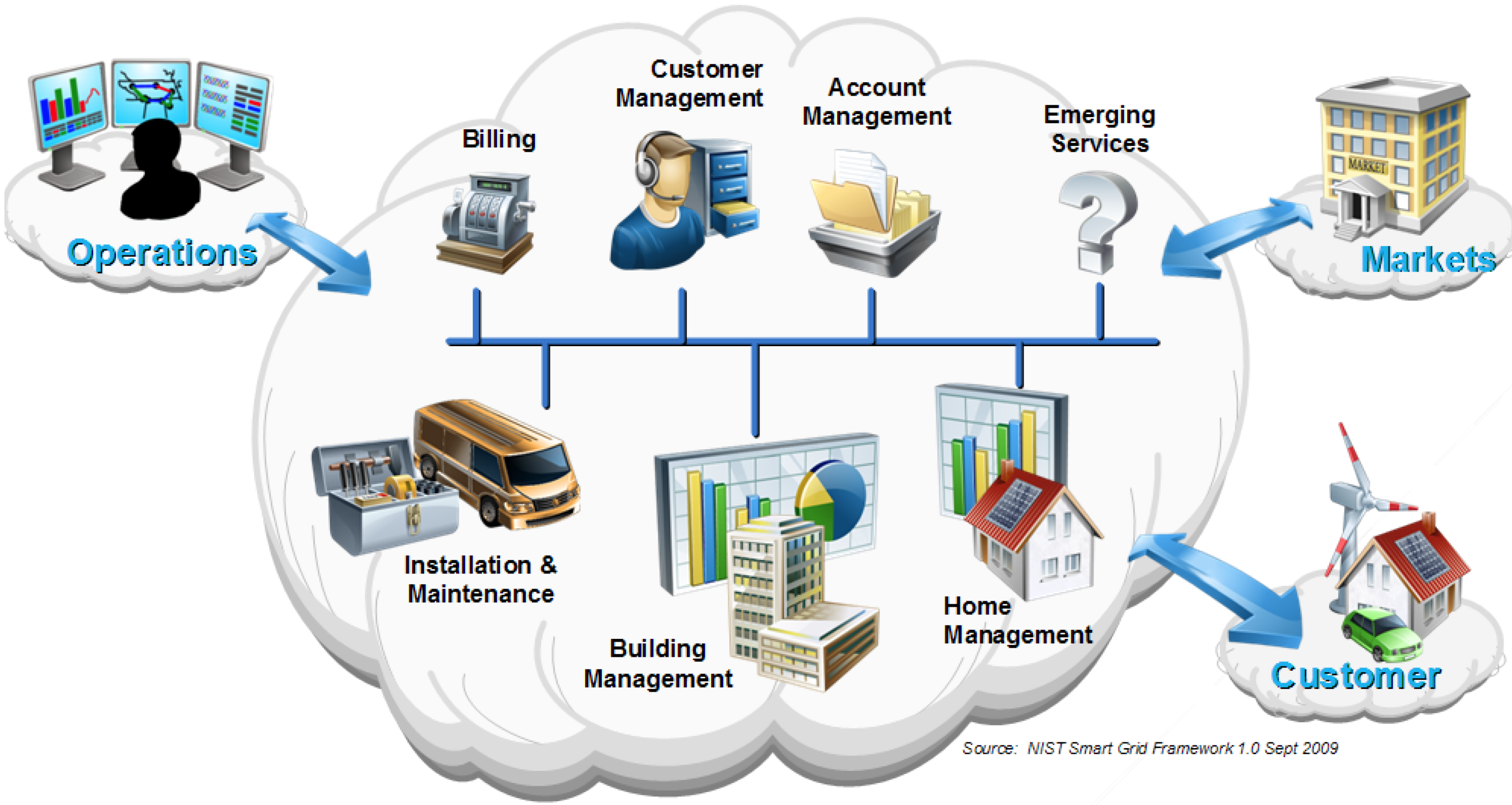
Source: NIST & IEEE, Smart Grid Conceptual Model

Energy Markets, Operation, & Service Providers Domains



Source: NIST & IEEE, Smart Grid Conceptual Model

Energy Markets, Operation, & Service Providers Domains



- External Communication Flows
- Internal Communication Flows
- Electrical Flows
- Domain

Service Provider

Source: NIST & IEEE, Smart Grid Conceptual Model

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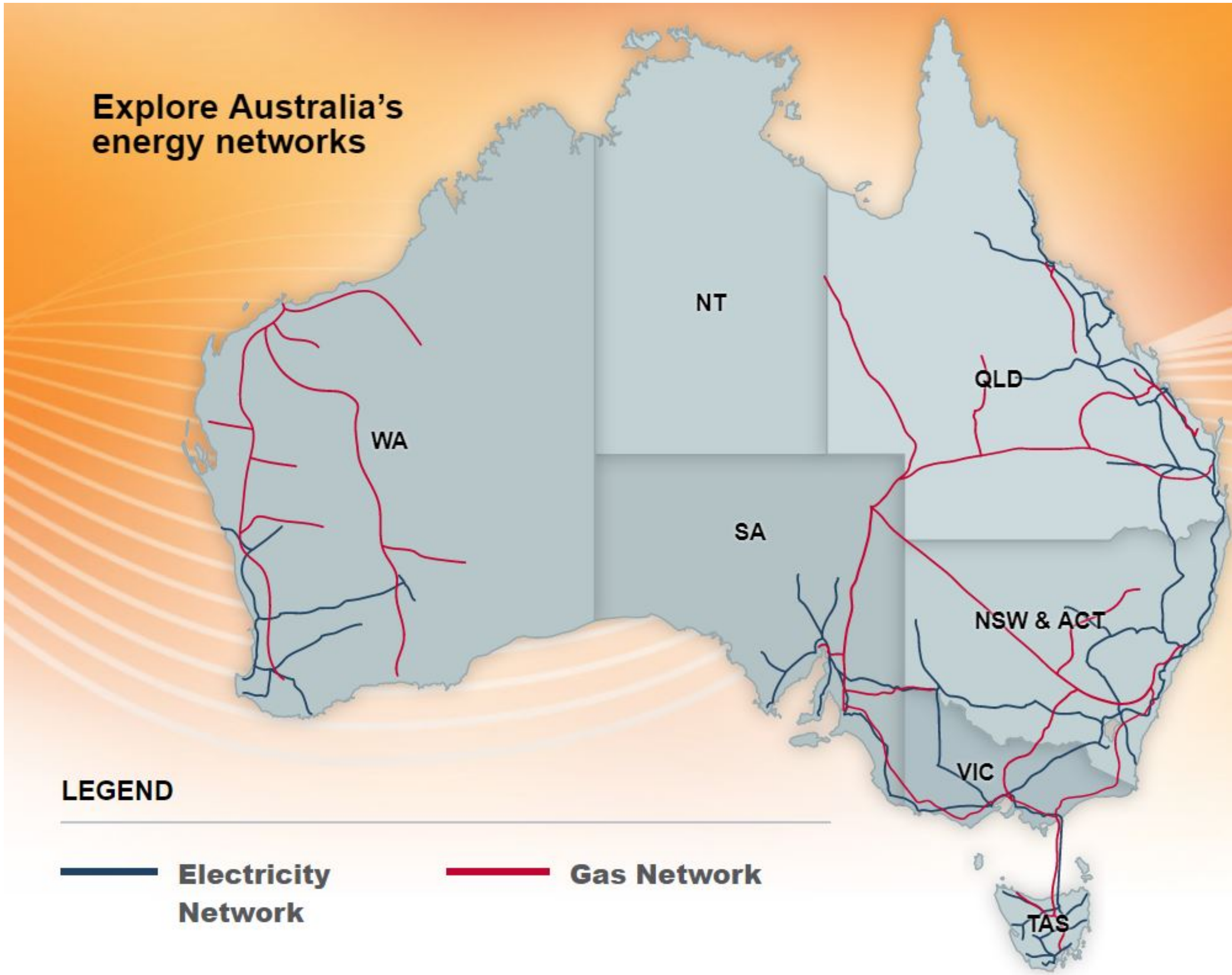
Smart Grid: How does it work?

Lets watch a 7:30 minutes video

Video Source and Copyright:

Australia’s Energy Networks



Annual generation by fuel type

(2016/17):

100%
196.5 TWh

77%
150.9 TWh
COAL

9%
17.6 TWh
GAS

8%
15.5 TWh
WATER

5%
10.6 TWh
WIND

0.3%
0.6 TWh
SOLAR

0.7%
1.3 TWh
OTHER

Data does not include generation from rooftop solar PV systems.

Source: AEMO

Surely Australia loves Coal ! !
77% of the total power generations are from the coals

Black Coal

Brown Coal

I also love coal. But that coal is little different. I call it the yellow coal.

The yellow Coal!!! Seriously! Does that even exist?

Yellow Coal

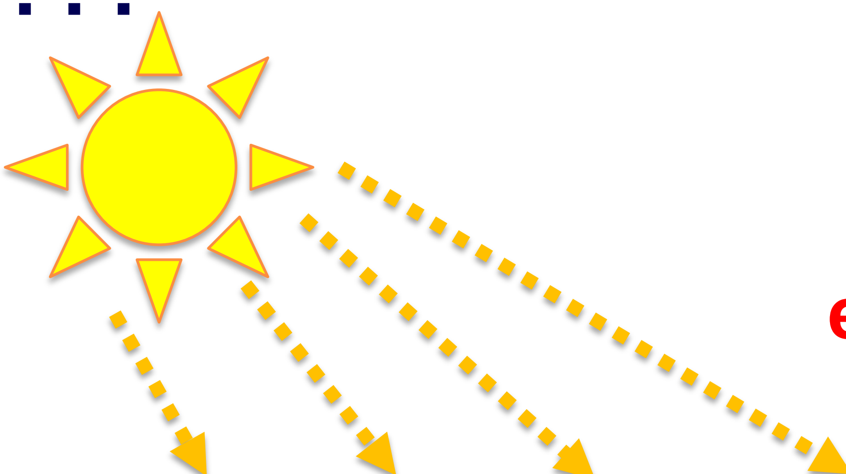
The Sun-The Yellow Coal- The infinite source of energy!!

Yellow Coal

Solar Energy

Wind Energy

However, Solar-PVs are very dumb. Why???



× Very low system efficiency (10% ~ 25%)

Input

1000 W/m²

Photon energy

Output

230 W/m²

Electrical energy

Only 23% efficient. That's actually a good one in the market standard. We need to continue our research to increase the efficiency

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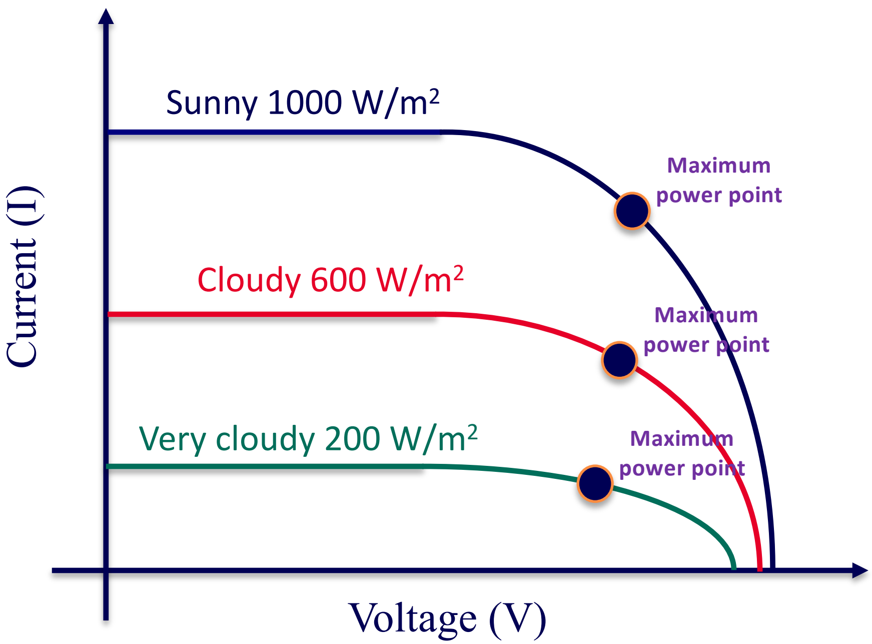
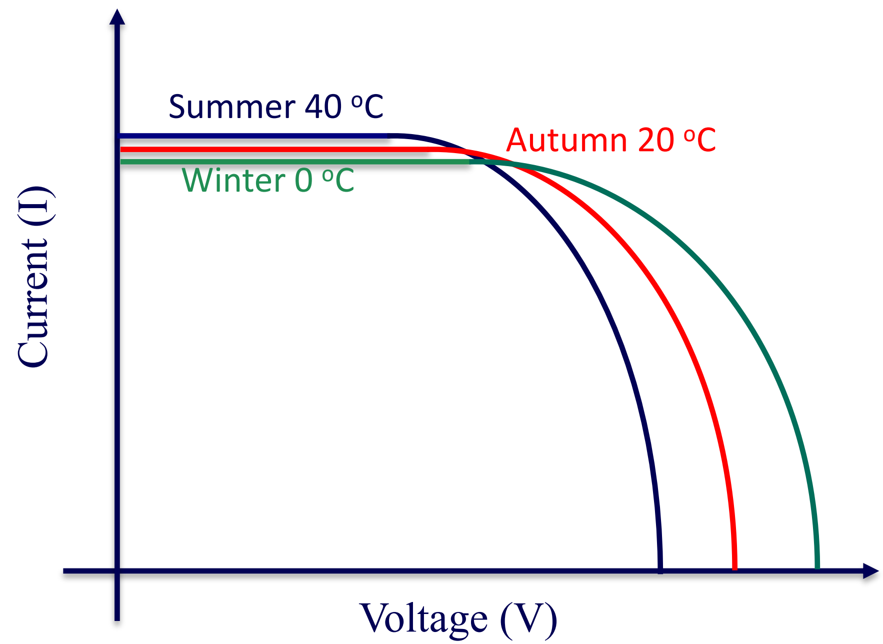
However, Solar-PVs are very dumb. Why???

× The output electrical energy varies with the weather changes

Solar-PV Electrical Characteristics under Constant Temperature (25 °C)



Solar-PV Electrical Characteristics under Constant Solar Irradiance (1000 W/m²)



Power (P) = Voltage (V) x Current (I)

We use a power electronic system to track the maximum power point (MPP). We need to continue our research to increase the tracking efficiency

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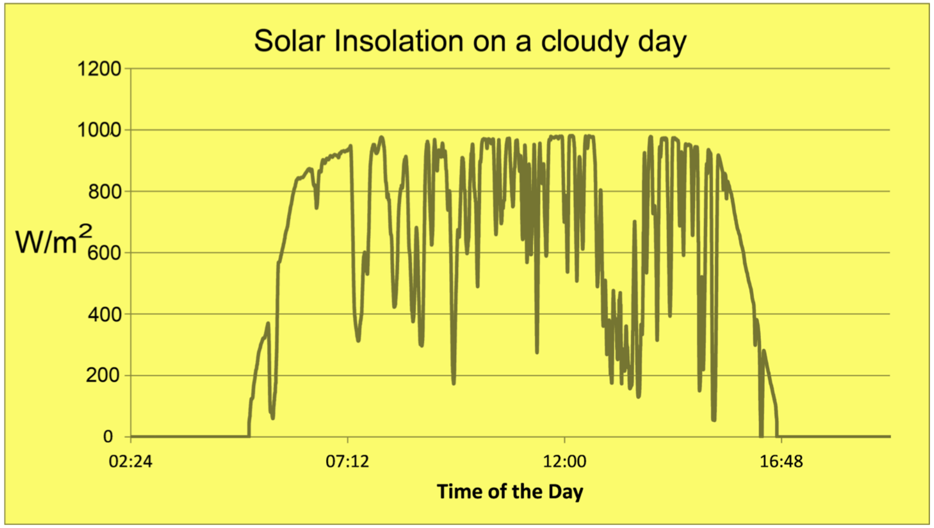
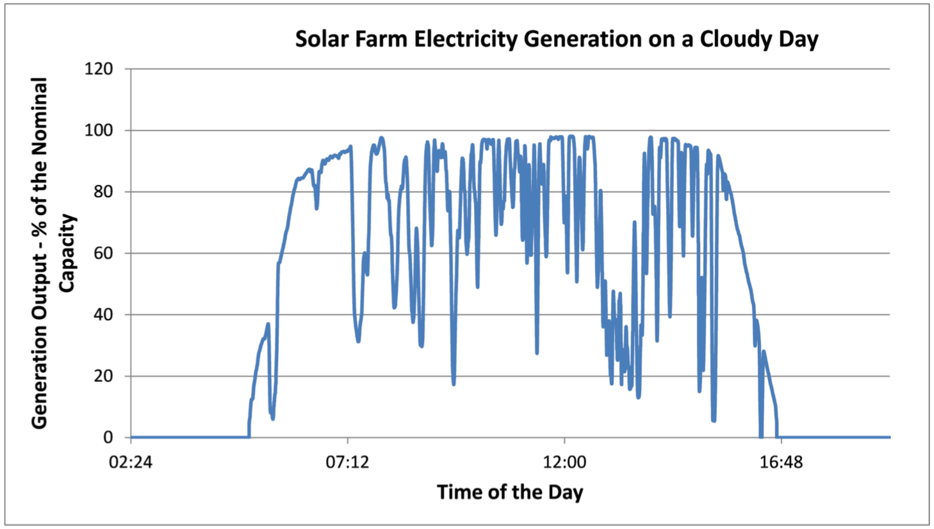
Large Solar-PV output power variations on a cloudy day





- ? Variable output power. Will be difficult to match with the variable loads. Will it create severe frequency deviations or fluctuations?
- ? Energy storage could be a good solution. What size??
- ? What about the night time? No solar.
- ? Unpredictable, how these farms will participate in the energy market??

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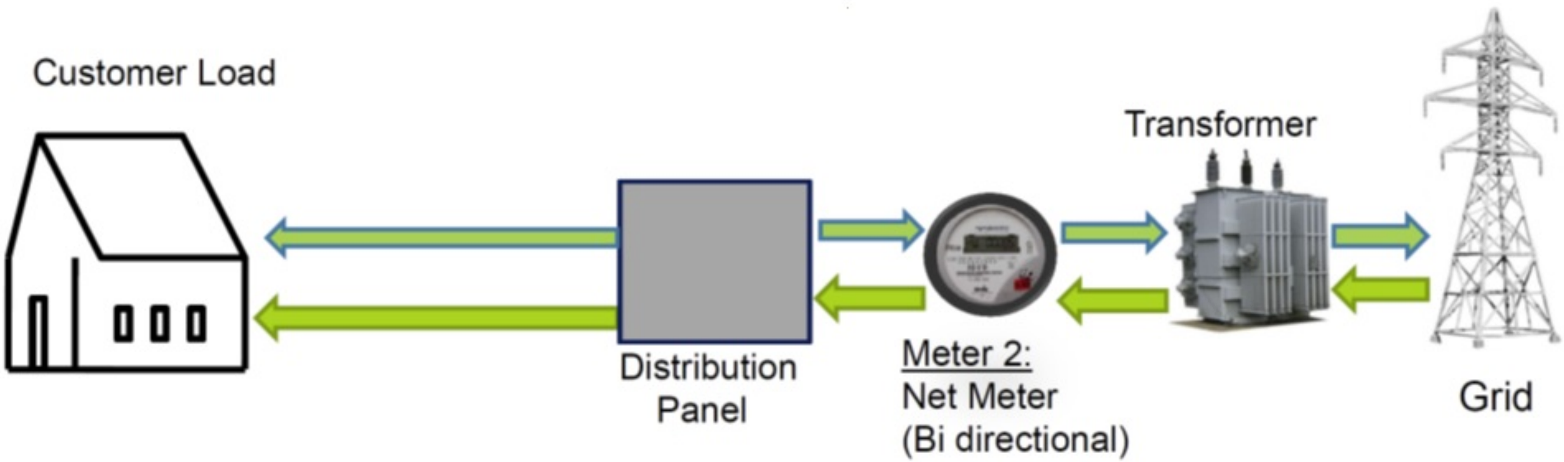
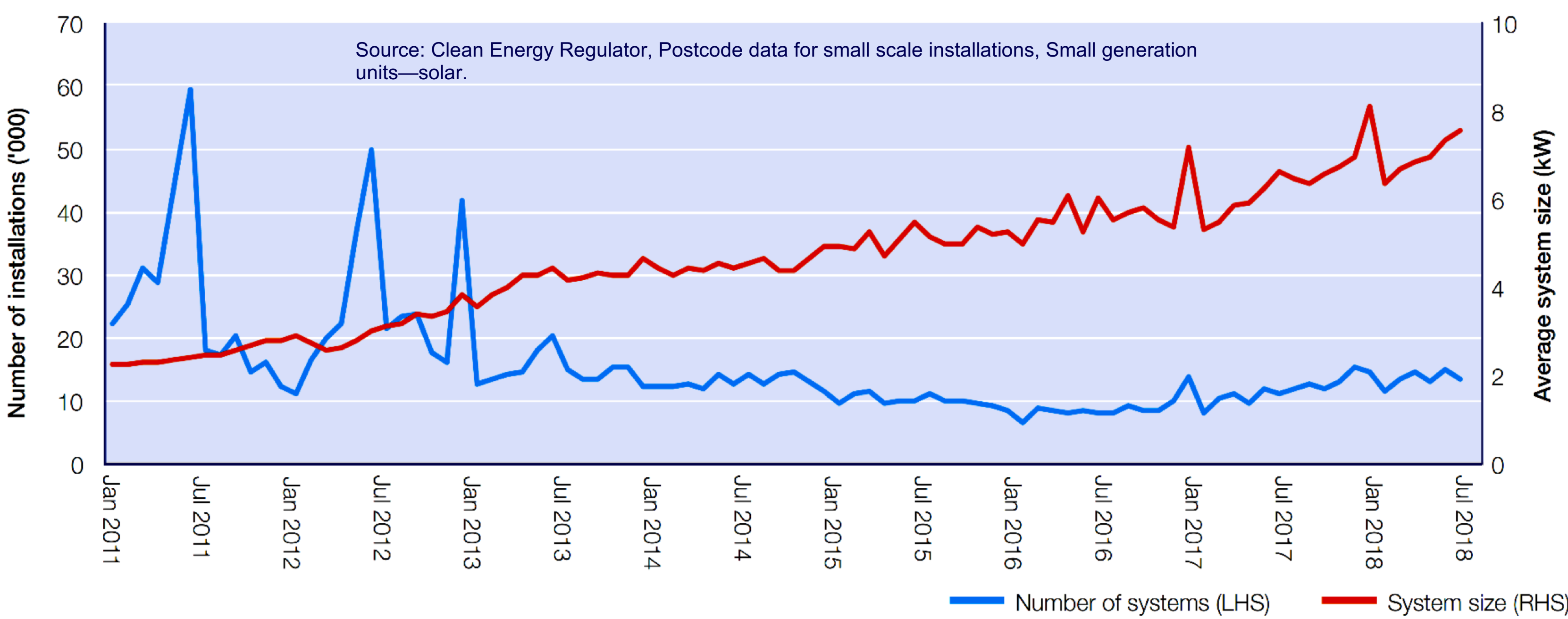
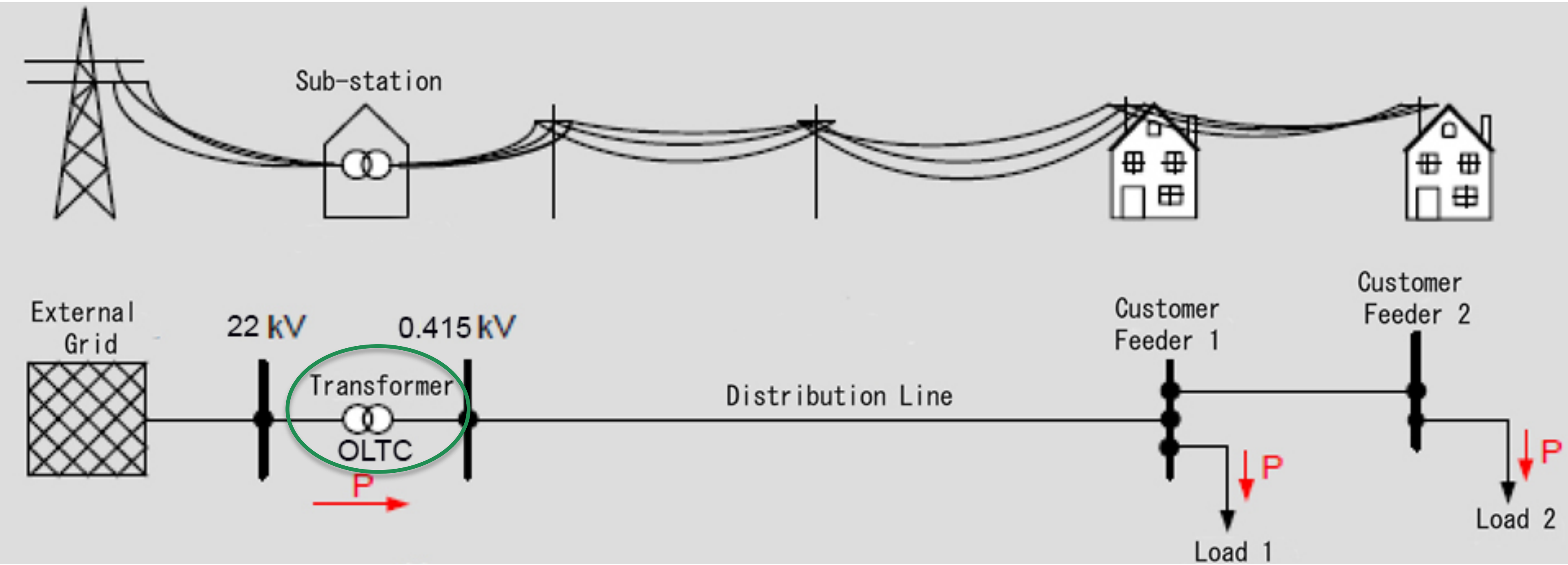
What's the problem with the Roof top-PV

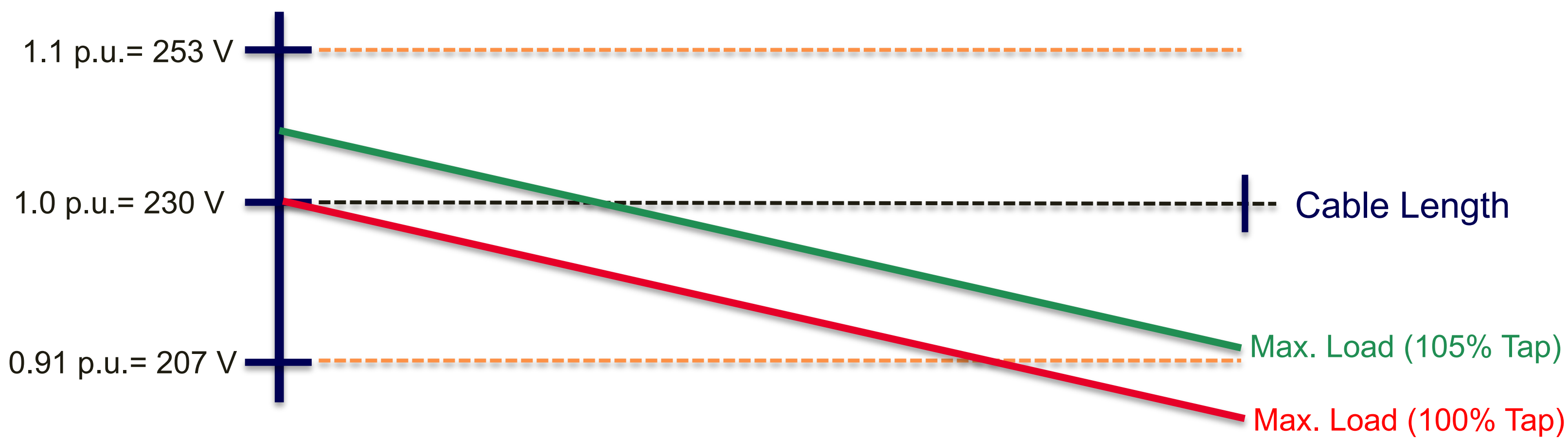


Let's watch another video

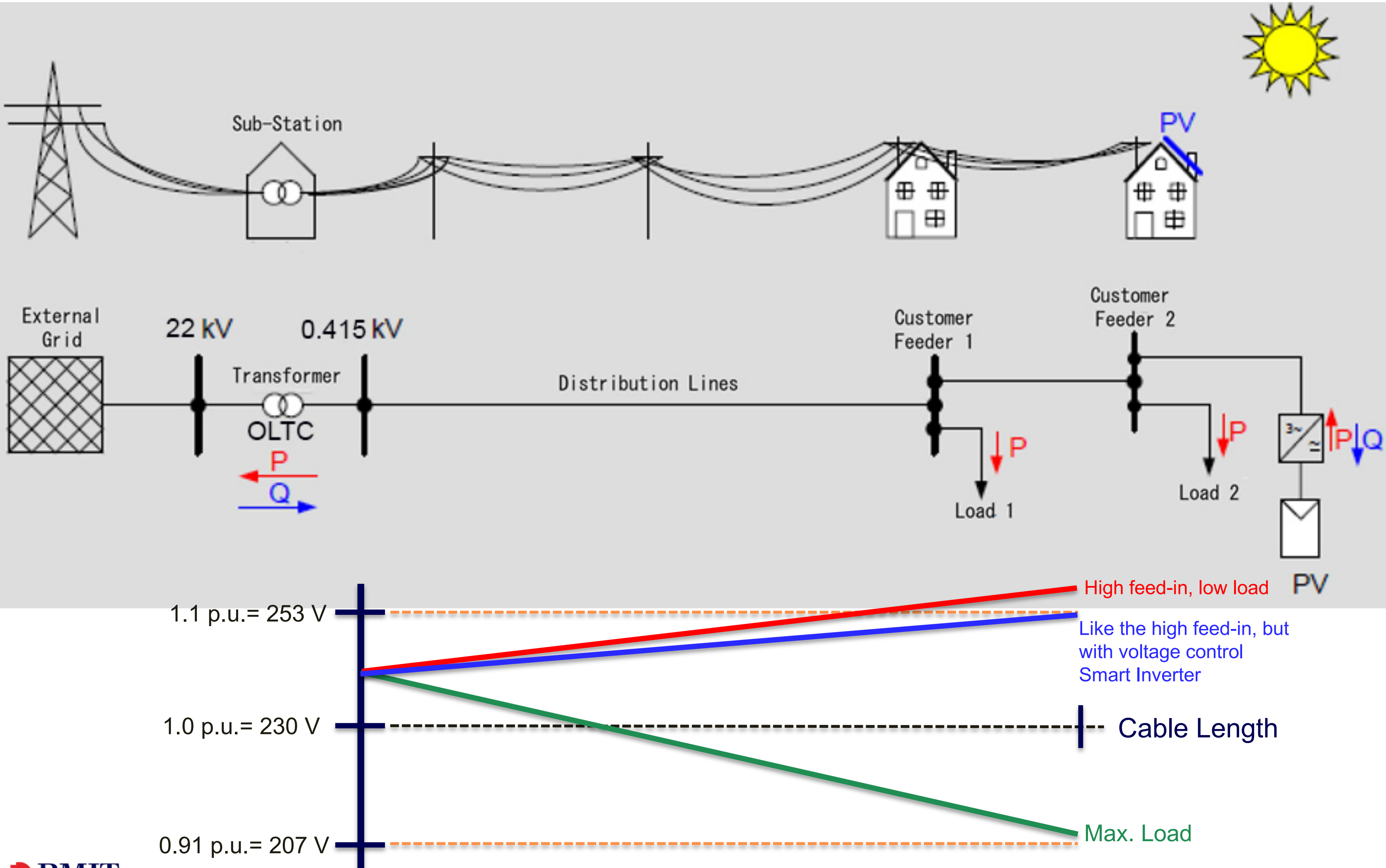


The old way and the problem





The new way and what's happening: Voltage fluctuations

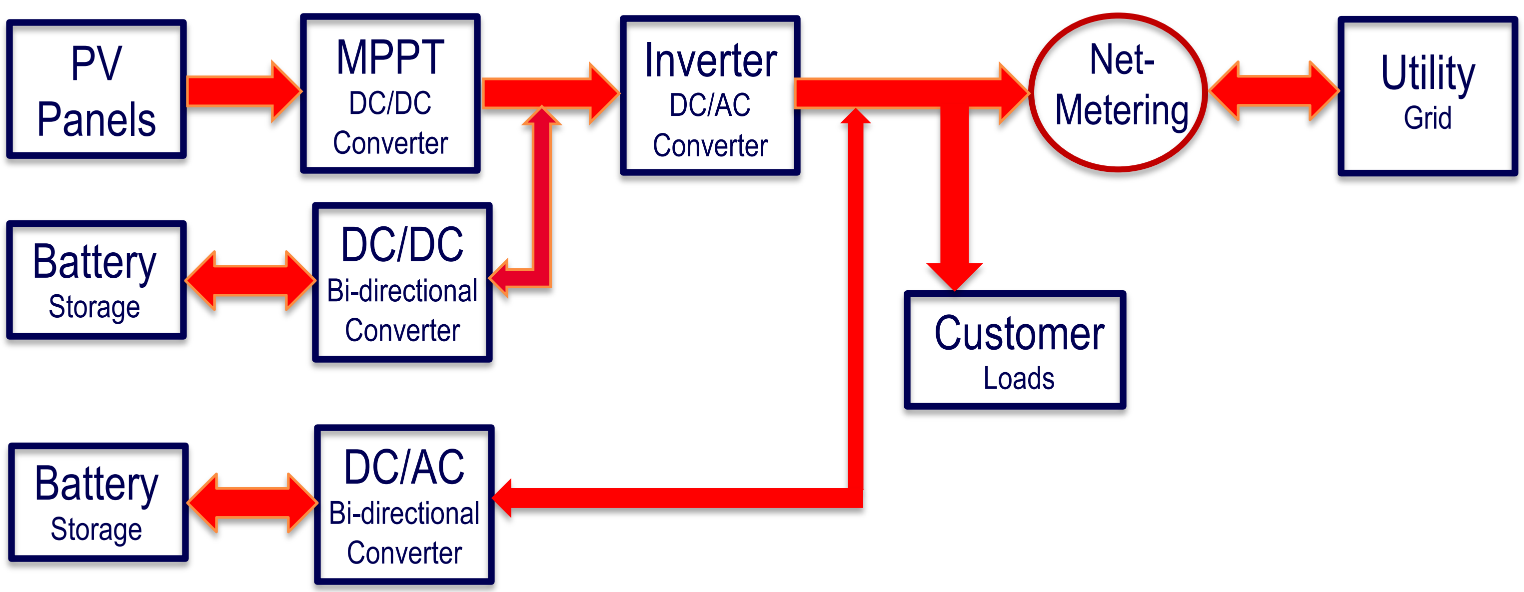


Roof-top and Utility level PV problems: The German 50.2 Hz incident

- Around 2006, due to strong incentives provided under the German Renewable Energy Sources Act (EEG), the installed amount of power from PV systems in Germany increased exponentially.
- Although connected to the low-voltage distribution system, the contribution from this large number of low power PV systems was already starting to influence the overall system, introducing previously unseen risks.
- June 2006 - according to the interface protection rules of that time an immediate shut-down of the PV inverter was required when the grid frequency reached or exceeded 50.2 Hz. It was an appropriate rule to prevent over generation until the grid's primary control systems have had time to recover the situation.
- However, as the power from the numerous PV inverters had reached several gigawatts, especially during sunny weather, the implementation of the interface protection rule at a fixed 50.2 Hz, unwittingly instigated an instantaneous loss of generation.
- That was significantly larger than the balancing power available Europe-wide for primary frequency control, rendering the overall system unstable, creating transients and spreading that transients Europe-wide.
- This incident is called the 50.2 Hz incident. Sincere then the grid code has been modified

The California Court Case-Green Energy Storage Incentives-

- In 2013, three California investor-owned utilities restricted participation in their net metering programs by customers with PV inverter integrated with storage.
- They argued that customers with storage should not be eligible for net metering because the utilities could not distinguish between power produced by the PV and power coming from the storage device. These customers could charge their storage device with power from the grid and be improperly credited for the storage output.
- The utilities were willing to enrol such systems in the net metering program if one of two conditions was met:
  1) The storage device only stores energy produced by the renewable energy system,
  2) The storage device serves only the customer and never discharges to the grid. It would require two separate meters capable of verifying that only renewable energy is being put onto the grid



What's the problem with wind energy?

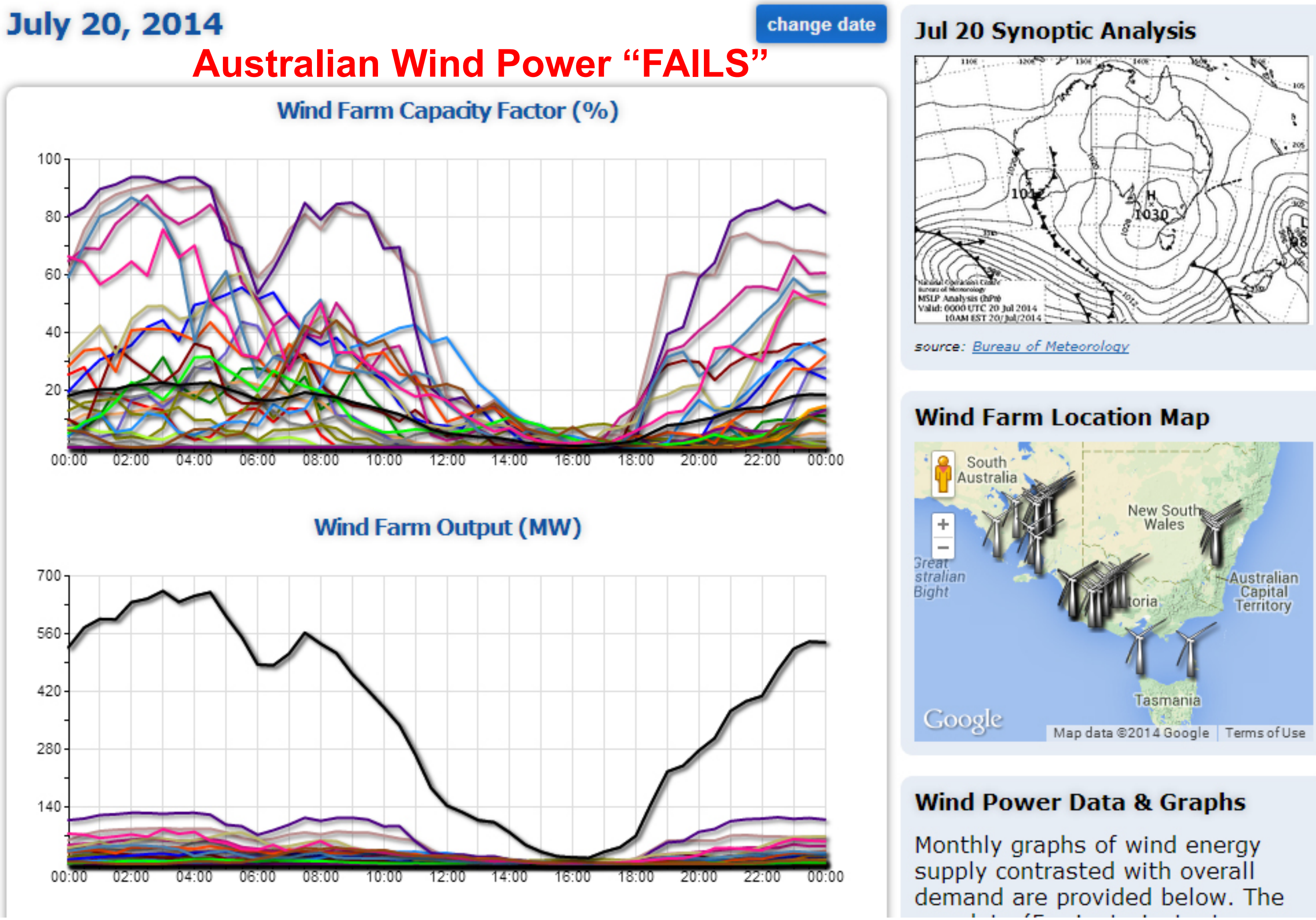


Figure Source: http://windfarmperformance.info/

Reading Sources:
http://stopthesethings.com/2014/08/04/more-australian-wind-power-fails/
http://www.heraldsun.com.au/business/when-the-wind-doesnt-blow-the-power-doesnt-switch-on/story-fni0d8gi-1226998025051

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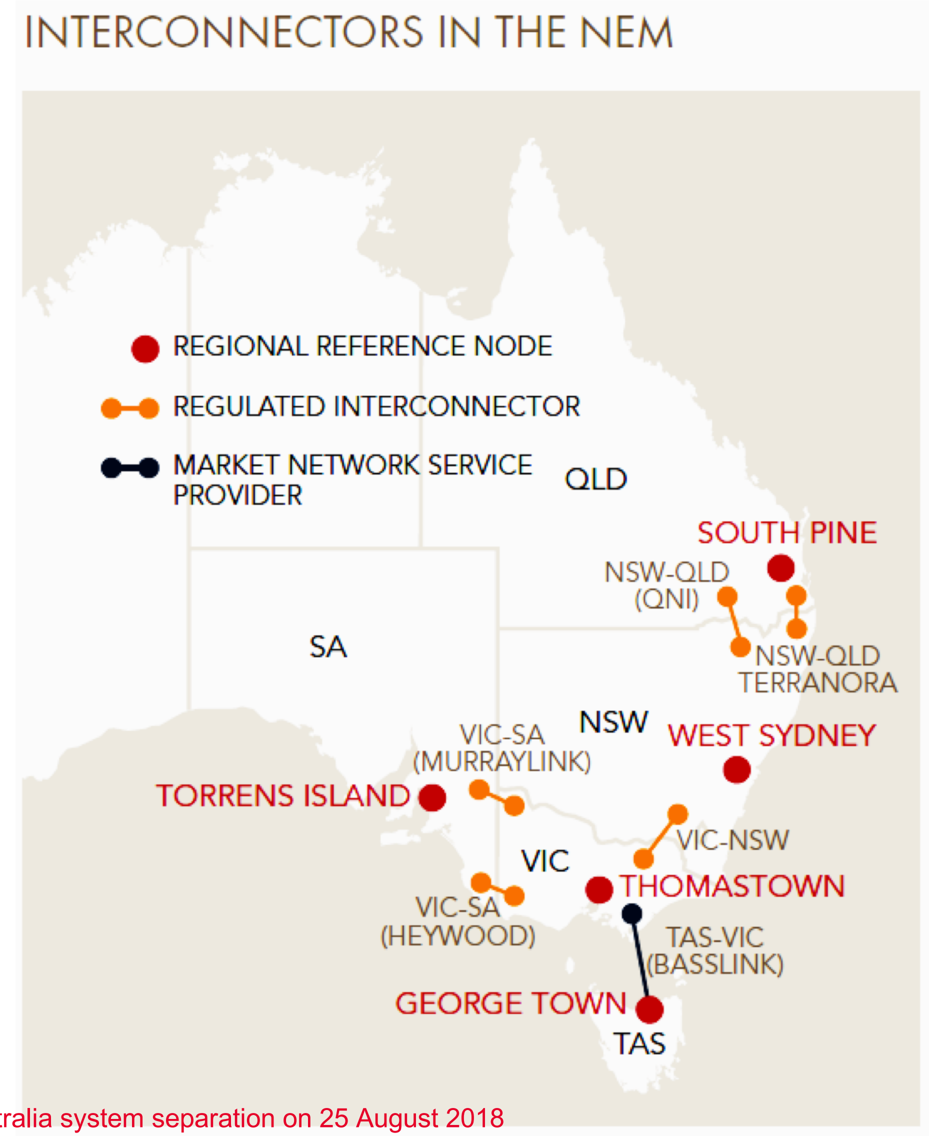
The South Australian Blackout, Wednesday 28 September 2016 -Wind Power Fails Again!

- As a result of cyclone damage to the transmission network, there were six voltage dips over a two-minute period.
- Wind turbines had protective features that result in a significant power reduction when they experience more than a pre-set number of voltage dips within a two-minute period.
- This information was unknown to AEMO. It was not provided to AEMO in the NEM connection process, nor is it included in AEMO's operational and planning modelling.
- A reduction in wind farm output of 456 megawatts (MW) from nine wind farms north of Adelaide over a period of less than seven seconds.
- The reduction in wind farm output resulted in a significant increase in power flow through the Heywood Interconnector.
- Approximately 700 milliseconds (ms) after the reduction of output from the last of these wind farms, the flow on the Victoria–SA Heywood Interconnector reached such a level that it activated a special protection scheme that tripped it and it went offline.
- The SA power system then became separated ("islanded") from the rest of the NEM, and the entire supply to the SA region was then lost due to a severe supply/demand imbalance ("Black System"), frequency transients, and other generators going off-line.

Source: AEMO report, BLACK SYSTEM SOUTH AUSTRALIA 28 SEPTEMBER 2016 THIRD PRELIMINARY REPORT

Queensland - South Australia system separation on 25 August 2018- PV and Wind are indirectly blamed for not helping

- On Saturday 25 August 2018, there was a single lightning strike on a transmission tower structure supporting the 330 kV Queensland – New South Wales interconnector (**QNI**). The lightning strike triggered faults on the interconnector at 13:11:39. The QLD and NSW power systems lost synchronisation, the QLD region was islanded at 13:11:41. At the time, 870 MW of power was flowing from QLD to NSW. QLD experienced an immediate supply surplus, resulting in a rise in frequency to 50.9 Hertz (Hz).
- The frequency controller on the **Basslink** interconnector between TAS and VIC immediately increased power flow from TAS to VIC from 500 MW up to 630 MW. This created a supply deficit in TAS, causing the disconnection of 81 MW of contracted interruptible load
- The SA–VIC interconnector at **Heywood** experienced rapid changes in power system conditions and tripped at at 13:11:47. At the time of separation at Heywood, SA was exporting power to VIC. This meant there was a supply surplus in SA immediately after separation, causing frequency to rise.
- In the remaining VIC/NSW island, the resulting power supply deficit caused frequency to fall below 49 Hz, triggering load shedding to rebalance supply and demand across those regions. A total of 997.3 MW of supply was interrupted in VIC.



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Source: AEMO, Final Report – Queensland and South Australia system separation on 25 August 2018

Queensland - South Australia system separation on 25 August 2018- PV and Wind are indirectly blamed for not helping

- **Synchronous generation** was providing 96% of the total generation in the NEM at the time of the event. The responses observed from synchronous generation during this event indicated that, unless enabled in the market for frequency control ancillary services, many generators either no longer automatically adjust output in response to local changes in frequency or only respond when frequency is outside a wider band (dead-band) than has historically been set.

- **Wind power generation** was low at 1.4% of total generation across all NEM regions at the time of the event. Of the wind generators online at the time, none was observed to assist in correcting the frequency deviations. Four wind farms in SA reduced output to zero due to an incorrect protection setting.

- **Utility-scale PV generation** was also low, at 2.7% of total generation across the NEM. It generally contributed to lowering frequency in SA and QLD but was not able to assist in limiting the initial frequency fluctuations.

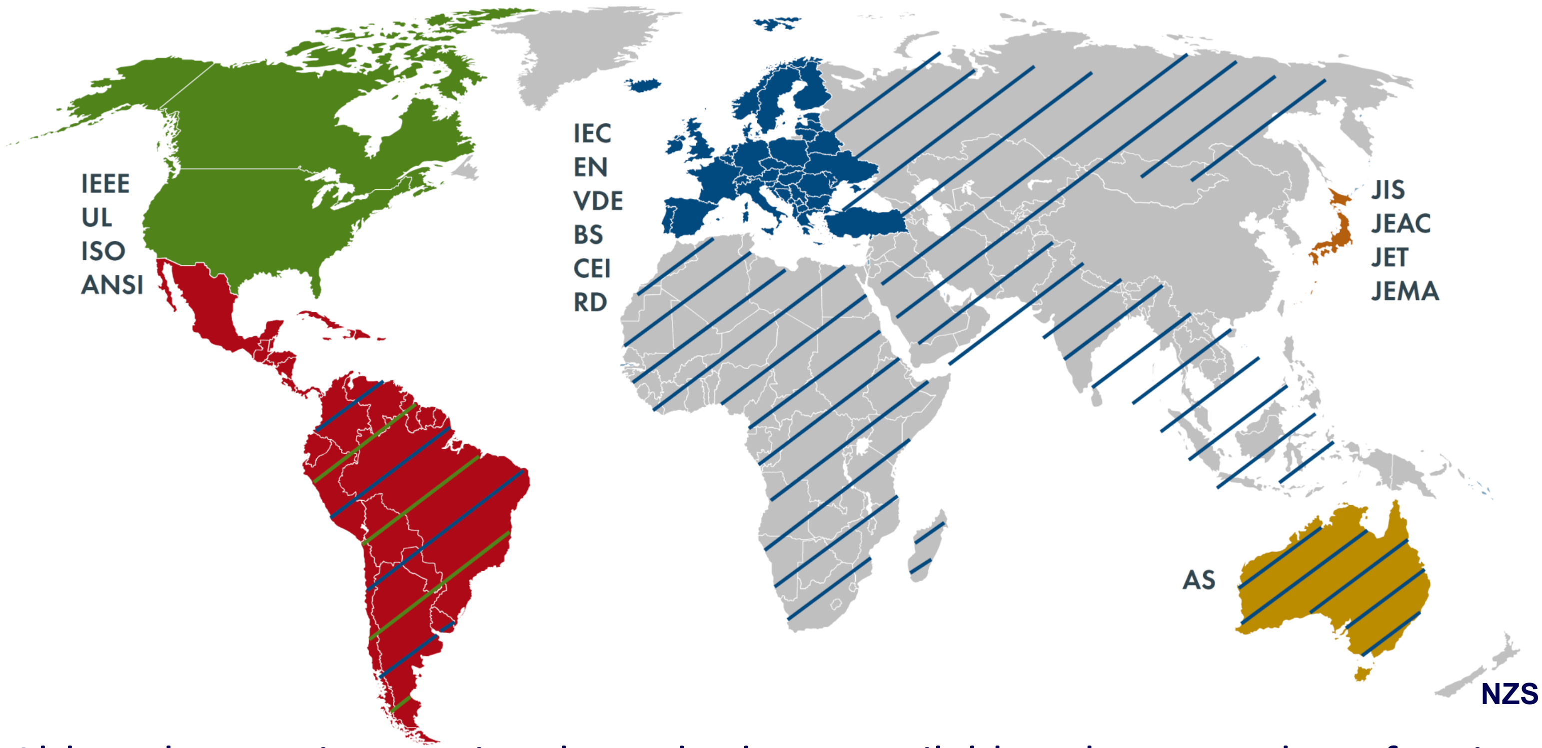
- Approximately 3,096 MW of **Distributed PV** of the total installed capacity of 6,278 MW across the NEM was generating at the time of the event. Similar to large-scale PV, the distributed fleet of solar PV generally contributed to assist frequency management in QLD and SA over the course of the event by reducing output. It was not able to assist in VIC or NSW, as those regions required an increase in supply.

- The **transmission system -connected large-scale battery storage** in SA was valuable in this event, assisting in containing the initial decline in system frequency, and then rapidly changing from the discharging to charging mode, to limit the over frequency condition in SA following separation from VIC.

Source: AEMO, Final Report – Queensland and South Australia system separation on 25 August 2018

In all the incidents, PV and wind could help. But we don't have proper grid codes in Australia to mandate frequency and voltage control support from them.

The Worlds of International Standards and Grid Codes



Although many international standards are available, a large number of national standards are designed to meet local needs and sometimes to fulfil political and vested interests

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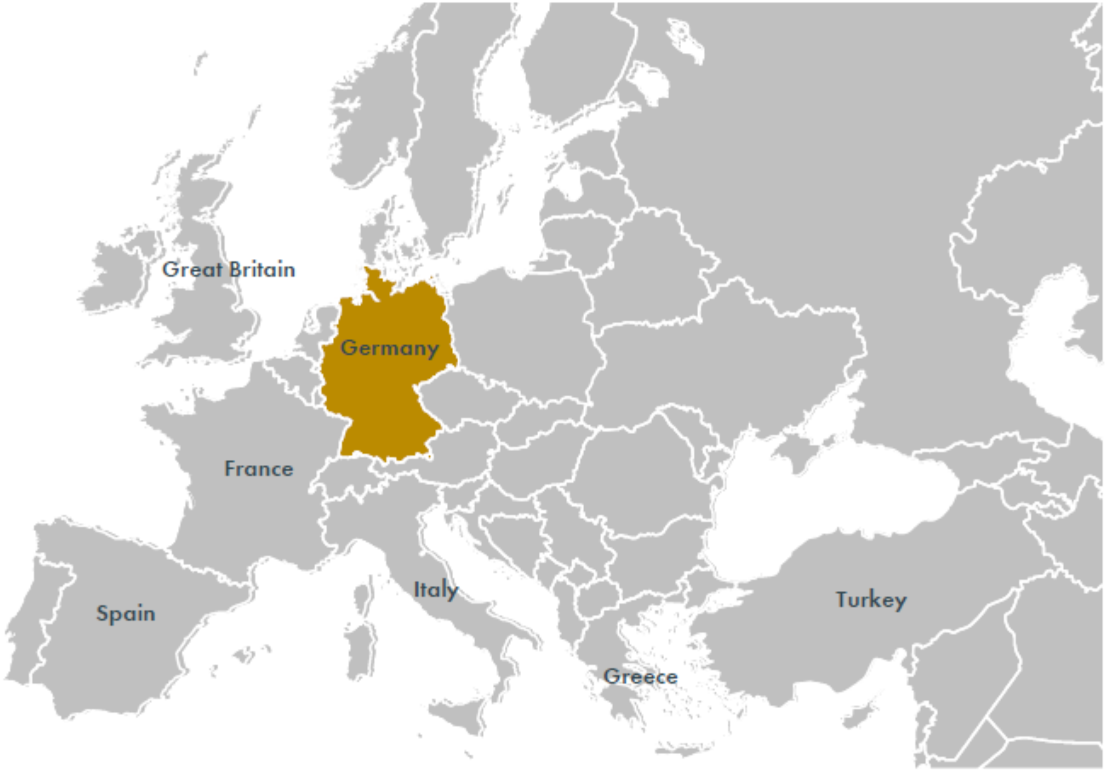
Fig. Source: International Grid Codes and Local Requirements – the Evolvement of Standards for Distributed Energy Resources and Inverter Technology, H. Knopf

The German Scenario



> **Geography**:
Centrally located

> **Grid structure**:
Highly interconnected with neighbouring countries

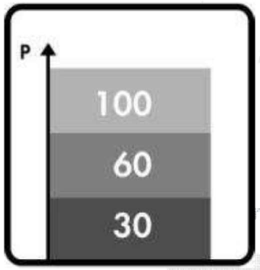
> Installed **renewable power** vs. installed **total power**:
30 GW PV
30 GW Wind
= **60 GW renewable**
vs. **172 GW total**

> Maximum load: 80 GW

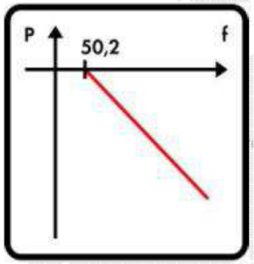
85% of PV power installed in the low voltage grid!

Fig. Source: International Grid Codes and Local Requirements – the Evolvement of Standards for Distributed Energy Resources and Inverter Technology, H. Knopf

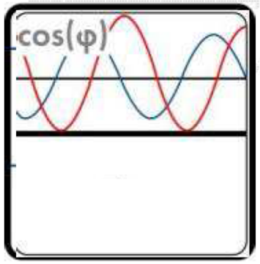
National Grid Standards and Requirements in Germany



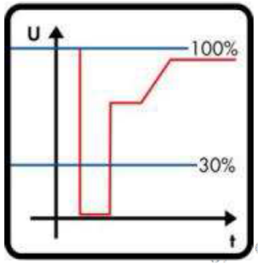
Power Curtailment – to control local over load conditions
> Ability to control PV generation to a specified % of nominal power rating



Frequency Support – for generation load balancing & to solve 50.2 Hz problem
> Ability to automatically reduce active power with increasing frequency



Voltage Support – to control local voltage levels
> Ability to supply/absorb reactive power during PV operation
> Ability to Control Power Factor



Dynamic Grid Support / Fault Ride Through (FRT)
> Zero Power Mode
> Ability to supply reactive current during fault ride-through period

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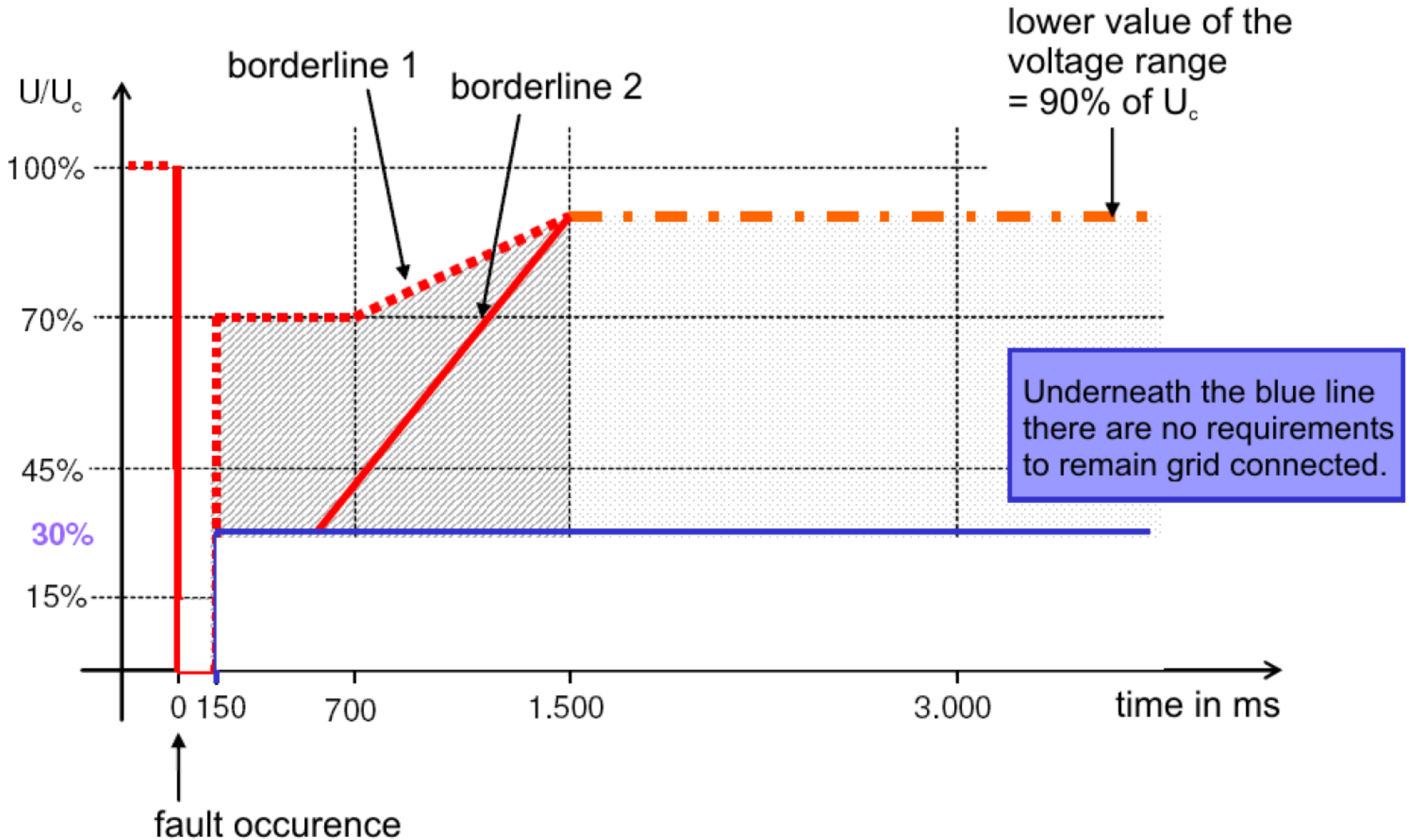
Fig. Source: International Grid Codes and Local Requirements – the Evolvement of Standards for Distributed Energy Resources and Inverter Technology, H. Knopf

German Grid Codes

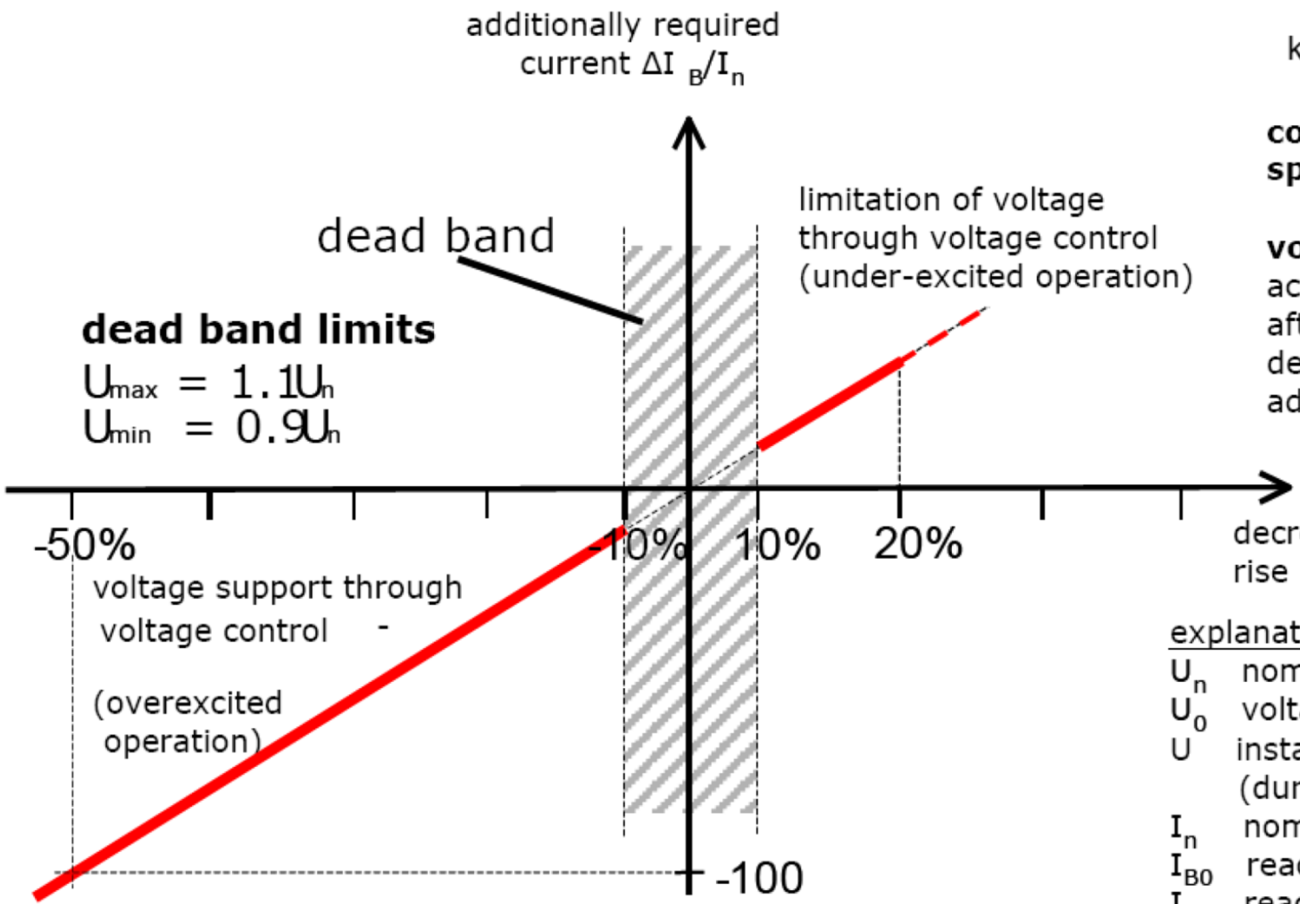
German Grid Codes when penetration of PV power is more than 10% of total load in an area



Source: http://www.concentrating-pv.org/darmstadt2009/pdf/papers/24-Troester-GermanGridCodes.pdf

German Grid Codes

German Grid Codes when penetration of PV power is more than 10% of total load in an area



$$k = \frac{\Delta I_B/I_n}{\Delta U/U_n} \geq 2.0 \text{ p.u.}$$

control response time < 20 ms

voltage support according to characteristic after return to voltage dead band over additional 500 ms

explanations:

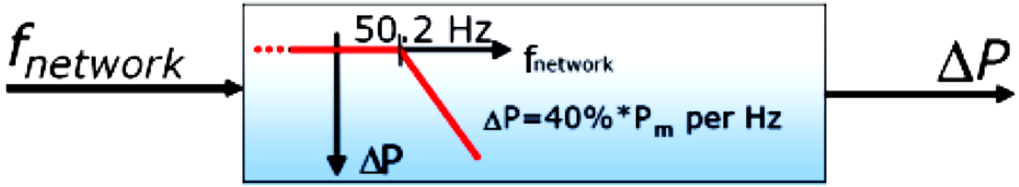
- U_n nominal voltage
- U_0 voltage prior to disturbance
- U instantaneous voltage (during the disturbance)
- I_n nominal current
- I_{B0} reactive current prior to dist.
- I_B reactive current

$\Delta U = U - U_0$; $\Delta I_B = I_B - I_{B0}$

Source: http://www.concentrating-pv.org/darmstadt2009/pdf/papers/24-Troester-GermanGridCodes.pdf

German Grid Codes

German Grid Codes when penetration of PV power is more than 10% of total load in an area



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

P_m instantaneously available power

ΔP power reduction

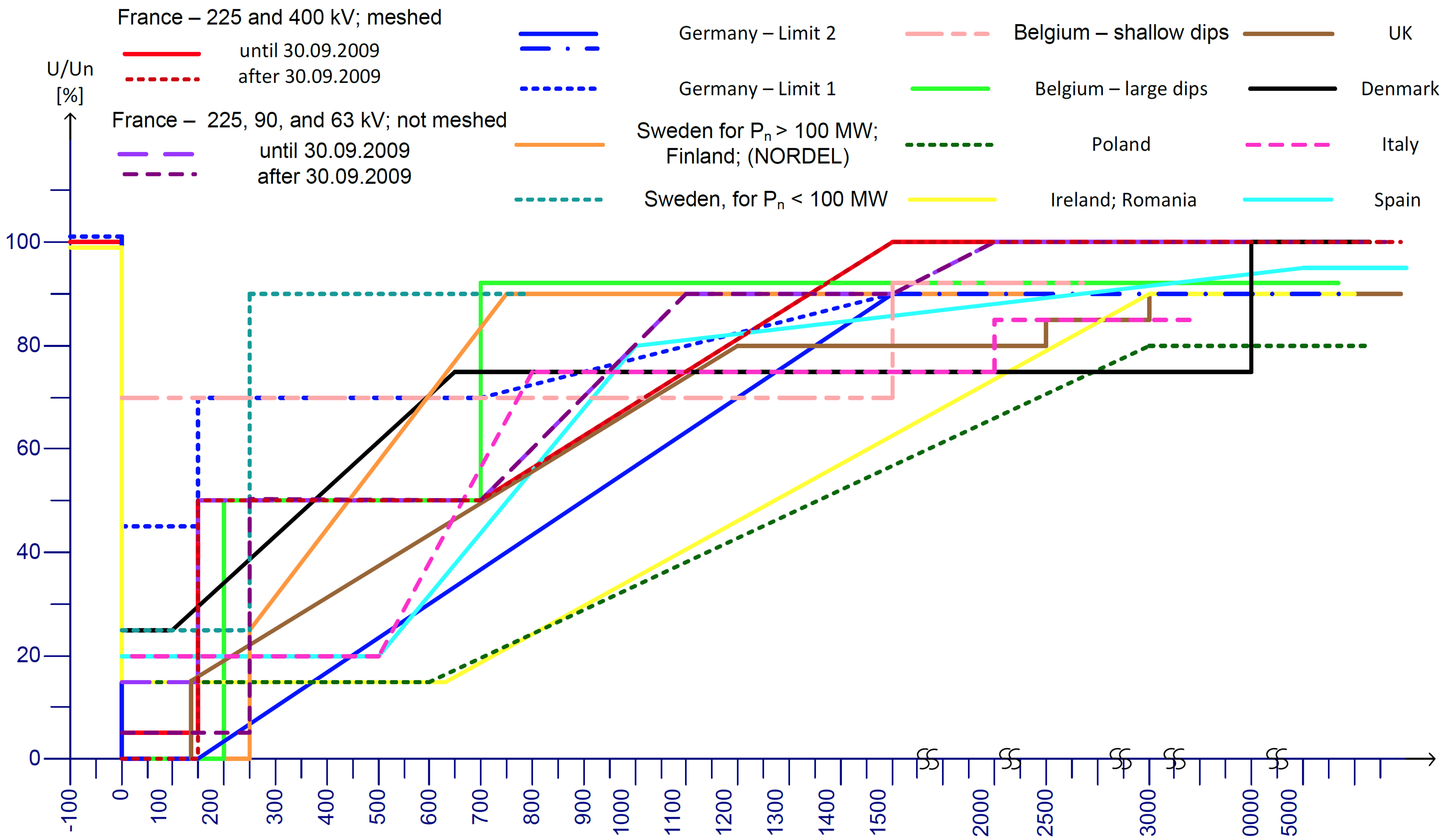
$f_{network}$ network frequency

within the range of $47.5\text{ Hz} < f_{network} \leq 50.2\text{ Hz}$ no limitation

at $f_{network} \leq 47.5\text{ Hz}$ and $f_{network} \geq 51.5\text{ Hz}$ disconnection from the grid

Source: http://www.concentrating-pv.org/darmstadt2009/pdf/papers/24-Troester-GermanGridCodes.pdf

Wind Power FRT Requirements in Europe



Source: W. L. Kling, L. Söder, I. Erlich, P. Sørensen, M. Power, H. Holttinen, J. Hidalgo, B. G. Rawn, "Wind power grid integration: The European experience", *Proc. 17th PSCC*, 2011.

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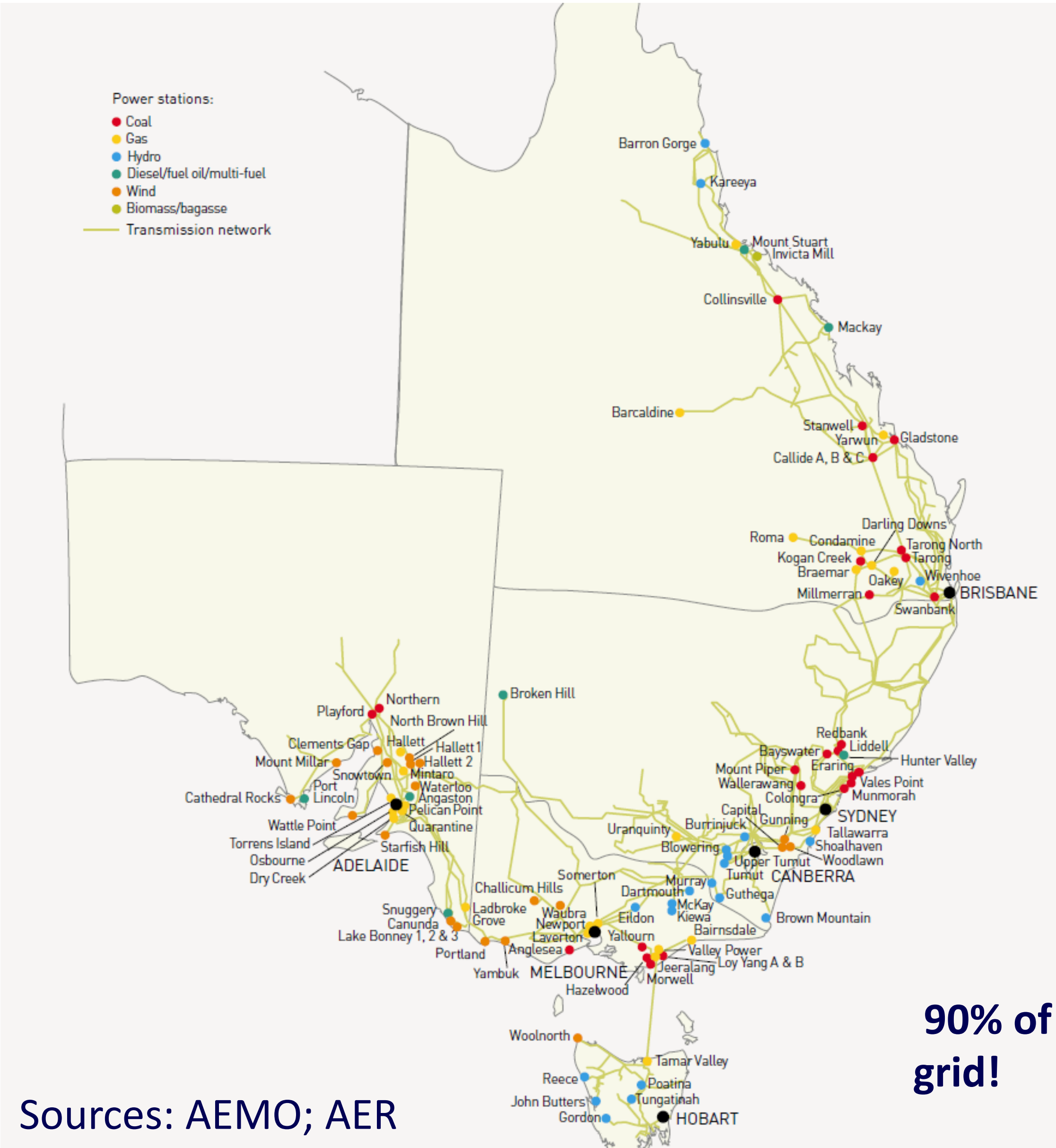
The Australian Scenario



Sources: AEMO; AER

> **Geography**:
  Islands

> **Grid structure**:
  Radial (50 Hz)

> Installed **renewable power**
  vs. installed **total power**:
  12 GW PV
  6 GW Wind
  = **18 GW renewable**
  vs. **54 GW total**

> Maximum load: 35 GW

90% of PV power installed in the low voltage grid!

Australian Grid Codes

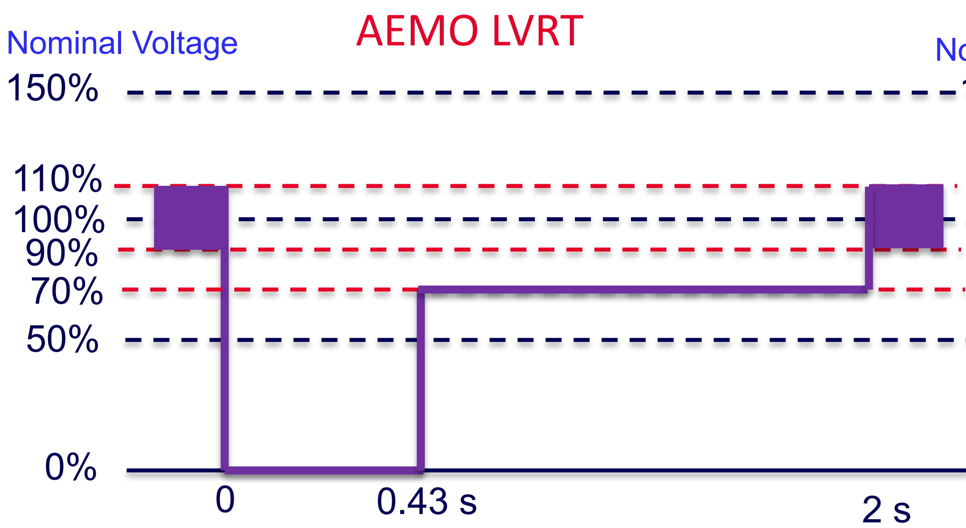
- **Electricity Distribution Code May 2012 Version 7**

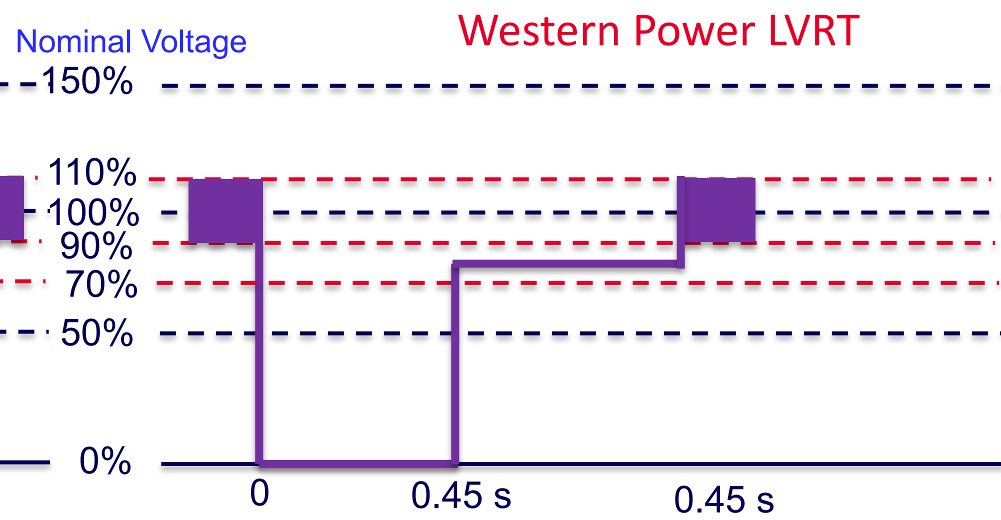
- **Australian Standard™ (2005)**
  - Grid connection of energy systems via inverters
    - ✓ AS 4777.1—2005: Part 1: Installation requirements
    - ✓ AS 4777.2—2005: Part 2: Inverter requirements
    - ✓ AS 4777.3—2005: Part 3: Grid protection requirements

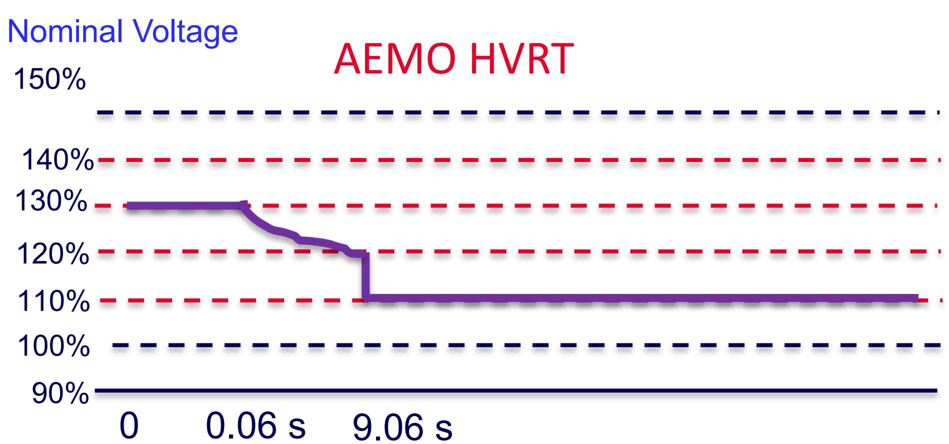
AS 4777.2—2005 is replaced by AS/NZS 4777.2-2015

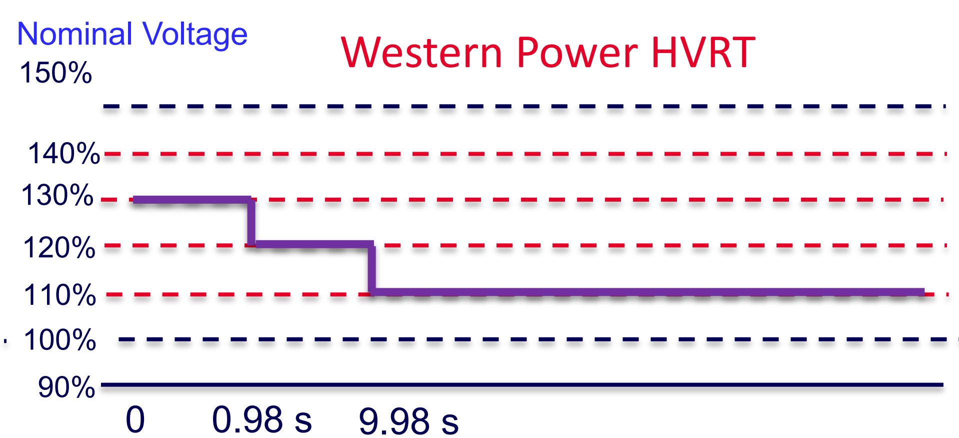
- **Australian Standard™ New Zealand Standard™ (2015)**
  - Grid connection of energy systems via inverters
    - ✓ AS/NZS 4777.2---2015: Part 2: Inverter requirements

Wind Power: LVRT and HVRT Requirements in Australia

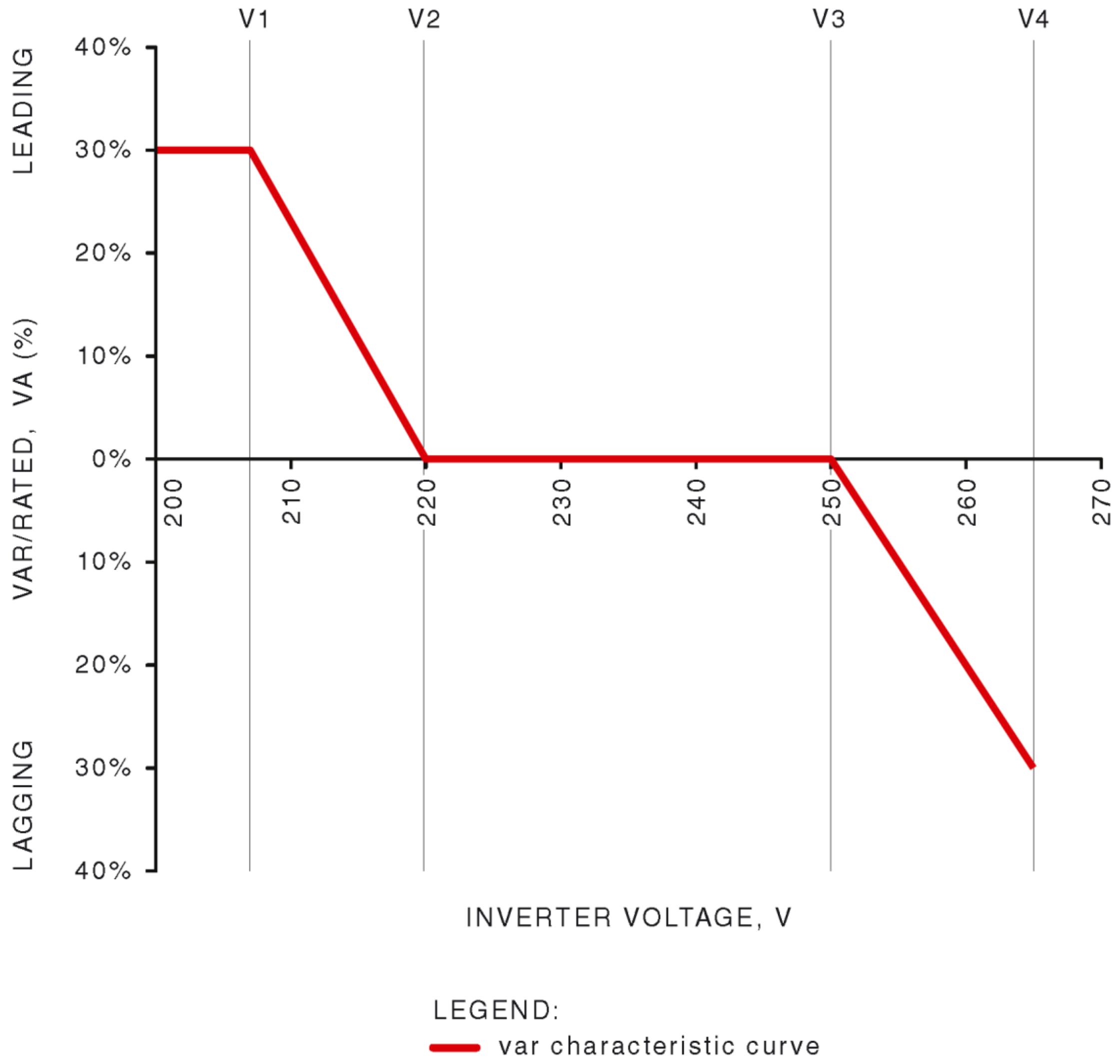








AS/NZS 4777.2—2015
DG Inverter Requirements



EXAMPLE CURVE FOR A POSSIBLE VOLT–VAR CONTROL MODE (AUSTRALIA)

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AS/NZS 4777.2—2015
DG Inverter Requirements

5.8 Transient voltage limits

- To prevent damage to electrical equipment connected to the same circuit as the inverter, disconnection of the inverter from the grid shall not result in transient over voltages beyond the limits specified in Table 4.
- Compliance shall be determined by type testing in accordance with the transient voltage
- limit test specified in Appendix D of AS/NZS 4777.2.
- The voltage-duration curve is derived from the measurements taken at the grid-interactive port of the inverter.
- The transient voltage limits listed in Table 4 are graphically illustrated in Figure 1.

TABLE 4

TRANSIENT VOLTAGE LIMITS

Duration	Instantaneous voltage	
	Line-to-neutral	Line-to-line
s	V	V
0.0002	910	1580
0.0006	710	1240
0.002	580	1010
0.006	470	810
0.02	420	720
0.06	390	670
0.2	390	670
0.6	390	670

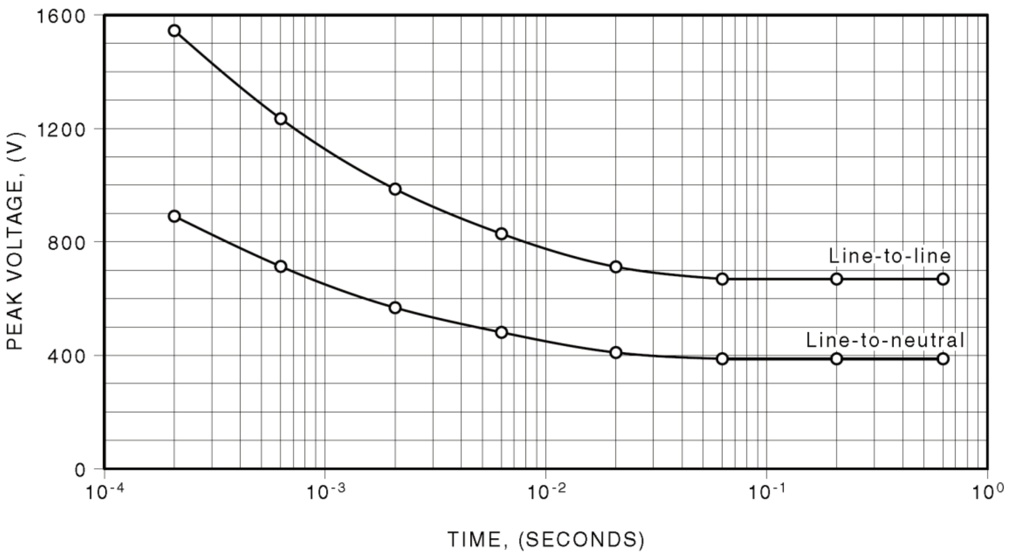
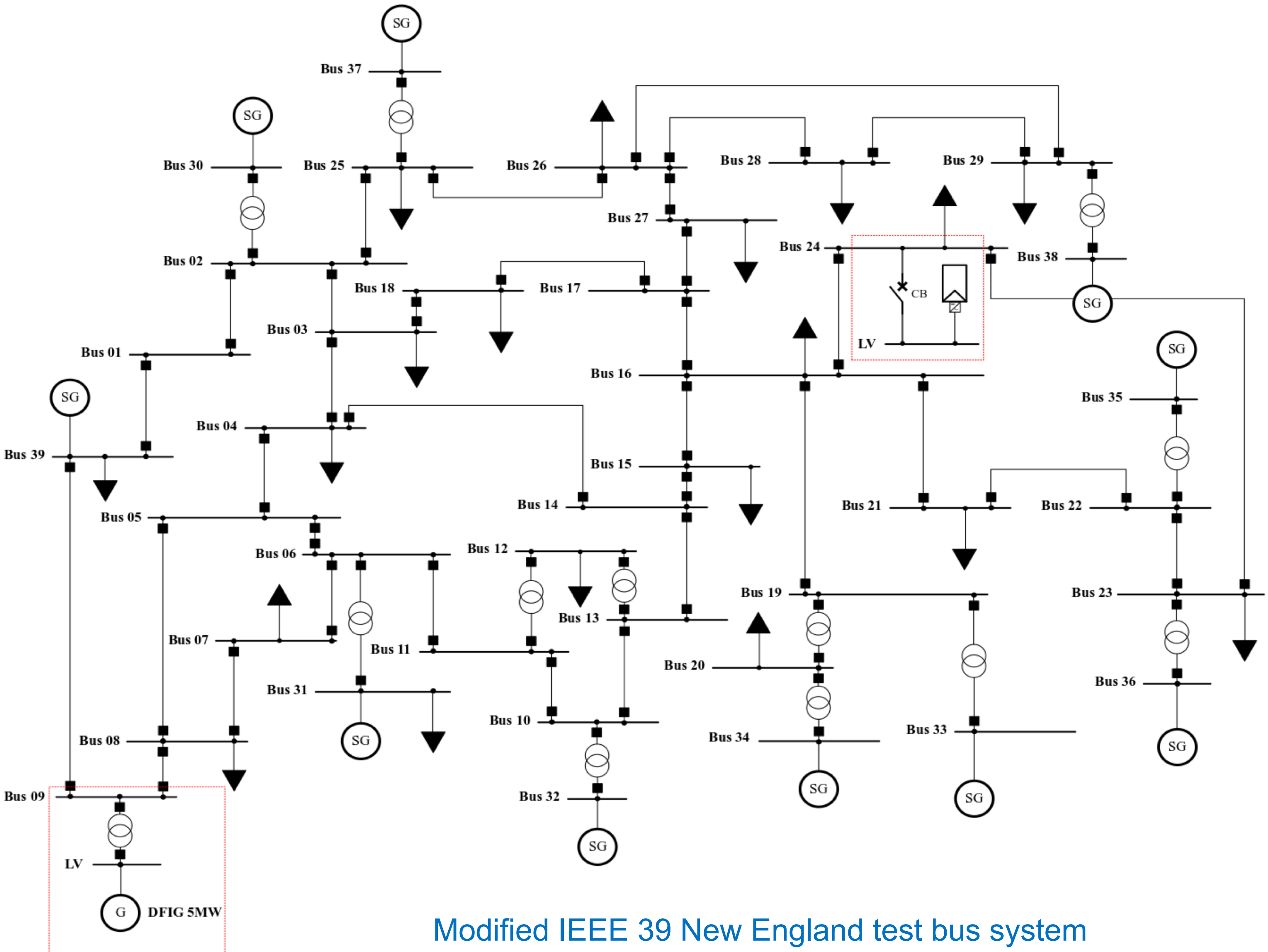


FIGURE 1 VOLTAGE-DURATION CURVE OF TRANSIENT VOLTAGE LIMITS

PV Integration Challenges: Mitigation Strategy 1

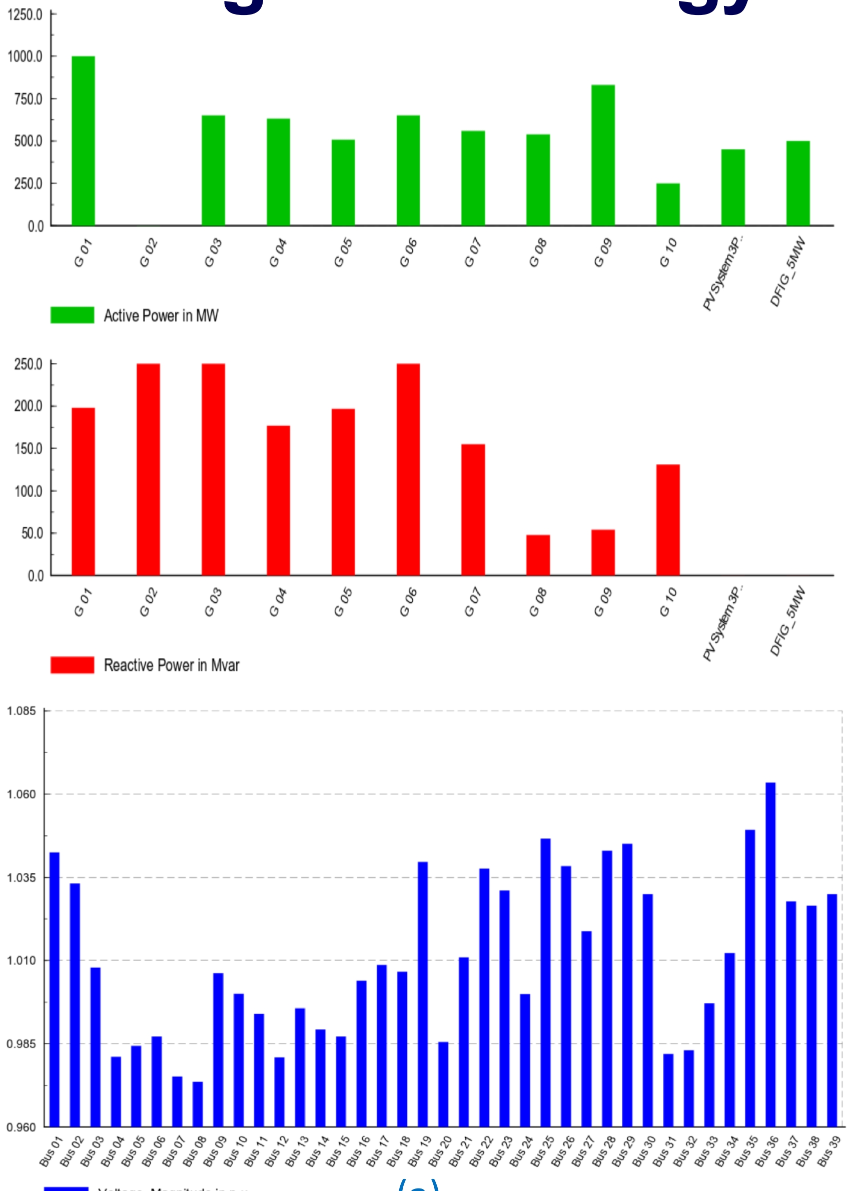
Reactive power and voltage control: Optimisation and coordination- who, where, and when???



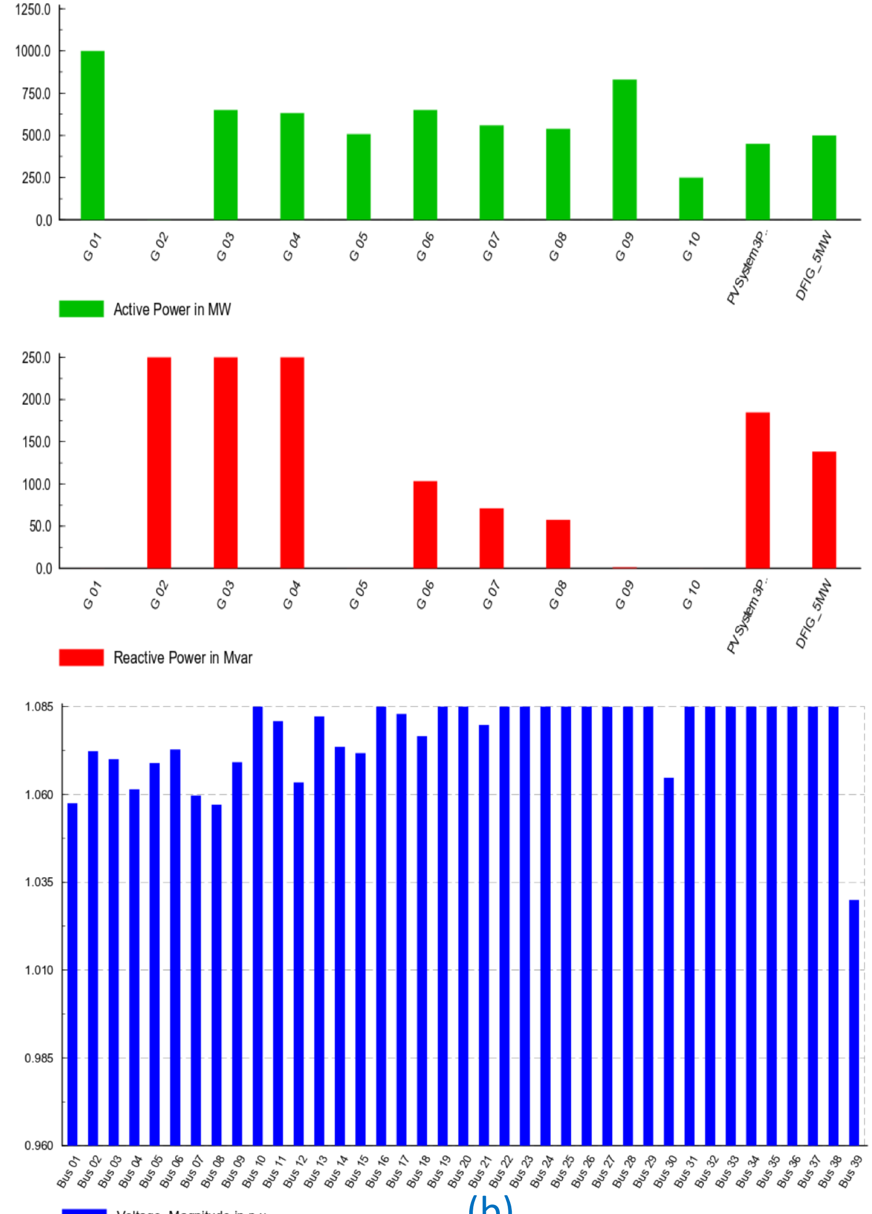
Modified IEEE 39 New England test bus system

PV Integration Challenges: Mitigation Strategy 1

Reactive power and voltage control: Optimisation and coordination



(a)



(b)

(a) Bus voltages before optimization and (b) bus voltages after optimization

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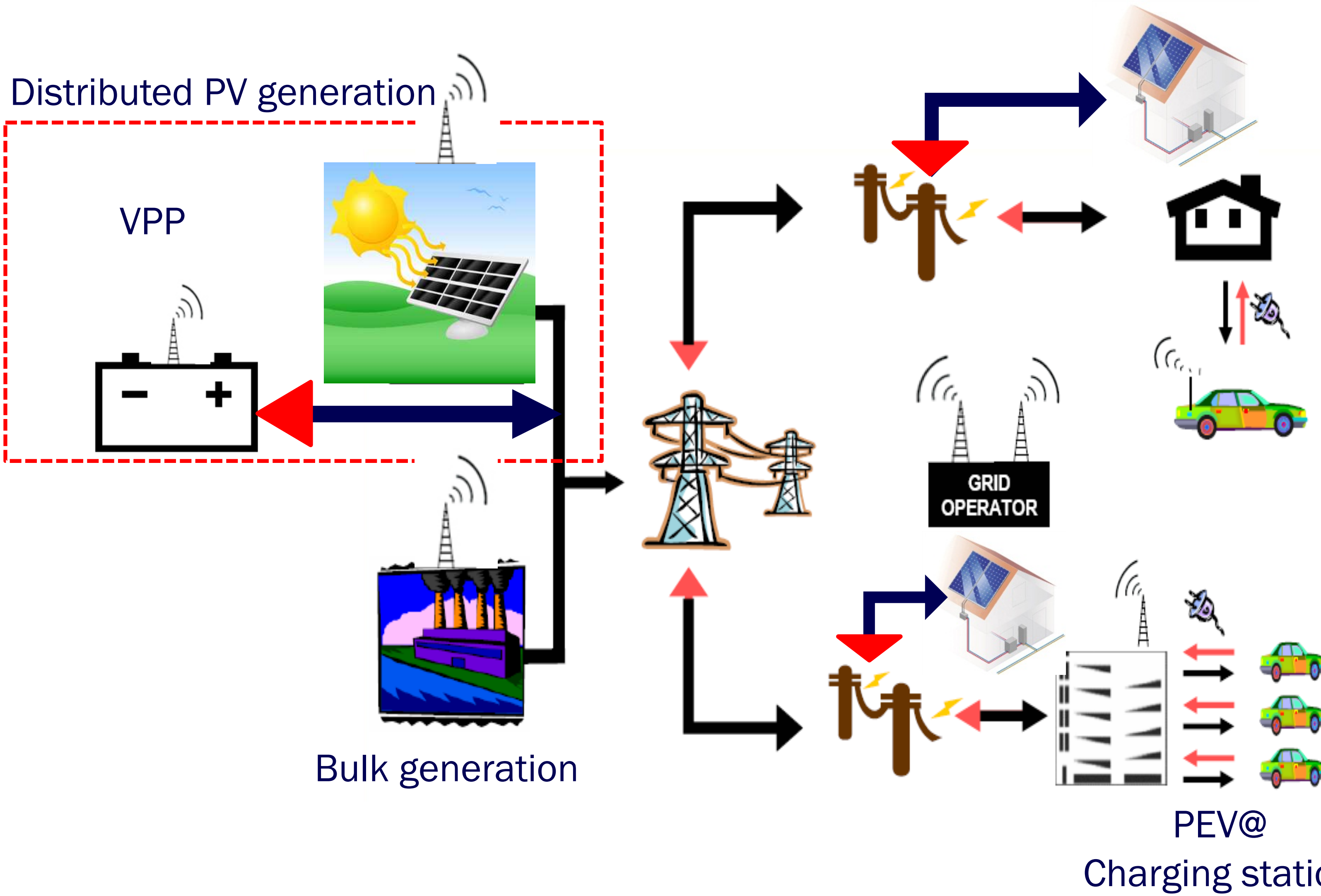
PV Integration Challenges: Mitigation Strategy 2

Virtual Inertia Mimicking or so called
Virtual Power Plant (VPP)
For Primary Frequency Control



PV Integration Challenges: Mitigation Strategy 2

Virtual Inertia Mimicking or so called Virtual Power Plant (VPP) For Primary Frequency Control

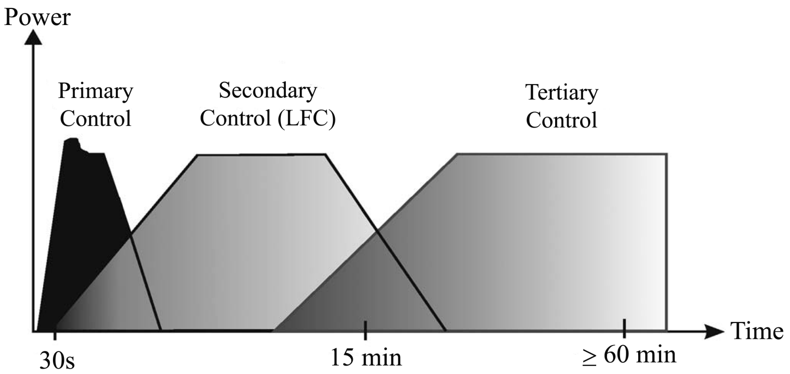


Fig. Approximate time scales of frequency control-reserve activation and delivery

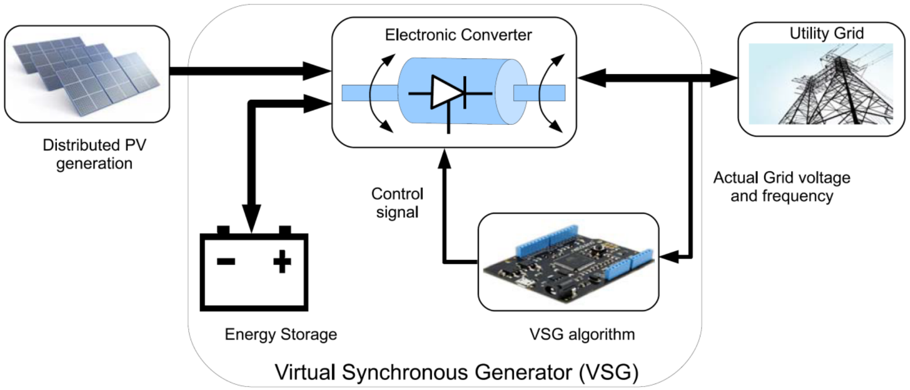


Fig. The layout of a VSG

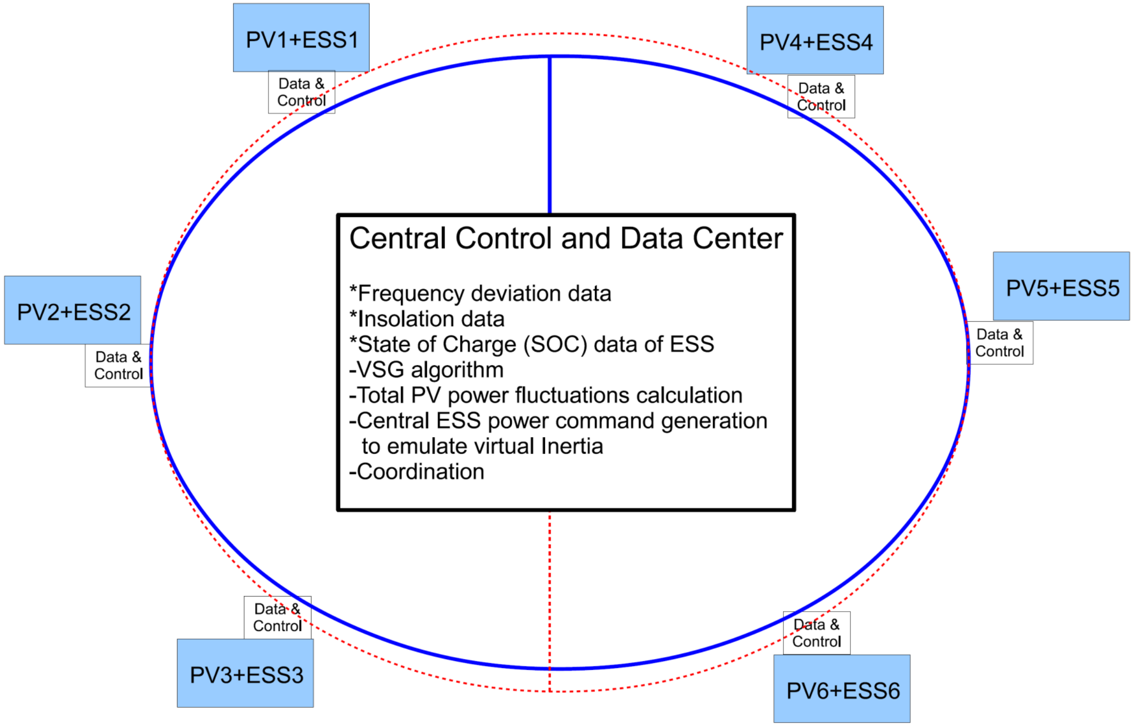


Fig. The coordination of the VSGs

PV Integration Challenges: Mitigation Strategy 2

Virtual Inertia Mimicking or so called
Virtual Power Plant (VPP)
For Primary Frequency Control

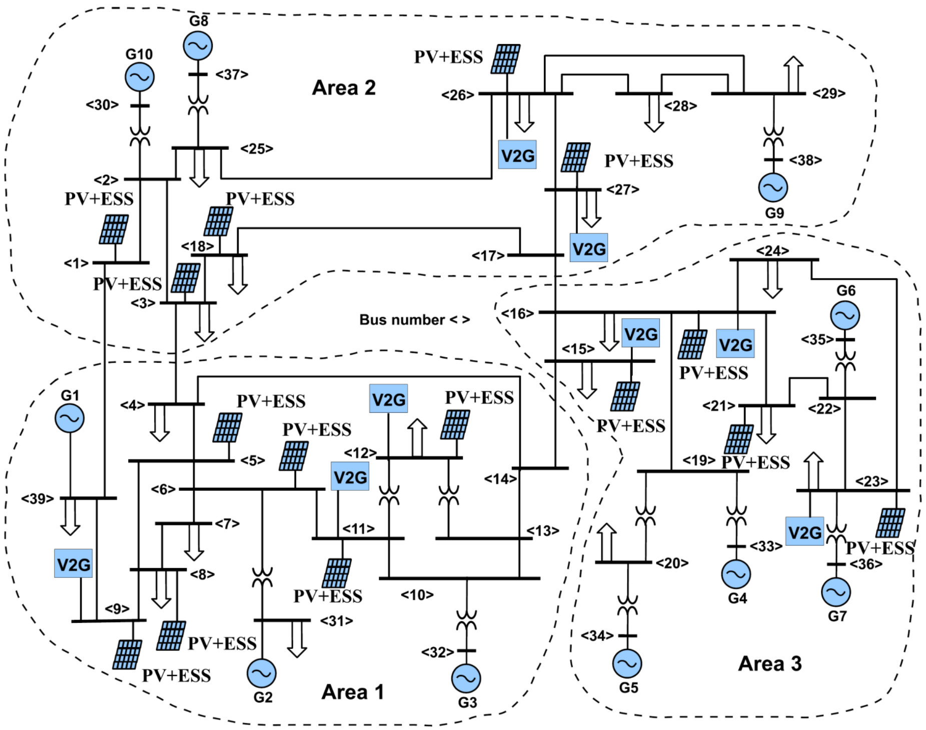


Fig. Single line diagram of 39-bus test system.

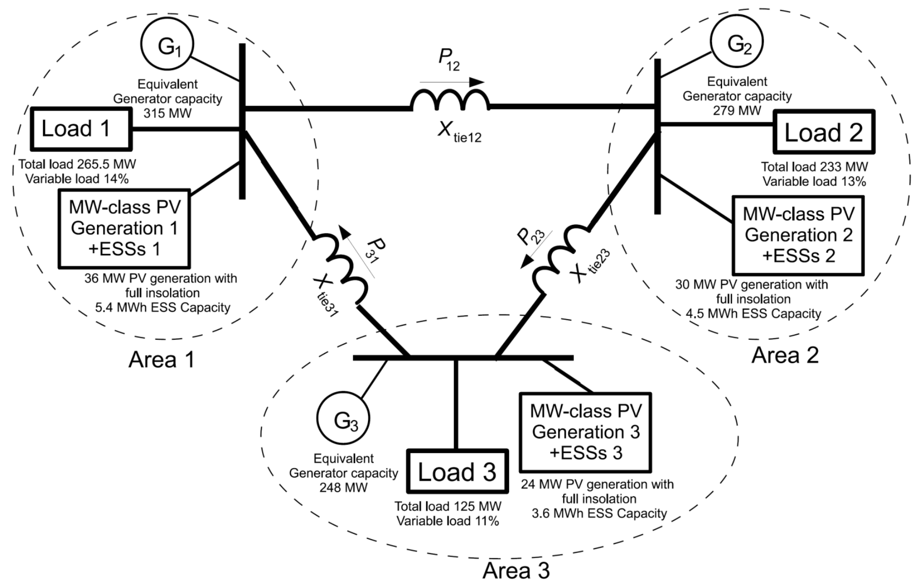


Fig. Three control area representation of the 39-bus power system.

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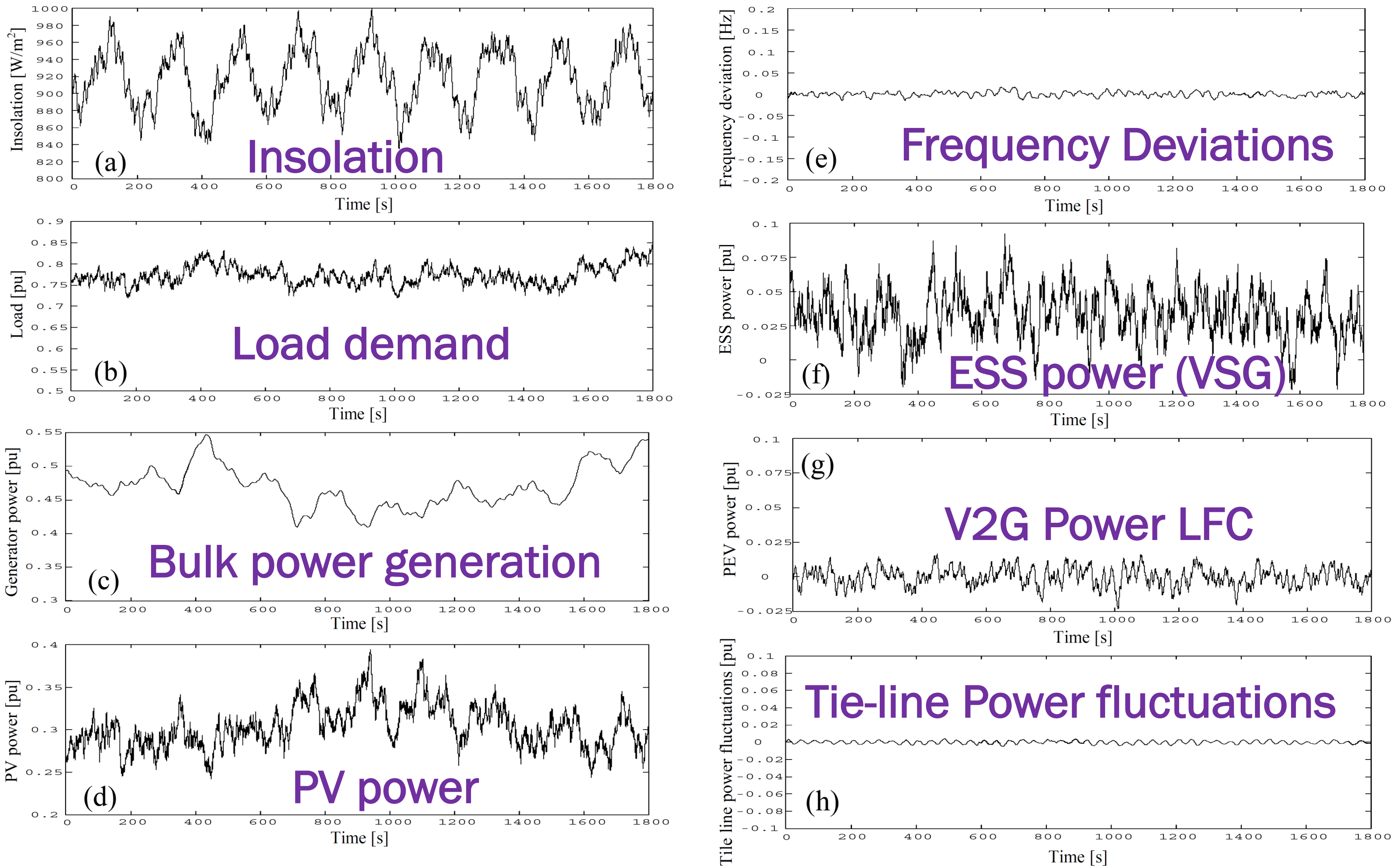
PV Integration Challenges: Mitigation Strategy 2

Virtual Inertia Mimicking or so called
Virtual Power Plant (VPP)
For Primary Frequency Control



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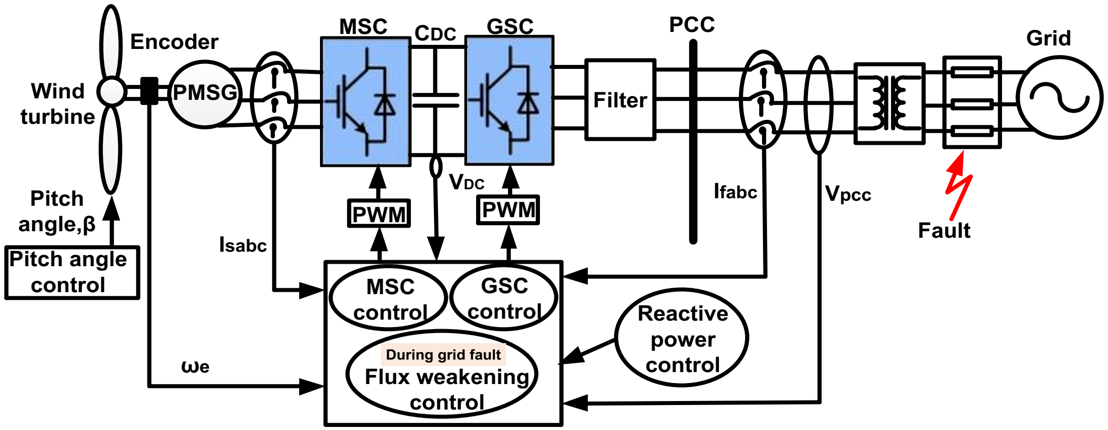
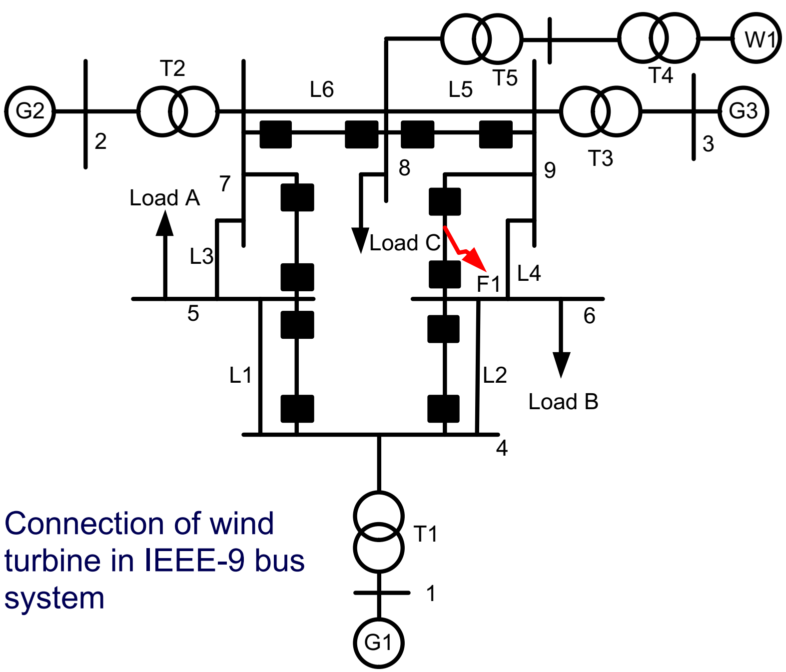
Results: LFC by Coordinated Virtual Inertia Mimicking

Wind Integration Challenges: Mitigation Strategy 1

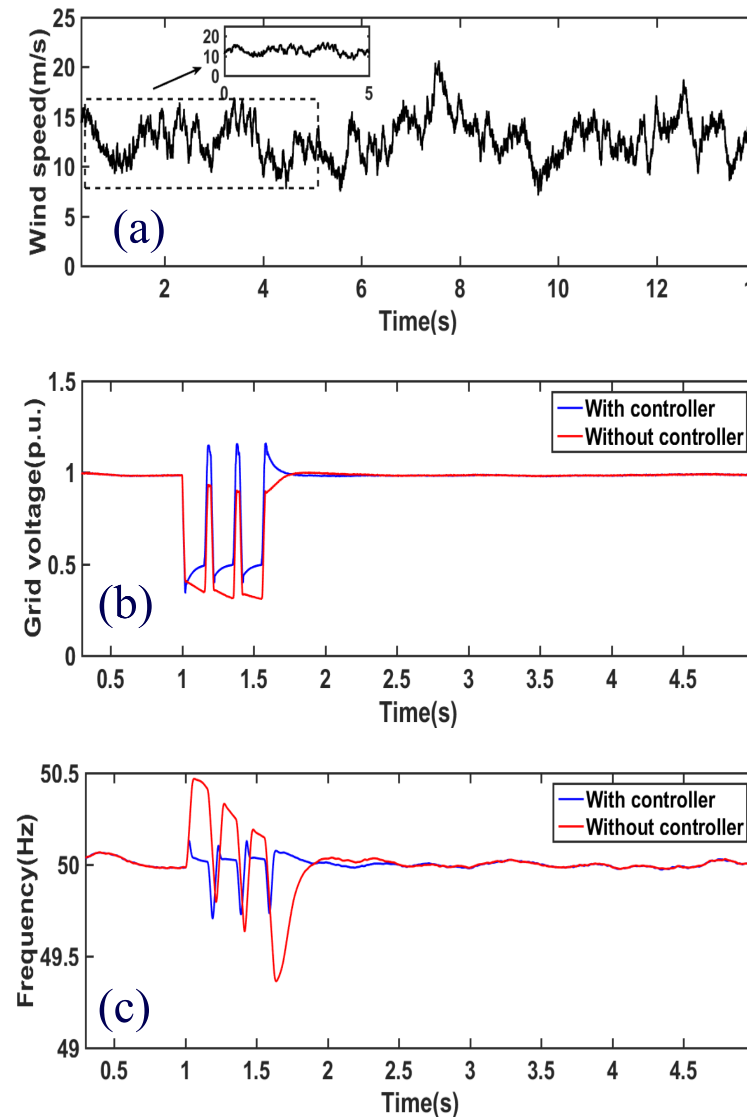
Fault Ride Through (FRT) for repetitive grid faults



FRT coordinated control diagram



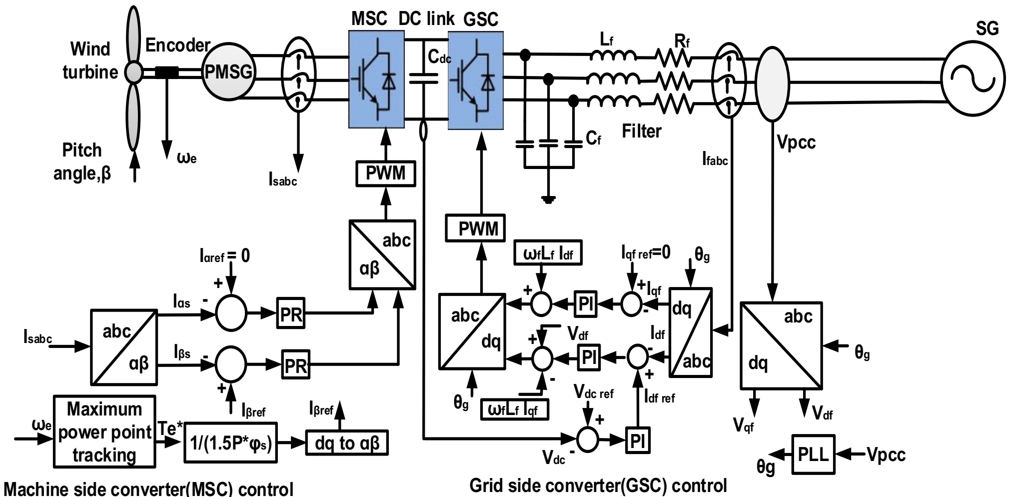
Connection of wind turbine in IEEE-9 bus system



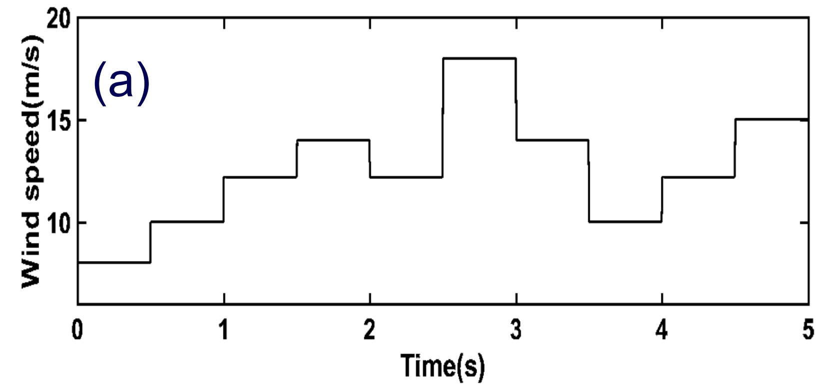
Results for symmetrical fault a) Variable wind speed b) Grid voltage c) Grid frequency

Wind Integration Challenges: Mitigation Strategy 2

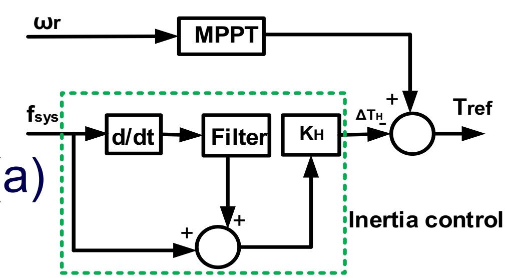
Frequency Supports after grid faults



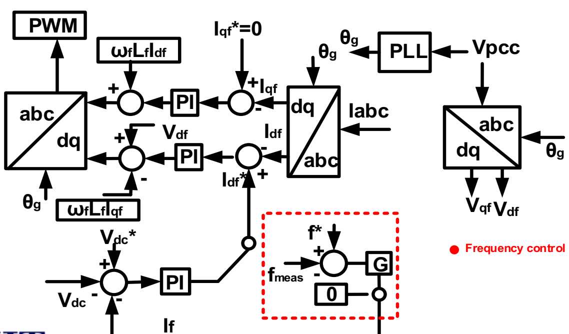
PMSG based WECS with back to back converter



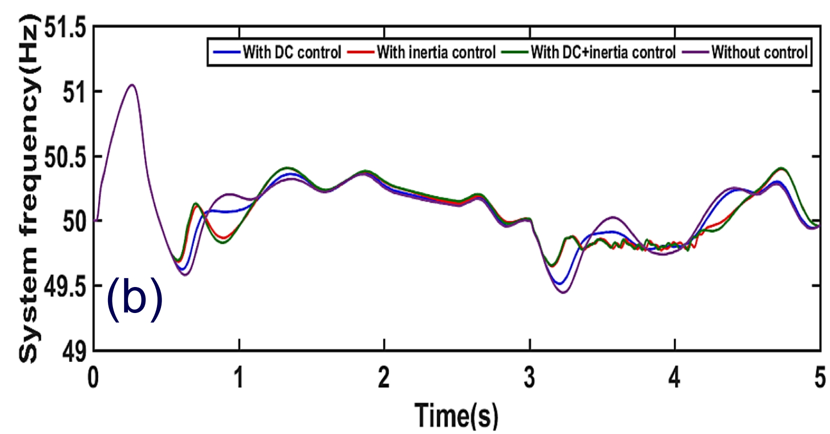
(a)



(b)



Frequency control. (a) Block diagram for MSC (b) Block diagram for GSC



Results for step wind speed. (a) Wind speed (b) System frequency for different controller

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Some Recommendations

- ✓ Our grid codes need to be modified. It's quite backdated compared to the grid codes world-wide
- ✓ Policy makers, regulators, technology innovators, researchers and academics need to work together with the government
- ✓ The blame game should stop, specially the propaganda against renewable energy
- ✓ Technology in the power and energy domain has advanced sufficiently enough to mitigate most of the PV and wind integration challenges. We need to embrace the technology and increase public awareness
- ✓ Real time transmission system and supply charge are a must to reduce electricity prices
- ✓ Optimal size of transmission level storages as well as cheaper residential energy storage will be a game changer
- ✓ Pumped hydro has a huge potential in Australia, specially in the secondary and tertiary frequency control. However, for the primary frequency control we need to depend on the quick acting generators

Thanks
Questions /Comments ?????????

"Upcoming Seminar":

Prof Andreas Löschel: *The Energy Transition and the Politics of Coal in Germany*, Tuesday 16 July (10.30am) @ the College