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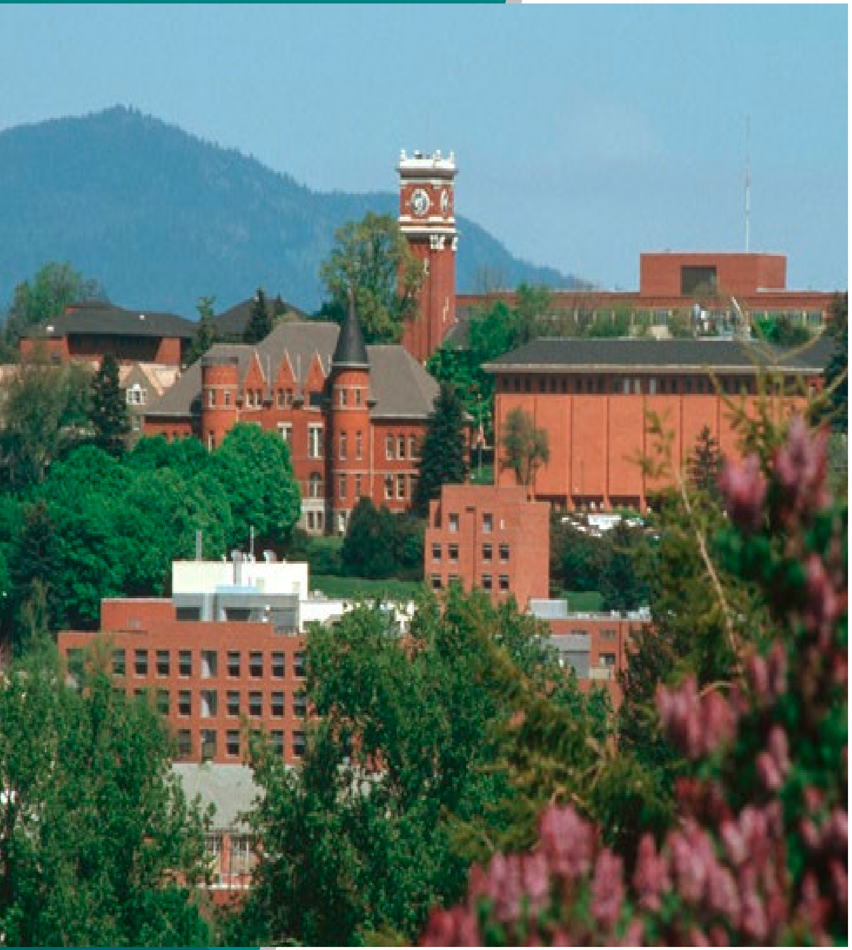


Evolution of Power Grid Control Centers

Anjan Bose
Washington State University
Pullman, Washington

International Symposium Smart Grid

Shandong, CHINA

October 29, 2021

Thoughts I want to leave you with

The low carbon future

- How are we going to get there?

The technology enablers

- Smart grid (sensors, computers, communications, power electronics, etc)

The policy enablers

- Mandatory clean energy vs cost

Different countries will take different paths

Control Centers before 1960s

- Hard wired metering
- Ink chart recording
- Light and sound alarming
- Hard wired remote switching
- Analog Load Frequency Control (1930s)
- Economic Dispatch (1950s)
- ED was first to go digital

The Present (since 1960s)

- The digital control center (SCADA-AGC)
- The RTU to gather digital data at substation
- Comm. channel from sub to control center (CC)
- The SCADA
  - The Data Acquisition from RTU to CC
  - The Supervisory Control signal from CC to RTU
- The screen based operator display
- Automatic Generation Control (AGC)
  - The digital algorithm for ED
  - The digital version of LFC

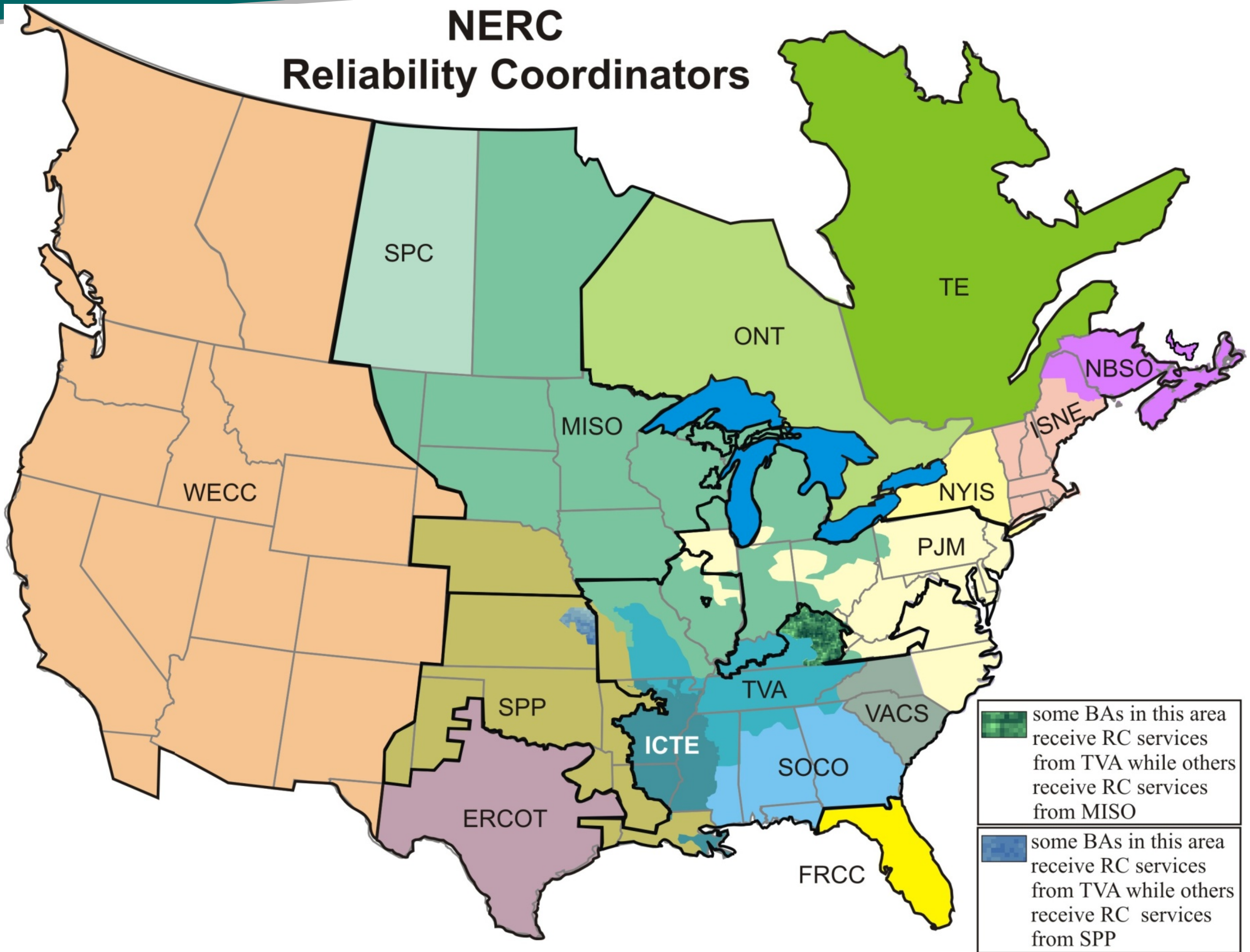
The Present (since 1970s)

- The Energy Management System (EMS)
- State Estimation (SE)
- Static Security Analysis (n-1)
- Dynamic Security Analysis (stability)
  - Transient, Oscillatory, Voltage
- Optimal Power Flow based analysis
  - Preventive Action calculation
  - Corrective Action calculation

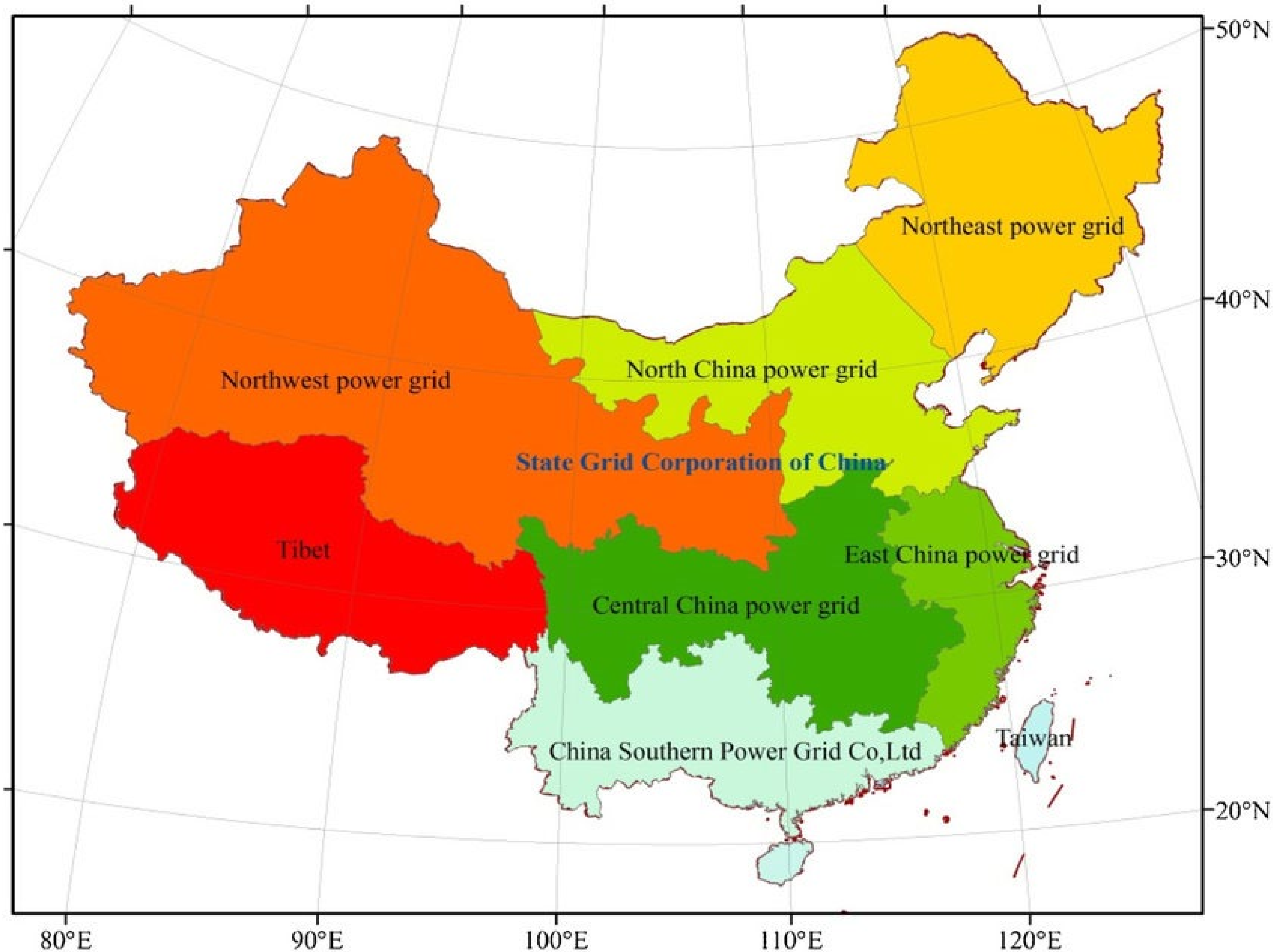
Evolution of Control Center Architecture

- Special real time computers for SCADA-AGC
- Mainframe computer back ends for EMS
- Redundant hardware configuration with checkpoint and failover
- Multiple workstation configuration
  - Back-up is more flexible
- Open architecture initiated
- CIM (Common Information Model) standard

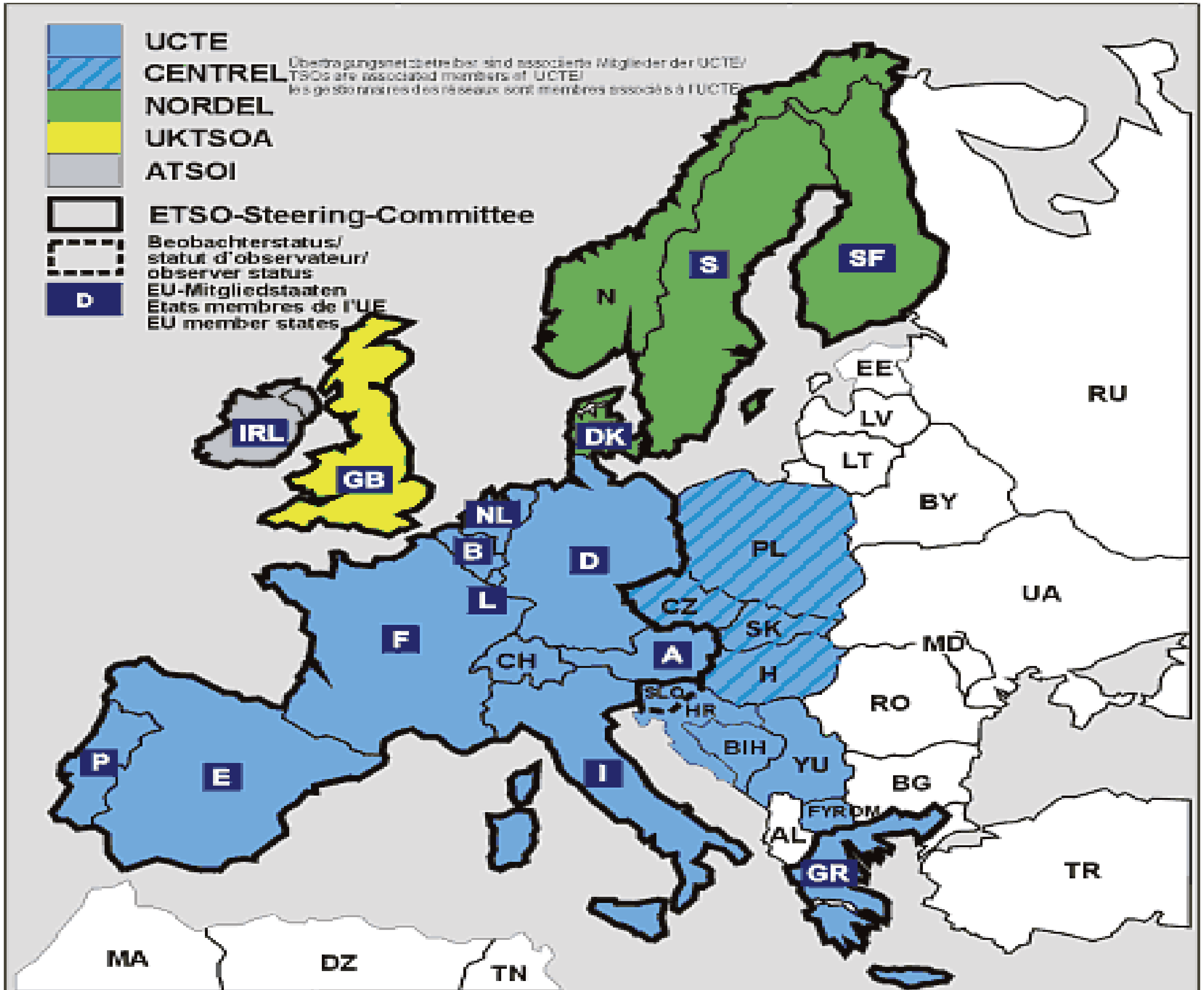
NERC Reliability Coordinators



China Grid


Northeast power grid
North China power grid
Northwest power grid
State Grid Corporation of China
Tibet
East China power grid
Central China power grid
China Southern Power Grid Co,Ltd
Taiwan
50°N
40°N
30°N
20°N
80°E
90°E
100°E
110°E
120°E

West European Power Grid



India Grid


JAMMU
AND
KASHMIR
Srinagar
Country Capital
State Capital
HIMACHAL
PRADESH
Shimla
Chandigarh
PUNJAB
Dehra Dun
UTTARANCHAL
HARYANA
DELHI
UTTAR
PRADESH
Lucknow
RAJASTHAN
Jaipur
NEPAL
SIKKIM
Gangtok
BHUTAN
ARUNACHAL PRADESH
Itanagar
ASSAM
Dispur
NAGALAND
Kohima
Shillong
MEGHALAYA
Imphal
MANIPUR
BIHAR
Patna
BANGLADESH
Agartala
TRIPURA
Aizawl
MIZORAM
MYANMAR
JHARKHAND
Ranchi
WEST
BENGAL
Kolkata
Gandhinagar
GUJARAT
Bhopal
MADHYA PRADESH
I N D I A
CHHATTISGARH
Raipur
ORISSA
Bhubaneshwar
New Moore I.
(India)
Diu
(D&D)
Daman
(D&D)
Silvassa
DADRA AND
NAGAR HAVELI
MAHARASHTRA
Mumbai
Hyderabad
ANDHRA
PRADESH
Yanam
(Pondicherry)
ARABIAN
SEA
BAY OF
BENGAL
Panaji
GOA
KARNATAKA
Bangalore
Chennai
PONDICHERRY
(Puduchcheri)
Karaikal
(Pondicherry)
Mahe
(Pondicherry)
Kavaratti
TAMIL
NADU
KERALA
Lakshadweep Sea
LAKSHADWEEP (INDIA)
Thiruvananthapuram
SRI
LANKA
ANDAMAN AND NICOBAR ISLANDS (INDIA)
Port Blair
Andaman
Sea
Indira Point
INDIAN
OCEAN

Phasor Measurement Units

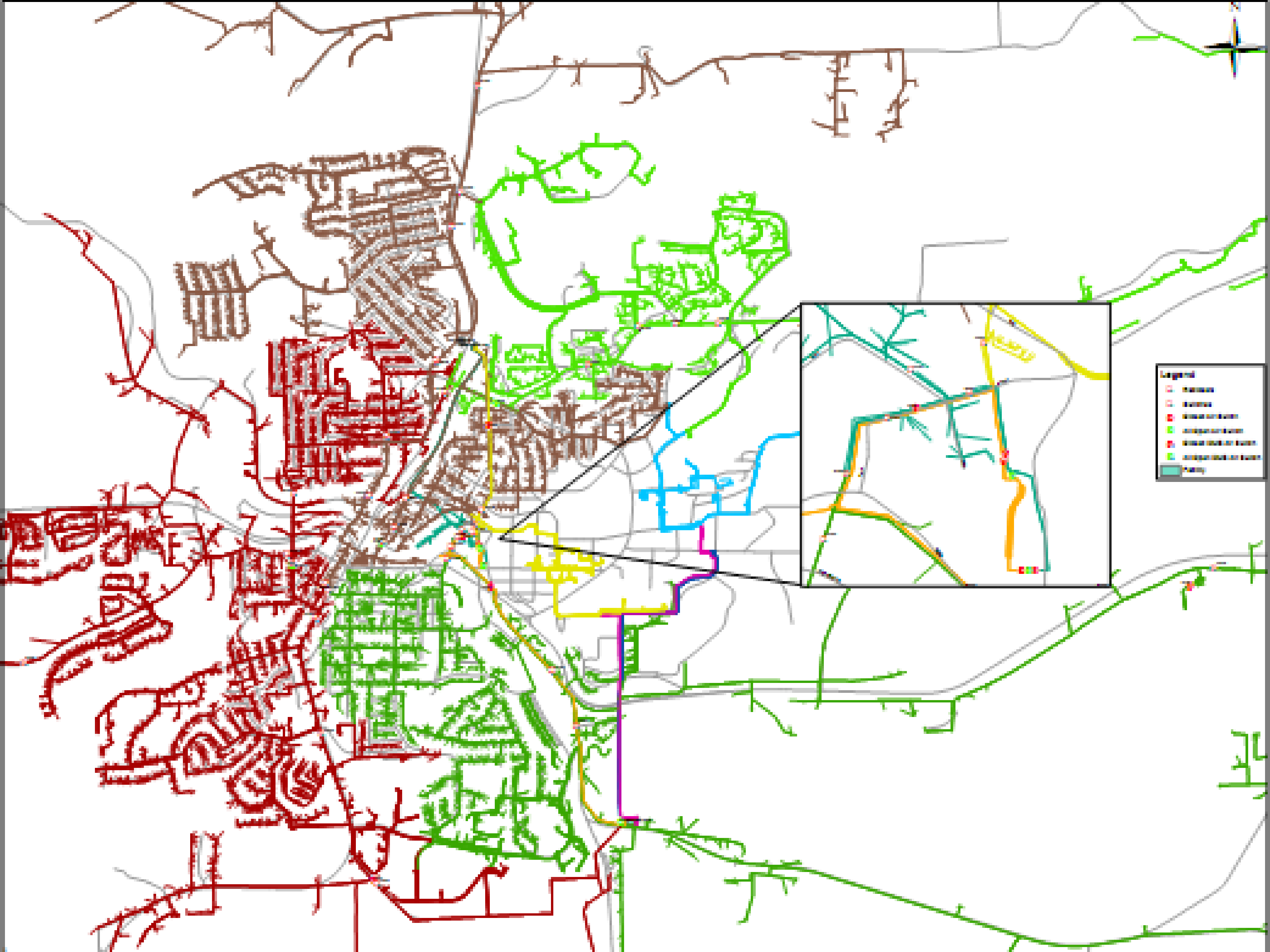
- Measurements at substations are now handled by microprocessors
- Measurements can be sampled at very high rates
- Measurements can be time-stamped by satellite

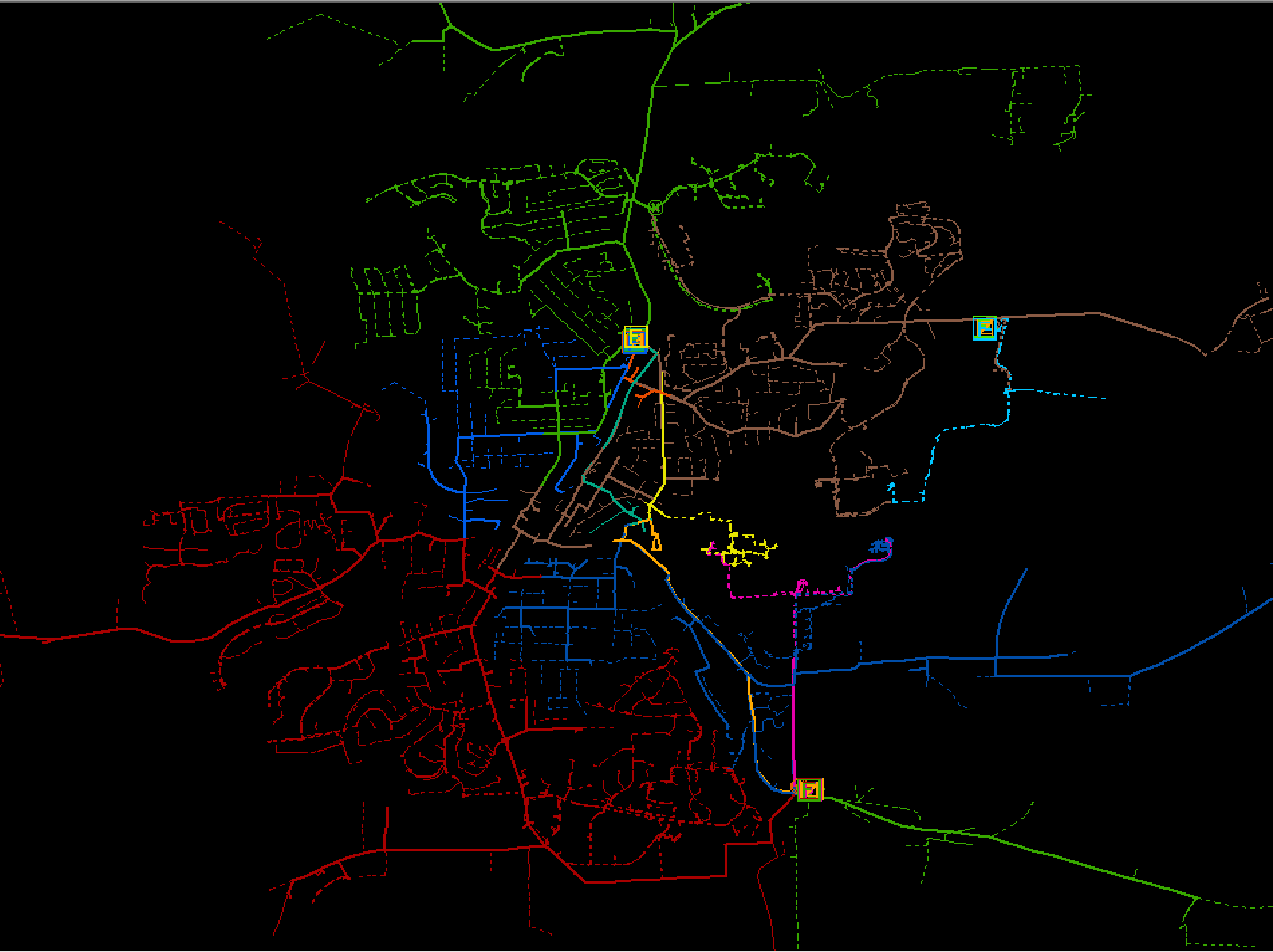
Measure magnitude and phase angle (PMU)

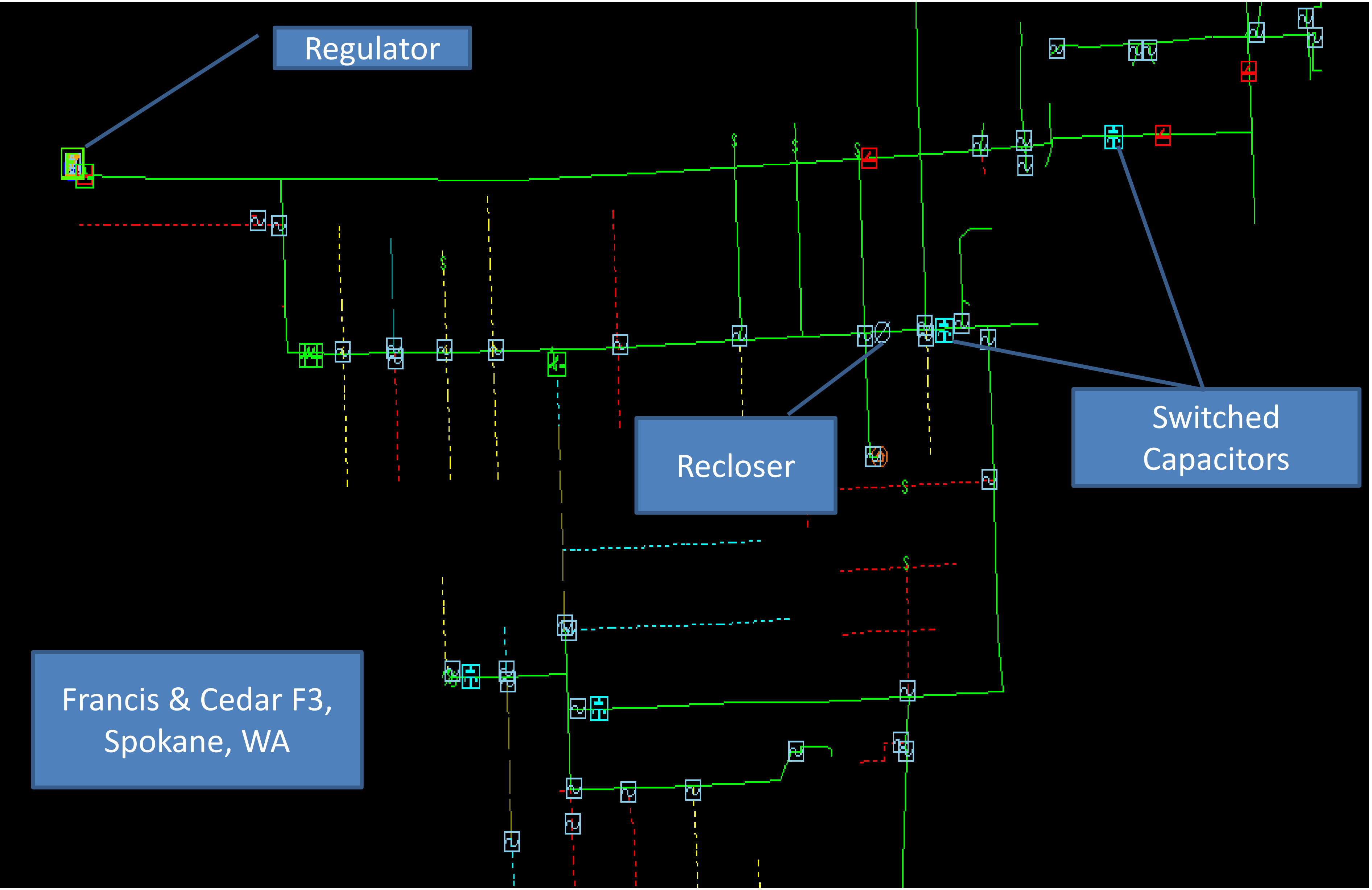
- PMU output rates: 30-120 per second
- Data rates for control centers will increase by 2-3 magnitudes

DISTRIBUTION MANAGEMENT SYSTEM

- **Measurements along the feeder**
- **Switches, transformer taps, shunt capacitor and inductor controls**
- **Communications: Radio, Power Line Carrier, Fiber backhaul**
- **Closer voltage control increases efficiency**
- **Greater switching ability increases reliability**
- **Better coordination with outage management**
- **Sets up for distributed generation, demand response, electric vehicles or local storage**






Regulator
Recloser
Switched Capacitors
Francis & Cedar F3, Spokane, WA

Geographic Information System

- GIS is getting more integrated into all aspects of system operations, especially
  - Distribution management
  - Outage management
- This has been helpful in other applications like Crew Management, Distribution Planning, etc

Outage Management System

- The computerization of Outage Management has made huge strides
- Requires less people to handle customer calls
- Requires less people to do crew dispatching
- Time savings are significant

SMART ELECTRIC GRID

Technologies involved

- Sensors (PMU, AMI)
- Computers and Communications (to manage data)
- Controls (including power electronics)
- Software (for operation and analysis)

For developed countries making the grid smart is mainly retrofit

For developing countries the ICT and T&D are mostly greenfield

Advanced Metering Infrastructure

- Smart Meters
  - Gateway between utility and customer
  - Communication to utility and home appliances
  - Time-of-day and real-time rates
- Applications
  - Optimize energy efficiency and energy cost
  - Demand response
  - Can integrate generation (roof PV), storage (EV)
- Microgrids

MICRO-GRID

- Can operate in isolated mode
- Can be few kW or hundreds of MW
- Suitable for isolated areas or weakly connected areas
- Suitable for critical loads (hospitals, military bases, etc)
- Strategic approach for increasing resiliency

Building Automation

- Smart Meters
  - Gateway between utility and customer
  - Utility can send price signals or control signals
  - Change rates (in real time?)
  - Control appliances (especially heating/cooling)
- Customer Applications
  - Optimize energy efficiency and energy cost
  - Demand response
  - Can integrate generation (roof PV), storage (EV)
- Microgrids

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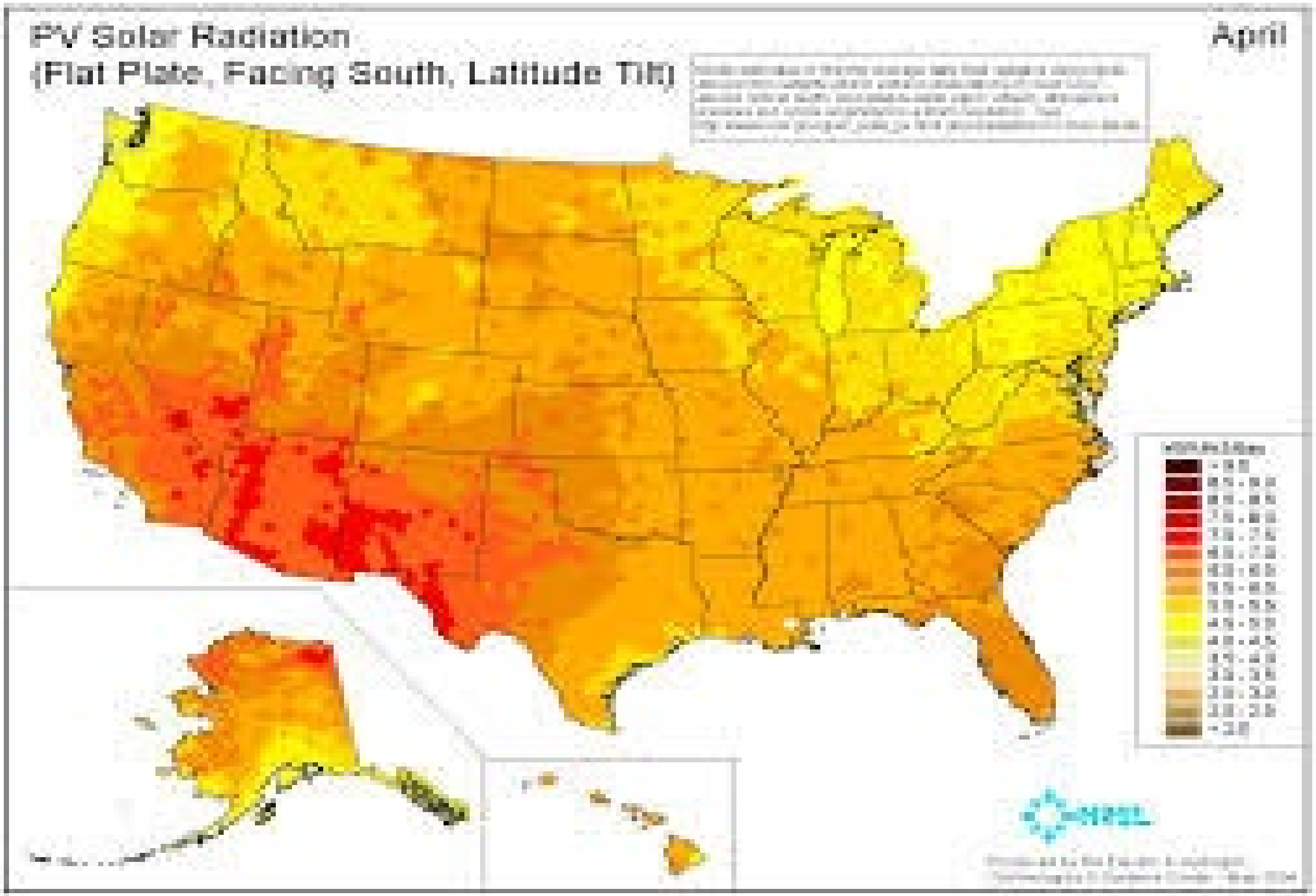
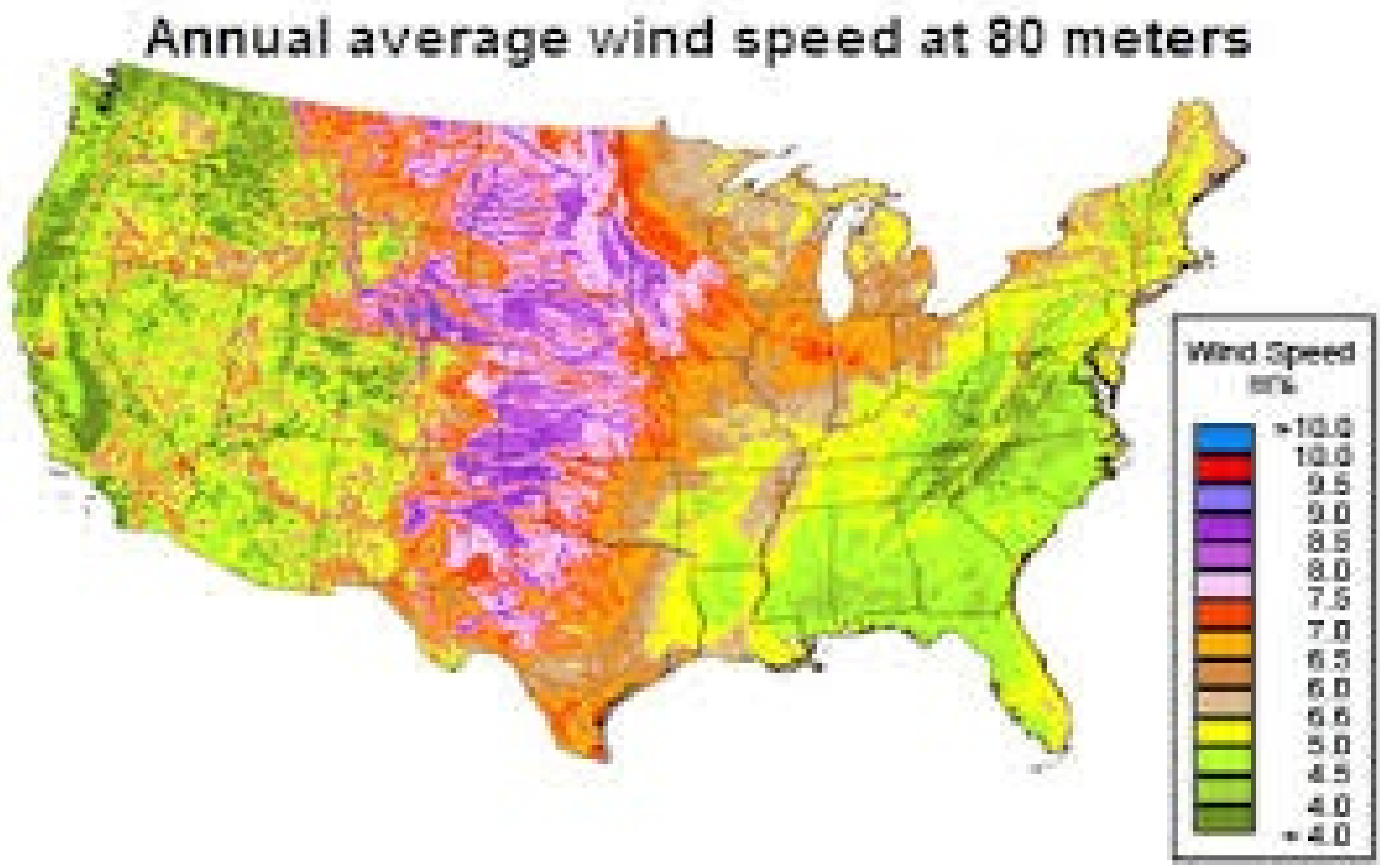
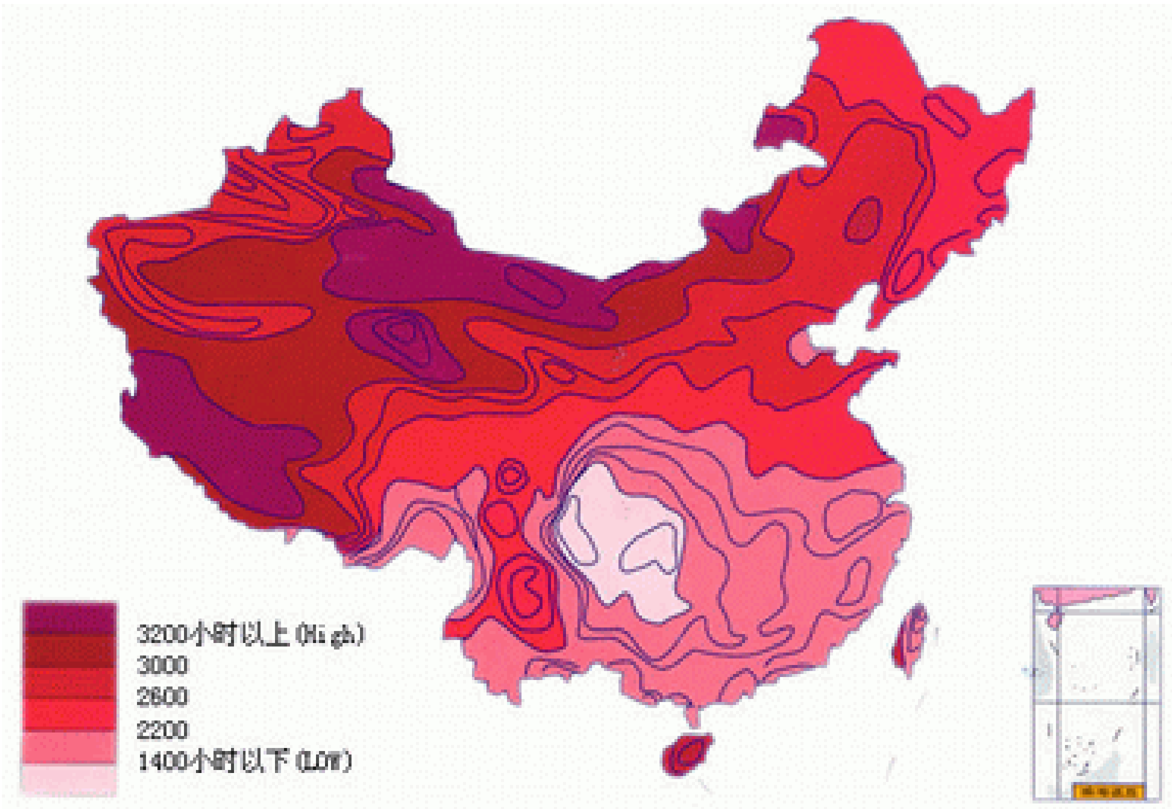
US SOLAR POWER



US WIND POWER

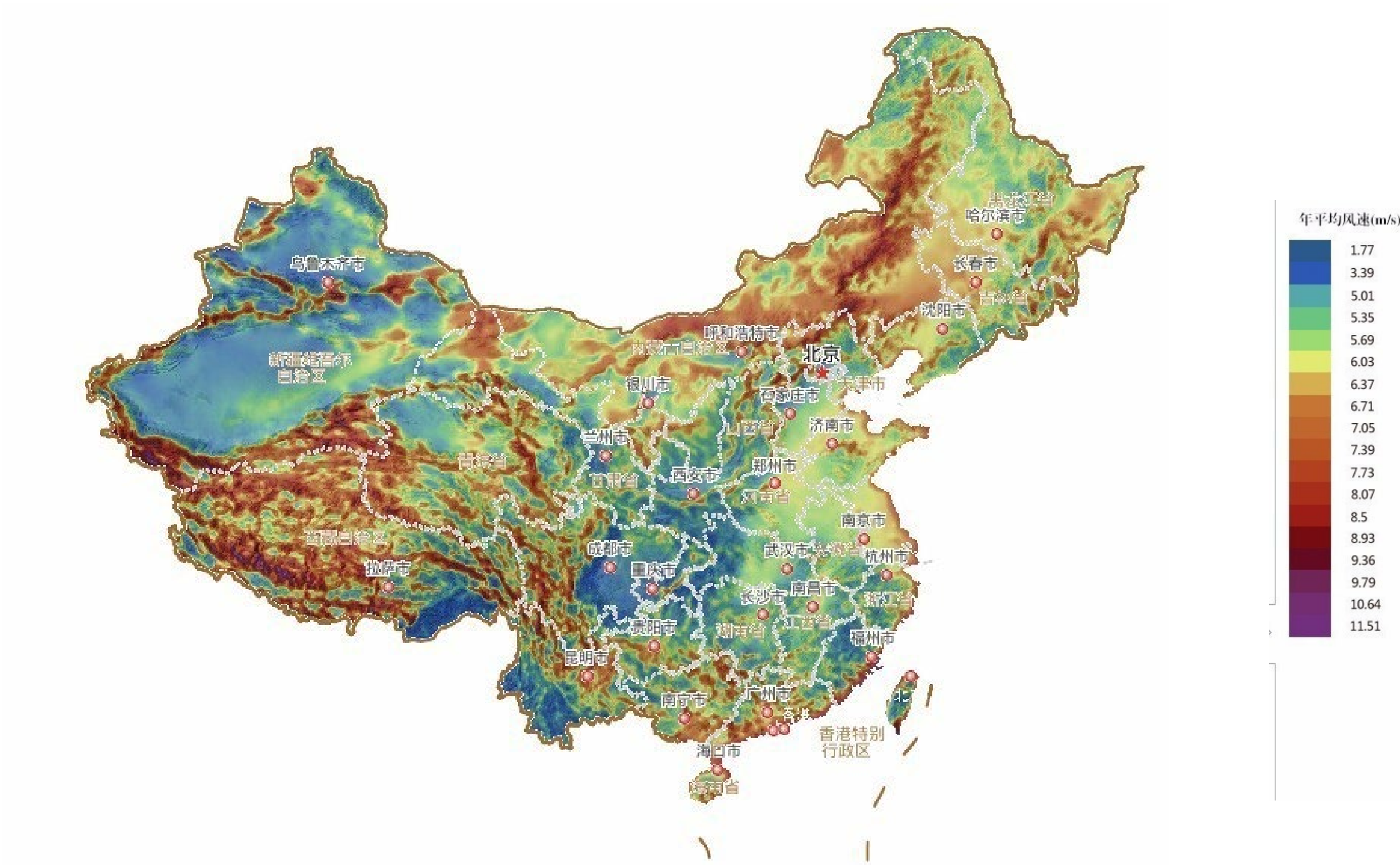


China Solar Energy Resources



China Solar Energy Resources

China Wind Energy Resources



ELECTRIC GRID GROWTH

Clean Energy Strategy must be adapted to Local needs

- For developed countries with low load growth
  - Changing generation mix means new investment without increasing energy production
- For developing countries with high load growth
  - Changing generation mix means new investment will be in cleaner technologies

Both will benefit from increasing ICT or smart grid technologies

CLEAN ENERGY STRATEGY

In terms of investment

- Generation technologies cost the most
- T&D technologies is a magnitude less
- ICT is another magnitude less

In terms of strategy

- ICT (smart grid) should be part of any investment
- Whenever possible, interconnect for economics and reliability
- If necessary, start local and build out

POLICY IS THE DRIVER

- Clean generation targets – sustainability vs economics
- Reliability standards – need emphasis on best practices rather than compliance
- Transmission planning – who is responsible?
- Operational procedures – e.g. data sharing
- Market rules – often does not take into account operational realities
- Rate regulation – FERC, state PUCs
- Federal or state energy policies

CONCLUDING REMARKS

- Alternate Grid Futures
  - More Interconnections at High Voltage
  - More Stand-alone Microgrids
  - Depends on Regional Needs
- Smart Grid
  - Retrofitting ICT is Expensive
  - Greenfield ICT has Low incremental Cost
- Government Policy is the Driver
  - Sustainability, Reliability, Market Rules
  - Technology and Economics are Still Important