A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

NREL National Renewable Energy Laboratory

Innovation for Our Energy Future

Renewable Electric Distributed Generator Critical Impact Areas on the T&D System

Tom Basso - NREL* Electric Systems Center

Presentation at Panel Session:

Rethinking T&D Architecture for DER

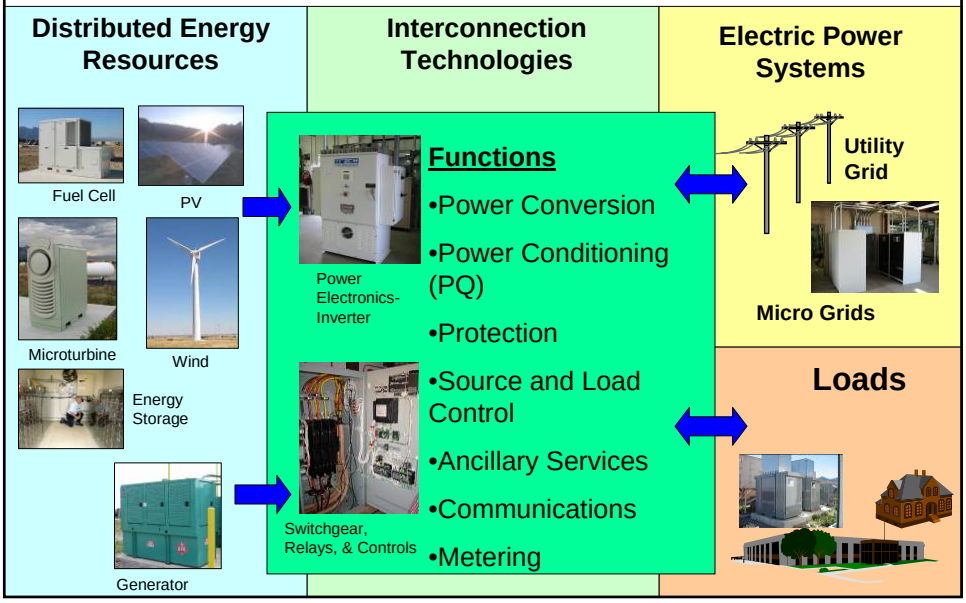
IEEE PES T&D Conference & Exposition
April 24, 2008 -- Chicago IL

---

*National Renewable Energy Laboratory (NREL): Distributed Energy and Electricity Reliability Program - US DOE Office of Electricity Delivery and Energy Reliability; US DOE Solar Energy Technology Program.

IEEE

Interconnection Technologies

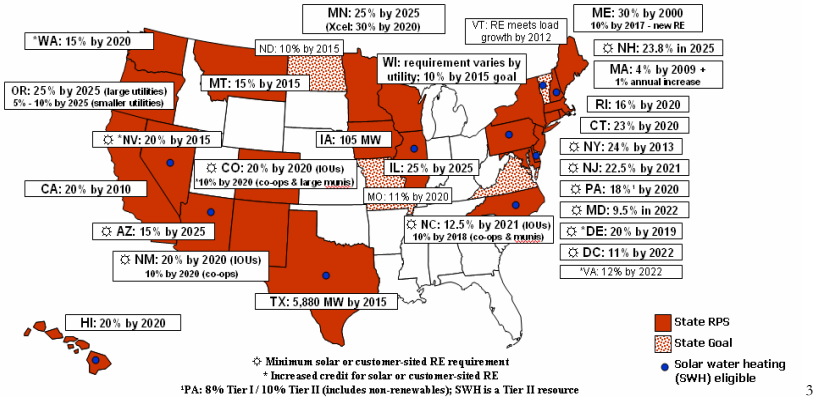


An Emerging Market: Preparing for Large-Scale Renewable Energy Interconnection

New Market Scenario: Climate change concerns, renewable portfolio standards, incentives, and accelerated cost reduction driving steep growth in U.S. renewable energy system installations.

DSIRE: www.dsireusa.org August 2007

Renewables Portfolio Standards

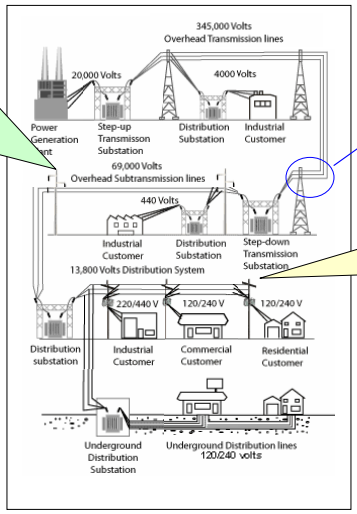


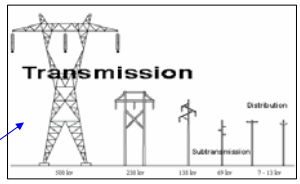
3

Where Renewable Energy Interconnects

Central Station

Large wind farms, CSP PV, biopower, hydro, geothermal, hydrokinetic, interconnect at transmission and sub-transmission levels



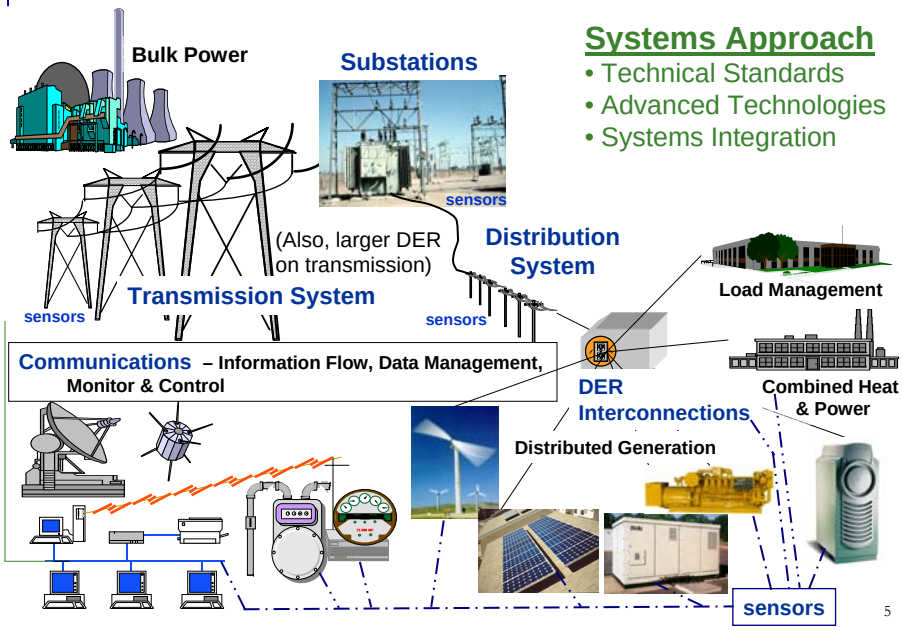


Distributed

PV, small wind, and fuel cells interconnect at the distribution level

4

DER on Transmission and Distribution



5

Performance Expectations at Various Connection Points in the Electric System

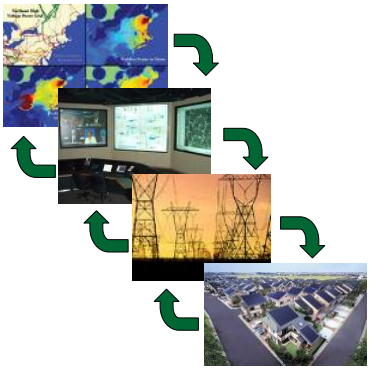
RE Connection Level	*Interconnection Rules*	*System Integration Concerns*	*Local and System Values*
Connection at End Use Low Voltage (LV)	Local connection requirements…. e.g. IEEE 1547 and derivatives	Feeder- level issues such as power flows, protection, and voltage impacts… e.g. Issues related to high penetration levels	Power, heat, load control, quality and reliability
Connection at Distribution (MV)			Ancillary service support to utility T&D e.g. reserve capacity, demand response, deferral of expansions, etc.
Connection at Transmission (HV)	National Grid Codes -FERC 661-A -General Requirements for Interconnection (Utility document on file with FERC)	Understanding how to plan and operate the transmission grid and other generation resources based on RE operating characteristics	Variable energy resources displace fuel use and avoid emissions

6

Concerns with Integrating Renewables

- **Penetration**
  - Affected by utilities' existing generation mix regulating capabilities, load characteristics, resource availability, and correlations between system load and resources
  - Additional systems costs imposed by variability and uncertainty may go up with increasing penetration
  - Costs are moderate – up to 20-30% Penetration – and depend on balancing authority and market structure
- **Infrastructure Capacity**
  - Lack of transmission capacity from stranded renewable resource locations
- **Variable and Uncertain Generation**

  Solved by
  - spatial diversity of the resource
  - flexible conventional generation
  - grid operations and control areas
  - limited curtailment for extreme events
  - load management
  - and at high penetrations possibly storage



➢ **Technical Concerns:** Real and solvable

7

RE Interconnection – Technical Concerns

Wind and Large Solar (Bulk System Connected Generation)

- Steady state and transient stability analysis
- Load/Generation Coincidence (Peak Load and Variability of Source)
- Regulation Requirements
- Integration with Automatic Generation Control (AGC)
- Incorporation of renewable resource forecasting
- Examine current operating practice and new concepts to enable high penetration;
  - frequency responsive (create regulating reserves)
  - demand side coordination

Distributed Solar and Small Wind (DG)

Issues listed above, plus

- Voltage and VAR Regulation
- Power Quality (Harmonics, Flicker, DC Injection)
- Protection design and coordination (short circuit, recloser, etc.)
- Unintentional Islanding
- Equipment grounding
- Load and generation imbalance
- Generation interaction with controllable loads (DSM)
- Storage and storage controls.

➢ Most technical concerns at the bulk level have been solved with modern wind turbines and grid codes.

Interconnection concerns are real and solvable: e.g., specific to: equipment, design, location, application, etc.

➢ Technical concerns at the distribution level have been identified, but small RE have not been fully integrated into planning and operations.

8

Historical & Current DOE Integration Activities Regarding Large Wind Integration Studies

- A large amount of research has looked into the technical concerns regarding integration of wind farms into the electrical grid.
- Several studies have examined 20-30% penetration.
- For large, diverse electric balancing areas, existing regulation and load following resources and/or markets are adequate and associated costs are low.
- Moderate cost increases may be needed to account for variability and uncertainty of wind resource (3-4% low to 7-10% high).
  - Largely dependent on local utility market design and resource constraints
- State of the art forecasting can reduce costs
  - majority of the value can be obtained with current state-of-the-art forecasting
  - additional incremental returns from increasingly accurate forecasts
- Realistic studies are data intensive and require sophisticated modeling of wind resource and power system operations

9

Large Wind Integration Study References

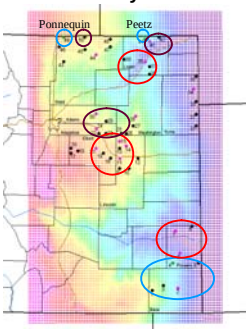
- **California Intermittency Analysis –** The Intermittency Analysis Project conducted a series of scenario based studies to examine the statewide system impacts of higher levels of intermittent renewables on the California electricity and transmission infrastructure.
  http://www.energy.ca.gov/pier/notices/
- **Minnesota State 20% Wind Integration Study –** Wind Integration Study of the impacts on reliability and costs associated with increasing wind capacity to 20% of Minnesota retail electric energy sales by the year 2020.
  http://www.puc.state.mn.us/docs/index.htm
- **Northwest Wind Integration Action Plan –** The region's utility, regulatory, consumer, and environmental organizations worked together to address several major questions surrounding the growth of wind energy.
  http://www.nwcouncil.org/energy/Wind/Default.asp
- **New York ISO and NYSERDA -** A joint study to produce empirical information that will assist the NYISO in evaluating the reliability implications of increased wind generation.
  http://www.nyserda.org/publications/wind_integration_report.pdf
- **MISO 20-25% wind study –** Begins in 2008
- **Western Wind Integration Study –** Started in '07 – End results in '09

10

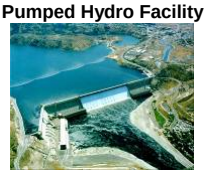
Solutions to Variable and Uncertain Generation

- Spatial diversity of the resource
- Flexible conventional generation
- Grid operations and control areas
- Load management
- Limited curtailment for extreme events
- And at high penetrations possibly storage

Wind Diversity in Colorado



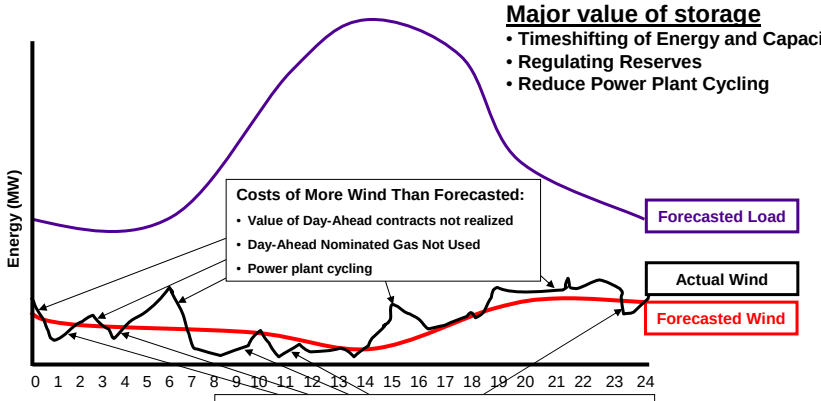
Pumped Hydro Facility



11

Energy Storage to Address RE Generation

Major value of storage
- **Timeshifting of Energy and Capacity**
- **Regulating Reserves**
- **Reduce Power Plant Cycling**



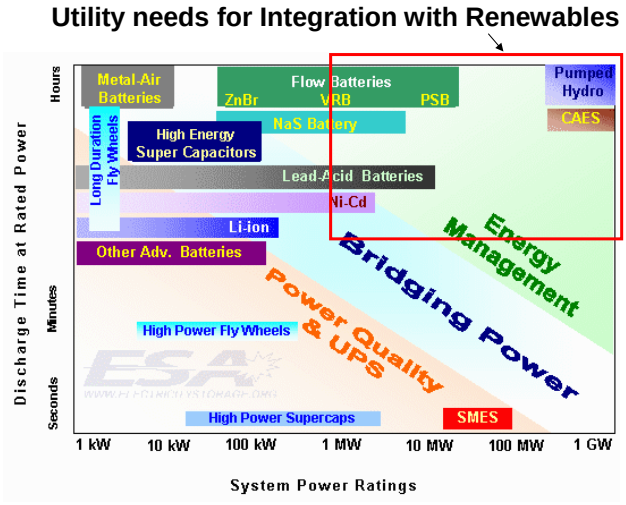
Note: At the utility scale, energy storage only needs to cover relatively small fluctuations

12

Energy Storage Options

- Pumped Hydro
- CAES
- Batteries (Lead Acid, NaS, VRB, Lithium ion, etc.)
- Super Caps
- Flywheels

- Hydrogen
- PHEV/V2G
- Thermal Storage
- Natural Gas



Notes: no storage need found yet in wind studies looking at up to 20-30%.
most storage is not economically feasible currently or in the near term

13

Historical and Current DOE Integration Activities Regarding Distributed Energy Interconnection

- DOE EERE Office of Power Technologies initiated Distributed Power Program in 1999 to look at integration and interoperability of distributed generation and renewable energy technologies into the electric power system through interconnection standards development in response to the deregulation movement at that time. That grew into a major program and was highly regarded in addressing the electric grid and renewable energy integration needs.
- With the formation of the DOE OE (formerly OETD) in the 2002 time frame the integration effort was re-located to the R&D area of OE within the systems integration and transformation area, and is currently funded regarding interconnection standards development (i.e. IEEE, IEA, and IEC), interconnection technology development, interoperability of the T&D system and the impacts on the grid and solutions to minimize these impacts to allow greater renewable and DG technology applications for interconnection and operability at the point of common coupling to the grid, both at the distribution and transmission connection points.
- The current effort by DOE EERE is to identify the path forward to high distributed penetration renewable energy scenarios. This effort is maximizing efforts of the past and providing potential solutions for renewable technology acceptance for grid planning and operation.

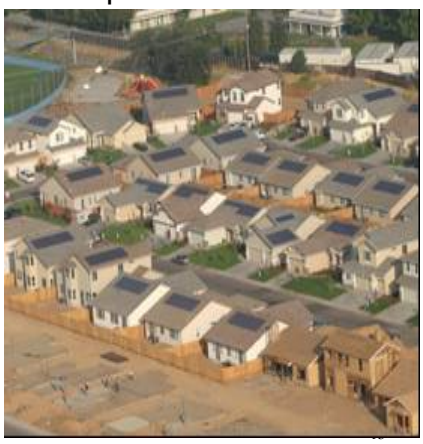
14

Distributed Renewable Systems Interconnection Studies

- DOE completed reports on Distributed Renewables (focused on PV): Target audience - DOE and external stakeholders (utilities, system integrators, regulators, trade organizations, etc)

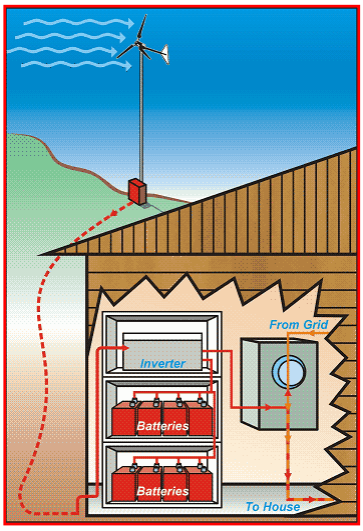
  http://www1.eere.energy.gov/solar/solar_america/rsi.html

- Renewable Systems Interconnection Reports:
  - Advanced Grid Planning and Operations Study
  - Utility Simulation and Modeling Study
  - High Penetration Distributed PV Studies
  - Resource Assessment Study
  - Distributed PV Systems Design & Tech Requirements
  - Test & Demonstration Program Definition
  - Production Cost Modeling Study
  - PV Value Analysis Study
  - Business Model Development Study
  - Market Penetration Study



Connecting to the Utility for Distributed Renewables

- Individuals contact utility before connecting to its lines and obtain an "interconnection agreement."
- Often, a simple, standard agreement is available for small renewable energy systems.
- **EPACT 2005** offers interconnection
  - Requires utilities to consider interconnection service to its customers (on-site generation connected to distribution facilities).
  - Interconnection services shall be offered based upon IEEE 1547.
  - Agreements and procedures shall be established, promoting current best practices of interconnection, including practices stipulated in state regulatory model codes.



DOE Interconnection Best Practices: http://www1.eere.energy.gov/solar/pdfs/doe_interconnection_best_practices.pdf

16

IEEE 1547 Series of Standards

Approved Standards

- **1547-2003** ***Standard for Interconnecting Distributed Resources with Electric Power Systems***
- **1547.1-2005** ***Conformance Test Procedures for Equipment Interconnecting DR with EPS***

Integrated with UL 1741 (2005) for equipment certification

Current Projects

- **1547.3-2007** ***Guide for Monitoring, Information Exchange and Control of DR***
- **P1547.2** Application Guide for IEEE 1547 Standard for Interconnecting DR with EPS
- **P1547.4** Guide for Design, Operation, and Integration of DR Island Systems with EPS — **Microgrids**
- **P1547.5** Guidelines for Interconnection of Electric Power Sources Greater Than 10 MVA to the Power Transmission Grid
- **P1547.6** Recommended Practice for Interconnecting DR With EPS Distribution Secondary Networks — **Urban distribution networks**

DOE has had a major role in supporting the development of these standards

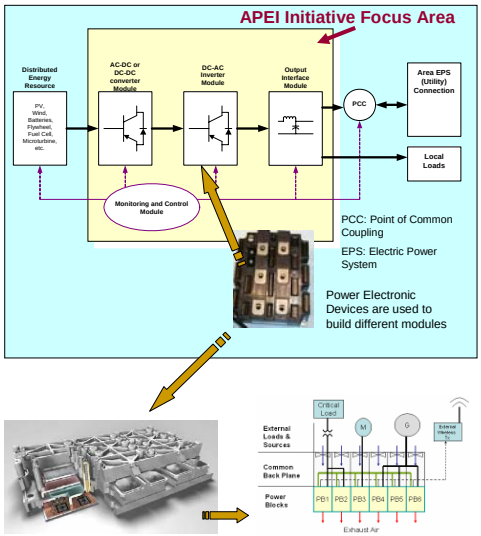
http://grouper.ieee.org/groups/scc21/index.html

17

NREL DER Test Facility: example project

CEC-NREL Advanced Power Electronics Interface (APEI) Initiative

- The APEI Initiative is a coordinated plan to develop a standardized, highly integrated, **modularized power electronic interconnection technologies** that will come as close as possible to "plug-and-play" for distributed energy resource (DER) platforms.
- The goal of the APEI Initiative is to develop power electronics technology that improves and accelerates use of DER systems - reduce costs for DER and interconnections by developing standardized, high production volume, power electronic modules.



18

NREL Renewable Planning Model (RPM)

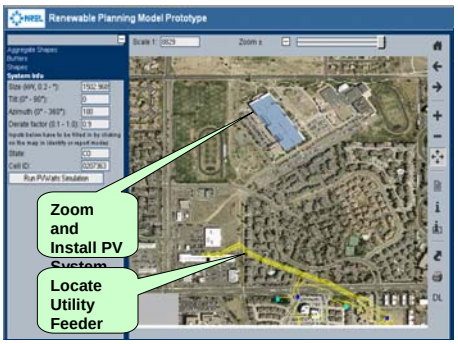
NREL is developing a software tool for visualizing and understanding the impacts of renewable and distributed energy systems.

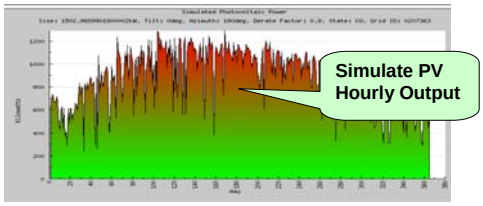
The tool: integrates

- resource data sets (NSRDB)
- geographic information systems (GIS)
- performance models (PVWatts, Homer)
- utility or customer load information;

and answers questions such as,

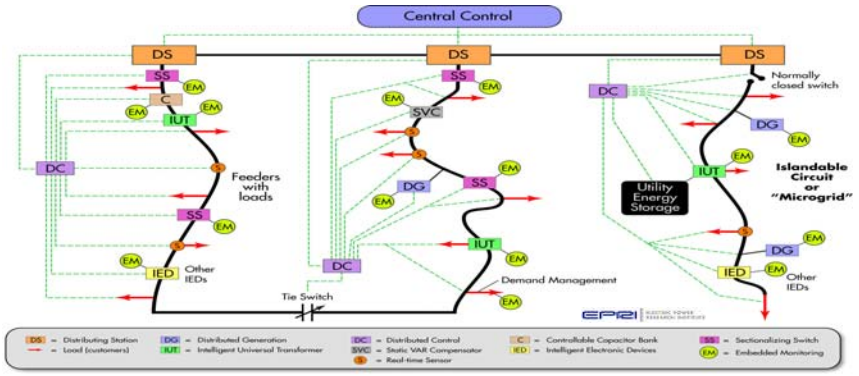
- What resources are available in an area?
- What loads are on the system?
- Where will generation help to optimize grid operation?





Needs for Distributed Renewables

- Distributed renewable interconnection technologies with advanced functionality.
- Integration of renewable energy with dispatchable load and storage.
- Electric power systems technologies, controls, and operations that enable high penetration of distributed renewable energy systems.
- Models for renewable energy systems that allow them to be included in the planning and analysis tools.



Contact Information

- **Dick DeBlasio, Technology Manager**
  NREL Distributed Energy & Electric Reliability (DEER) Program
  Chair IEEE SCC21, 1547; IEEE Standards Board Liaison to DOE
  em: Dick_Deblasio@nrel.gov voice: (303) 275 – 4333
- **Tom Basso* NREL**
  Sec'ty IEEE SCC21 & P1547.2.3.4.6
  em: Thomas_Basso@nrel.gov
  voice: (303) 275 - 3753
- **Ben Kroposki* NREL**
  Sec'ty 1547.1 & Chair P1547.4
  em:Benjamin_Kroposki@nrel.gov
  voice: (303) 275 – 2979

  ***** NREL DEER Program and Solar Energy Technology Program.
- **NREL** http://www.nrel.gov
  1617 Cole Blvd. MS-1614 Golden, CO 80401-3393

- **IEEE SCC21 -- IEEE Standards Coordinating Committee 21** on Fuel Cells, Photovoltaics, Dispersed Generation, & Energy Storage
  http://grouper.ieee.org/groups/scc21/
- **IEEE Std 1547 Series of Interconnection Standards** --
  http://grouper.ieee.org/groups/scc21/dr_shared/

21