Impact of Small Wind Turbine Generators on Distribution Lines

Small Wind Conference

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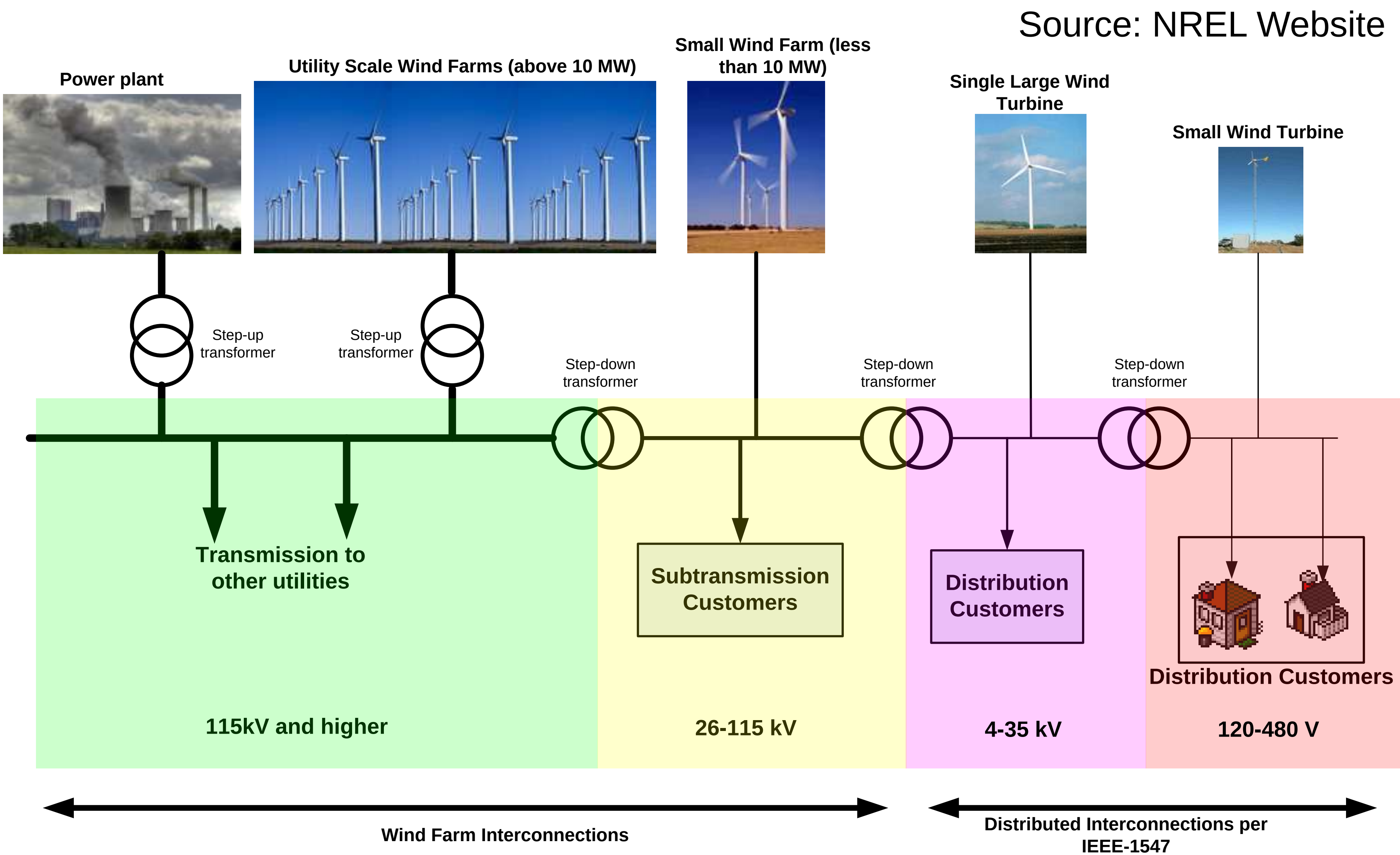
List of Topics:

- Overview
- System Integration
- Grid/Non-Grid
- Grid Integration on Distribution Network
  - Renewable Energy Resources Characteristics
  - Grid Condition
  - Control Opportunities
- NREL case studies and applicability for wind

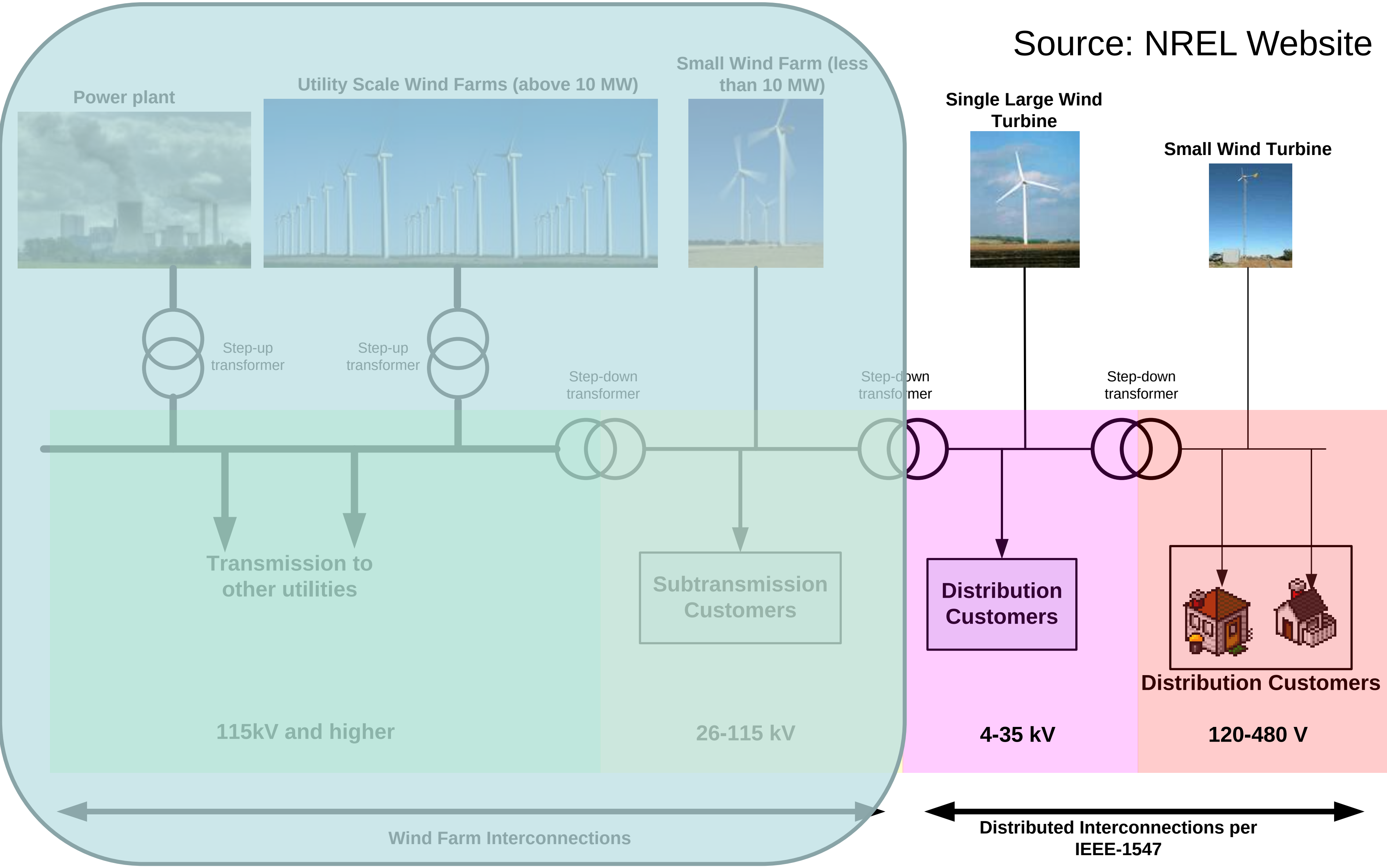
Overview

- Power rating of SWT (P< 100kW, now?)
- Small, but collectively is important to supply our energy need
- Small wind turbine more resilience than large conventional power plant:
  - Distributed in nature (multiple injection points on different buses/nodes)
  - In some regional grids, collectively can supply large portion of energy need
  - Response to disturbances (line faults) from conventional plant is massive and synchronized as compared to distributed RE.
  - Most of the DERs (wind, PV, etc.) has inverter grid-interface (fast, flexible, controllable) – response: non-synchronized, distributed

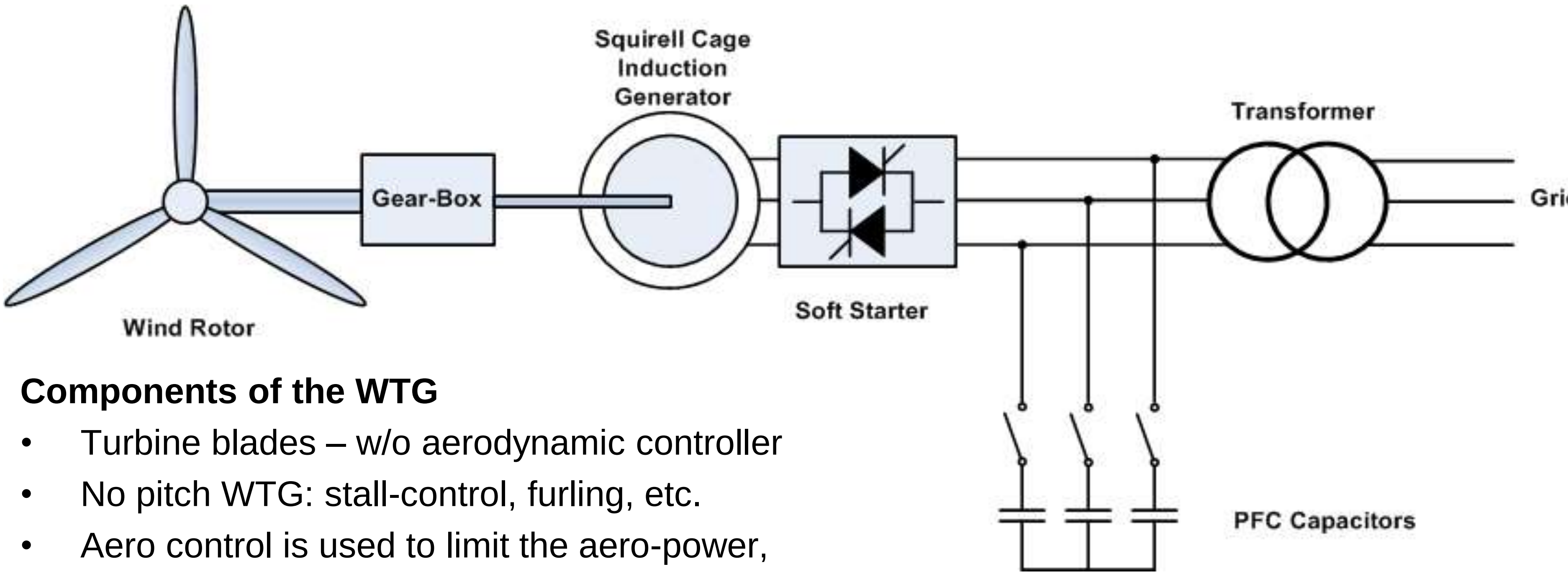
Grid Integration



Grid Integration



Type 1 Wind Turbine Generator



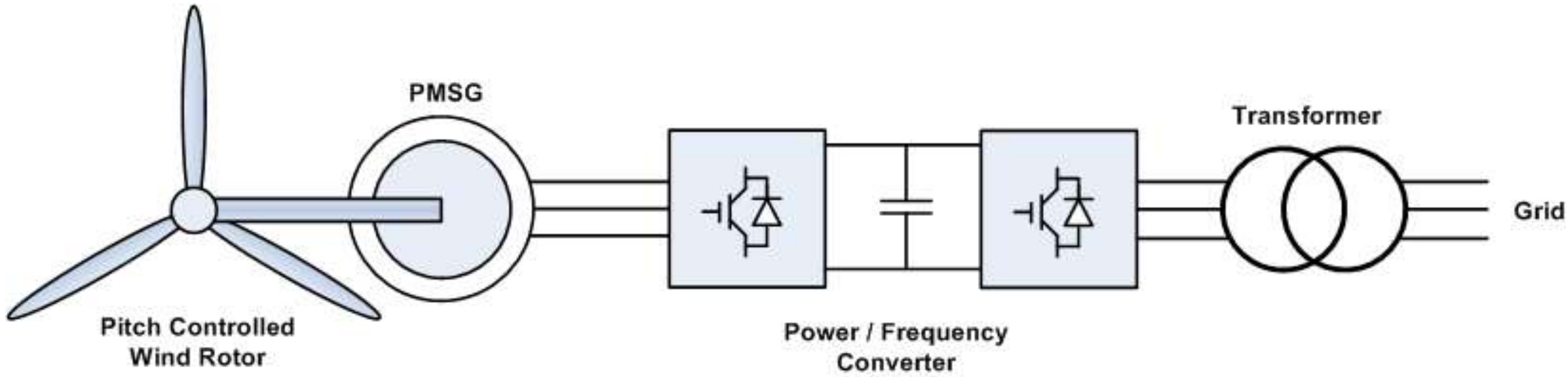
Components of the WTG

- Turbine blades – w/o aerodynamic controller
- No pitch WTG: stall-control, furling, etc.
- Aero control is used to limit the aero-power, thus reducing the components stresses during high winds
- Gear box (if needed) is used to match the rotational speed of the WTG and the generator
- Squirrel Cage Induction Generator (SCIG) is commonly used.
- In some cases, soft starter is used to limit the in rush current during start-up.

Power Factor Correction (PFC)

- IG – by nature it always absorbs reactive power from the grid. Power Factor Correction (PFC) capacitor bank is needed
- The size of the capacitance is adjusted as the output power varies with the wind speeds
- Ideally, PF ~ 1.0 is desirable for most type 1 and type 2 WTG (for stiff grid).

Type 4 Wind Turbine Generator



Components of the WTG

- AC generator can be used for variable speed generator.
- If high speed AC generator is used, a Gear Box is still needed.
- If a low speed AC generator is used, a direct drive generator can be used without a gearbox.
- The power converter (at Full Rating) has two different sides, the Machine Side Converter (MSC - variable frequency) connected to the generator and the Line Side Converter (LSC – operated at 60Hz) connected to the grid.

Components of the WTG

- The speed can vary up to 100% synchronous speed.
- Synchronous generator is commonly used (Permanent Magnet or Wound Field).
- The size of the converter-generator set is equal or larger than the P_{rated} of the turbine.
- The MSC – to control the generator (C_{pmax} operation, WTG stress minimization, etc.)
- The LSC – to control grid integration aspects (freq/voltage/reactive-power/power quality regulation, etc.).

Small Wind Turbine

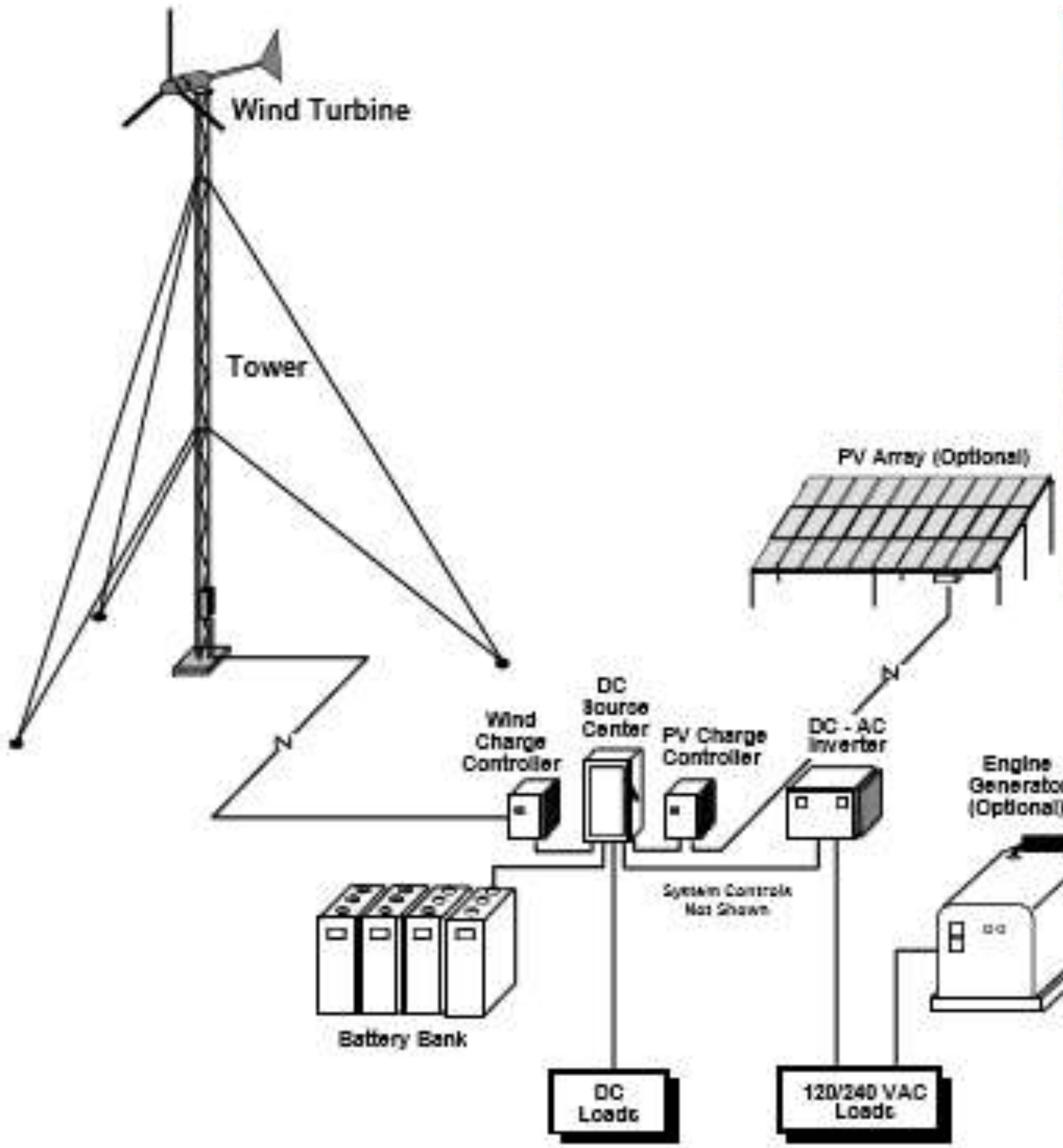
Southwest Windpower 1.8-kW
Skystream wind turbine.

Northern Power Systems
100-kW wind turbine

Windward Engineering
4.2-kW wind turbine.

Source: NREL Website

Hybrid – Microgrid Applications



Xinjiang Province, China

Source: http://bergey.com/documents/2014/06/small-wind-turbines-for-microgrids-faq.pdf

Non-Grid Applications

Ranchers in Oaxaca, Mexico, celebrate the installation of a new wind-electric water-pumping system, which will provide a dependable supply of water for crops and cattle.

A researcher holds ice made from the ice making experiment at the National Wind Technology Center. Variable-speed wind turbine ice making for remote fishing villages is being tested at NWTC.

Grid Connected

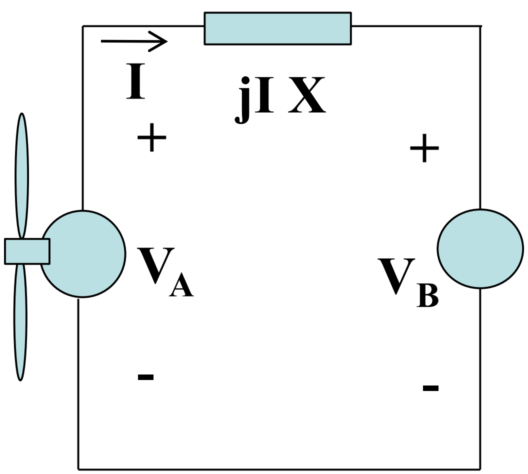
- Grid compliance (local, regional, national levels).
- Small, but collectively is important to supply our energy need.
- SWT is more resilient than a large conventional power plant:
  - Distributed in nature (multiple injection points on different buses/nodes)
  - In some regional grids, collectively WTG & SWT can supply large portion of local energy need (Denmark, villages in AK, islands in HI, etc.)
  - Response to disturbances (line faults) from a conventional plant is massive and synchronized as compared to distributed RE.
  - Most of the DERs (wind, PV, etc.) has inverter grid-interface (fast, flexible, controllable) – response: non-synchronized, distributed

Transmission vs Distribution

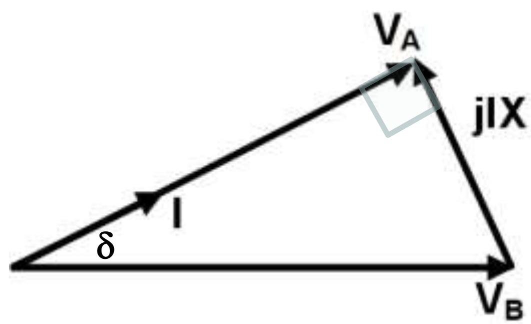
Characteristics	Transmission Lines	Distribution Lines
Distance	Long lines (high voltage)	Short lines (medium/low voltage)
Reactance (X)	High	Low
Resistance (R)	Low (1%-5%)	Low (3%-10%)
X/R ratio (extreme)	Large (~10)	Small (~1)
P impact on δ	Dominant	Not Dominant
P impact of $\|V_m\|$	Not dominant	Dominant
Challenges	Angle Stability Issues	Voltage Stability Issues

Voltage Regulation

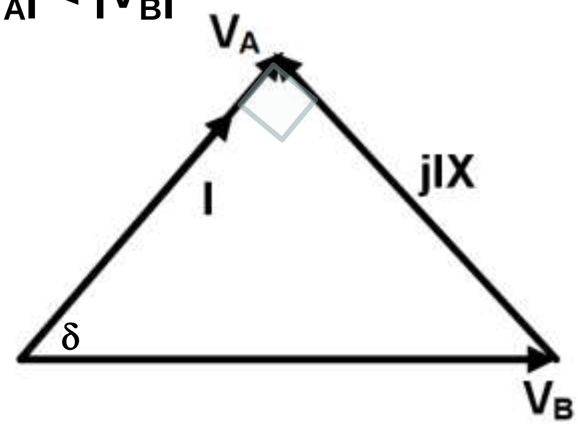
WTG is operated at PF=1.0



In the context of Transmission Lines
(to exaggerate R ~ 0) $|V_A| < |V_B|$



Low Wind Speed



High Wind Speed

In the context of Distribution Lines
(to exaggerate X ~ 0) $|V_A| > |V_B|$

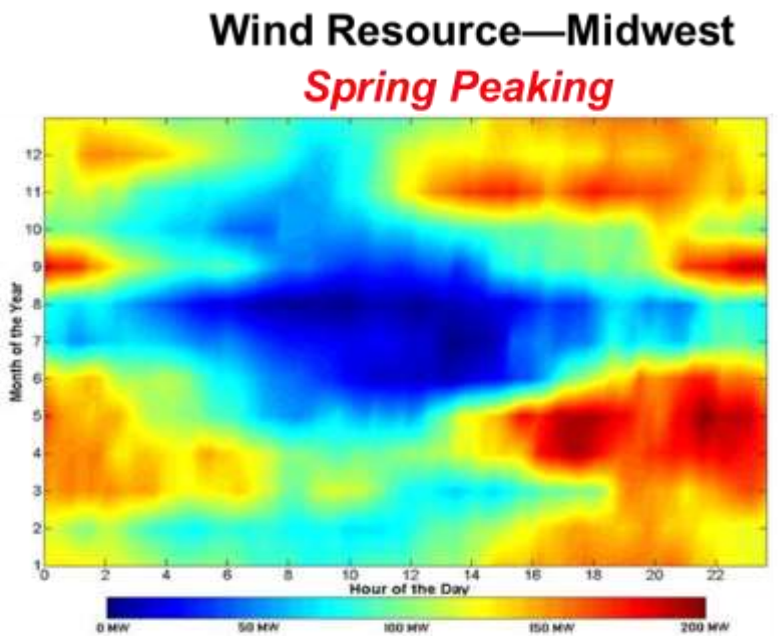
Low Wind Speed

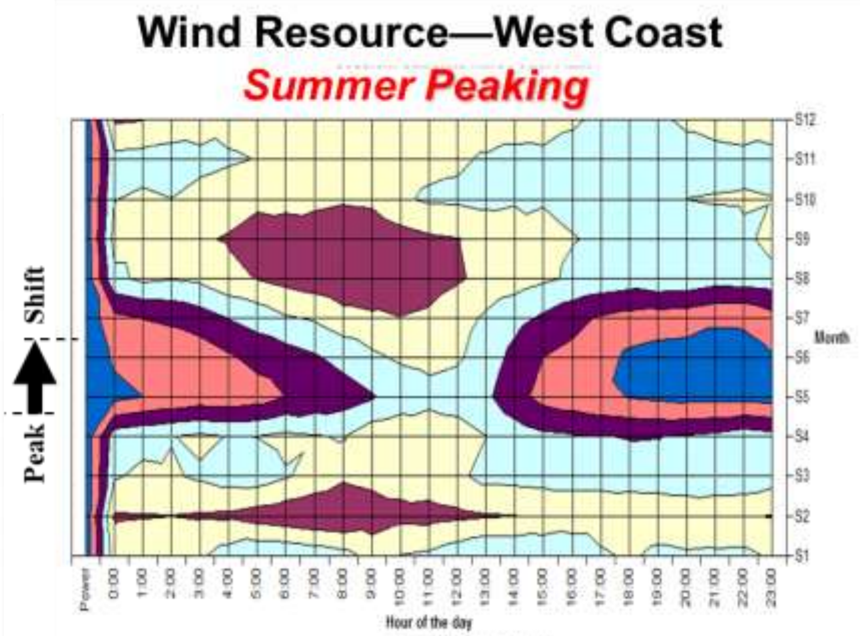
High Wind Speed

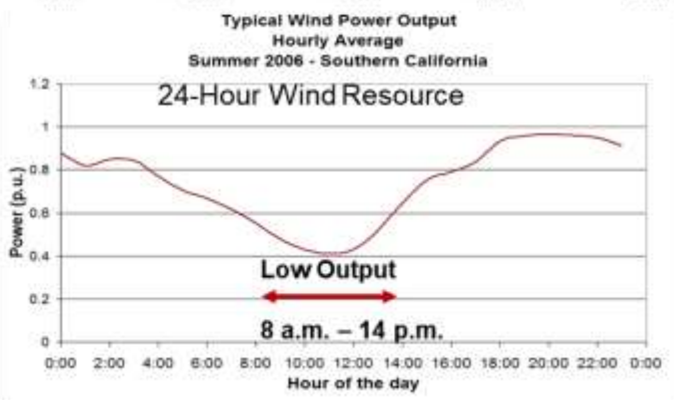
Present vs Future Power Systems

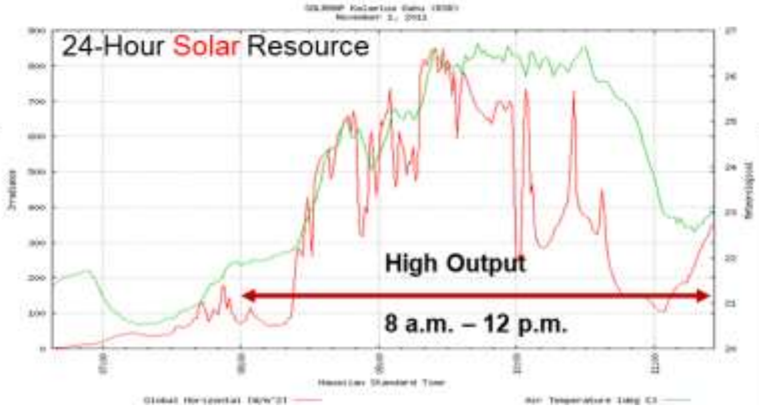
Characteristics	Future PS	Changes wrt Present PS
Source of the Power Flow variations	Loads and DER	Higher variability
Direction of power flow	May change directions	Over production of RE
Net Loads Average	Lower	partially from local sources
Lines efficiency	Higher than present	Higher than present
Ave. line congestions	Lower than present	Lower than present
Controller Activities	More active	Due to voltage regulations
System Kinetic Energy	Less conv. Power Plants	Less rotating generators
Challenges	Less inertia in the system, high load/source excitation, more active balancing	Requires faster smarter control, role of energy storage (ES)
Opportunities	PE, smart control, big data, computational, drop in cost of ES	SiC (faster, higher ratings of V,I,P), control (AI/ML), data: historical,experience,knowledge-base, high Perf. Comp.

Wind vs PV


Wind Resource—Midwest
Spring Peaking
Month of the Year
Hour of the Day
0 MW
50 MW
100 MW
150 MW
200 MW


Wind Resource—West Coast
Summer Peaking
Peak
Shift
Month
Hour of the day

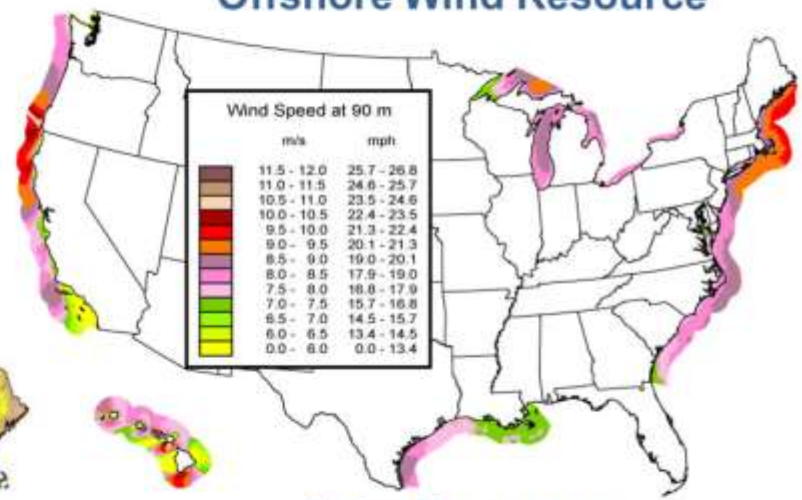

Typical Wind Power Output
Hourly Average
Summer 2006 - Southern California
24-Hour Wind Resource
Power (p.u.)
Low Output
8 a.m. – 14 p.m.
Hour of the day


24-Hour Solar Resource
High Output
8 a.m. – 12 p.m.

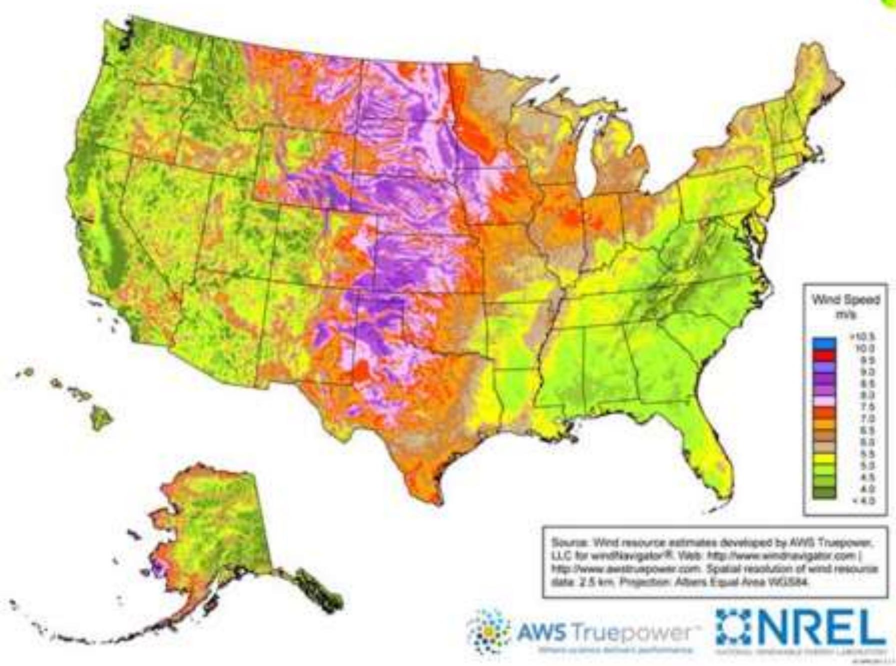
Wind vs PV

Resources

Offshore Wind Resource



U.S. Wind Resource



Solar Resource

Conclusions

PV & Wind are compatible and complementary resources

- Wind generates during the night, PV generates during the day time.
- Both of PV and Wind are inverter based renewable generators.
- The inverter based generator can potentially performs dual functions: as RE generators when resource available and as VAR compensator or energy storage (with BESS on the DC bus).
- Wind (night) production and during PV (day) production enables RE to supply grid in extended time duration.
- The seasonal impact of PV and Wind are complementary to each other
  - PV peaks are day-time summer months
  - Wind peaks are night-time winter and spring months
- As both are inverter based generators, and there is approx. 12 hours time shift, when PV generates, wind turbine can potentially performs to provide VAR compensation, and vice versa.