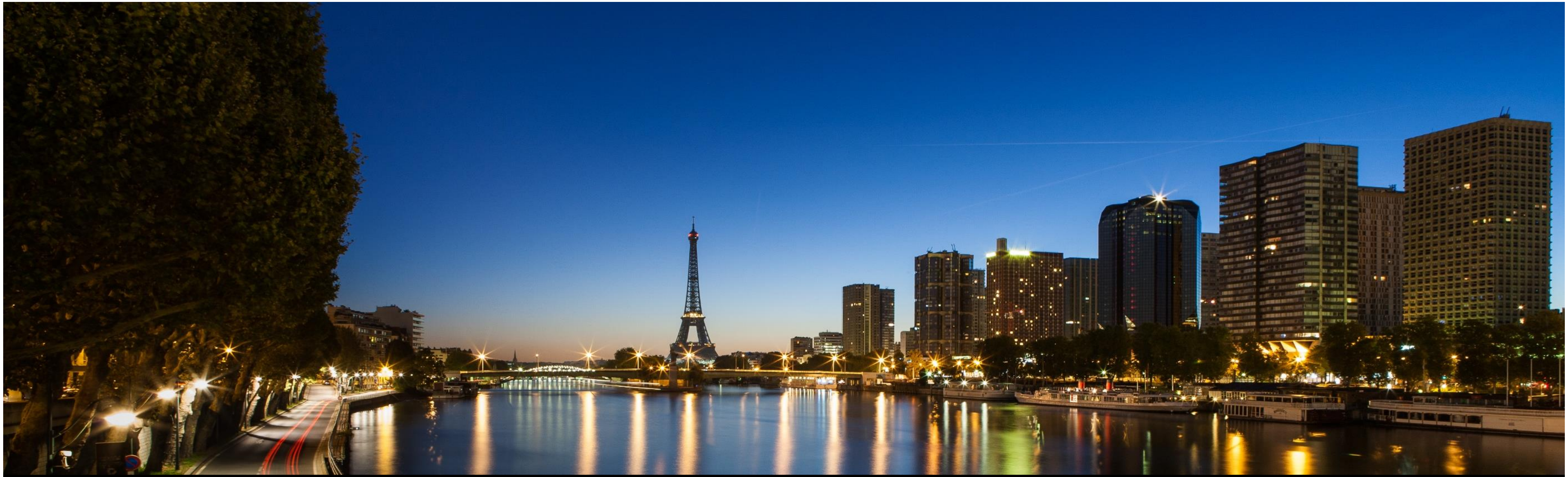


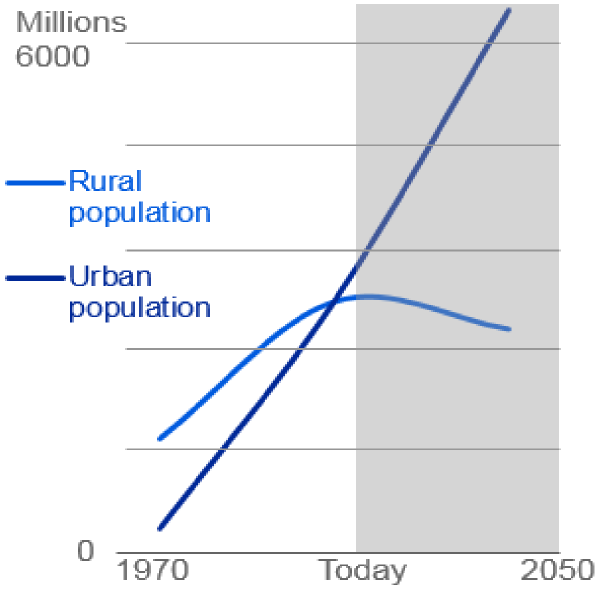
Claudio Facchin, President Power Grids division, ABB – Cigré Keynote Address, Paris, August 21, 2016

Big shift in power

Shaping power systems of the future

Big shift in power
Global challenges

Population growth & urbanization



Source: UN World urbanization prospects: 2012 revision

Paris climate agreement (COP 21)

- Average global temperature increase <2°C
- $100 billion per annum to support developing countries
- CO_2 Emission peak soon, 2050 balance of emissions and capturing

Manage economic growth and social challenges without consuming the earth

Big shift in power
Changing power generation balance

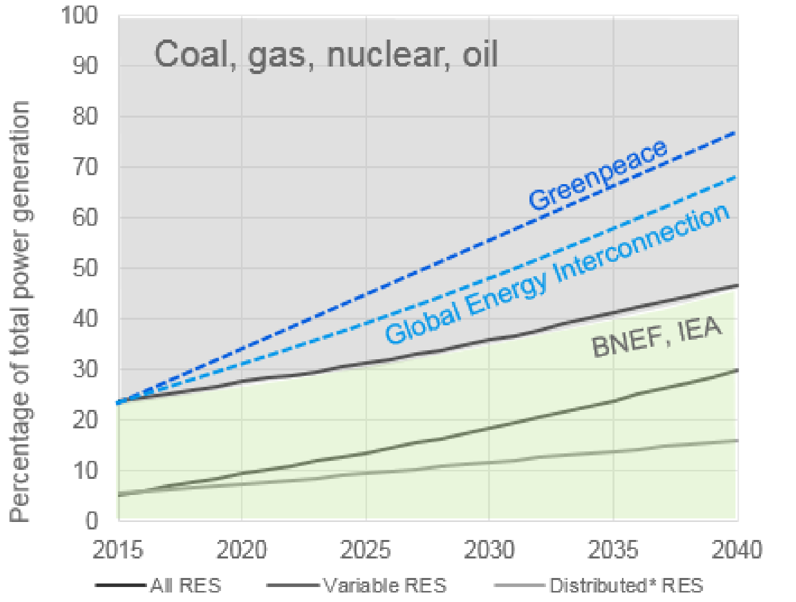
Power generation

Power balance tipping irreversibly towards renewables, driven by policy & disruptive technology cost reduction

Main growth is foreseen in variable renewables such as wind and solar

Two growth paths: centralized and distributed renewables

- Some countries / regions are more inclined towards distributed renewables
- Others are mainly on the centralized renewables path



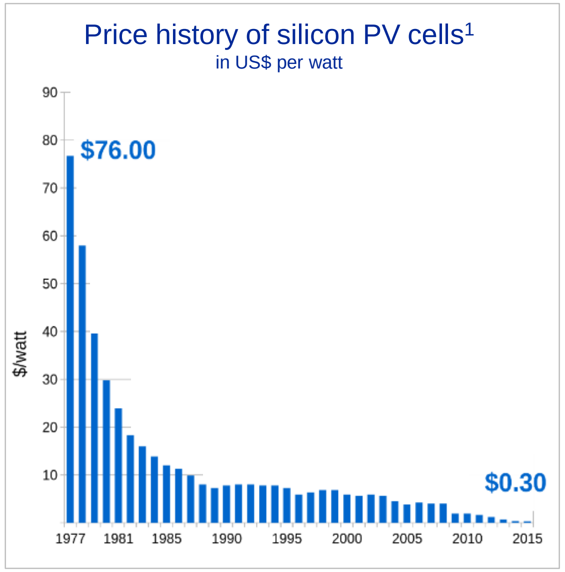
*units <50 MW connected to MV/LV

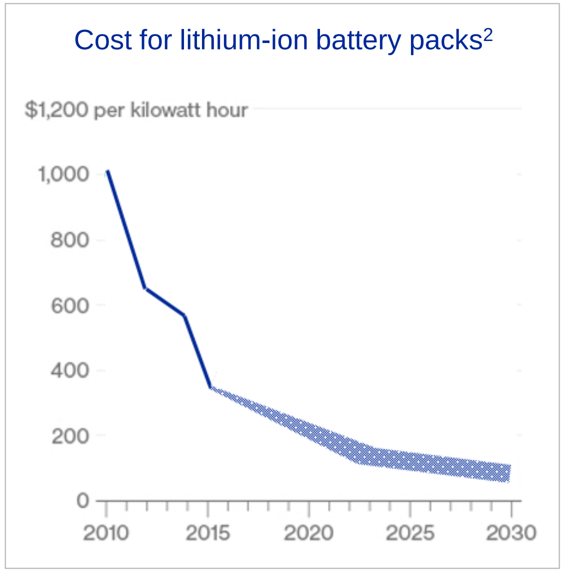
Source: BNEF, ABB analysis

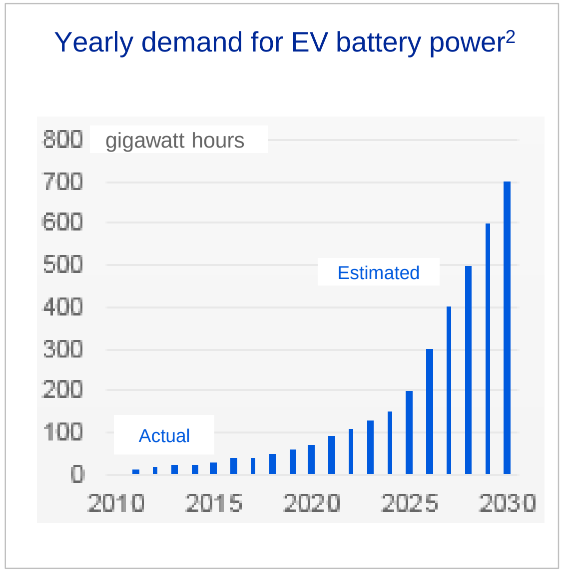
Renewables are expected to become the dominant source for electrical power generation

Big shift in power

Disruptive developments driving key changes in future grids







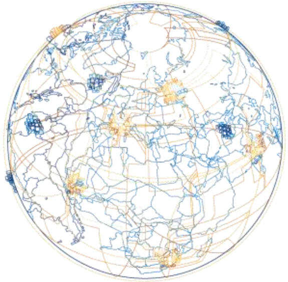
Batteries & photovoltaic

- Dramatic cost reduction – to be continued
- Scalability of technologies
- Consumer investment across market segments accelerating developments

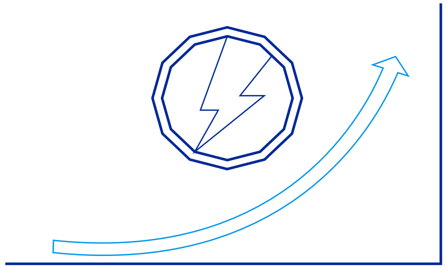
1 Source: Bloomberg New Energy Finance & pv.energytrend.com
2 Source: Data compiled by Bloomberg New Energy Finance

Big shift in power
Elements of the evolving grid

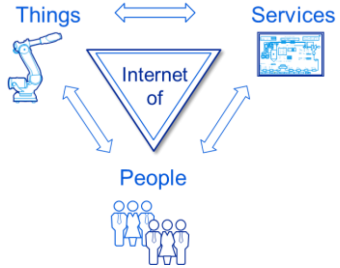
Global super grids



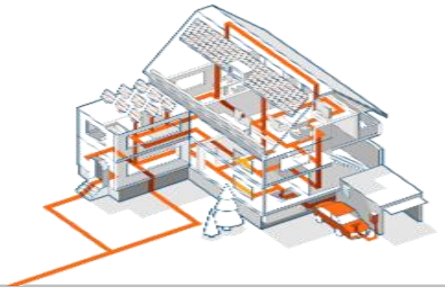
Power quality & demand management



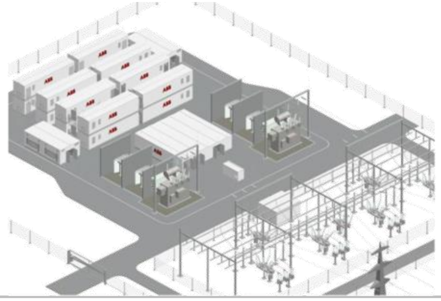
Digitalization



Residential roof top solar plus Micro- and Nano-grids



Energy storage

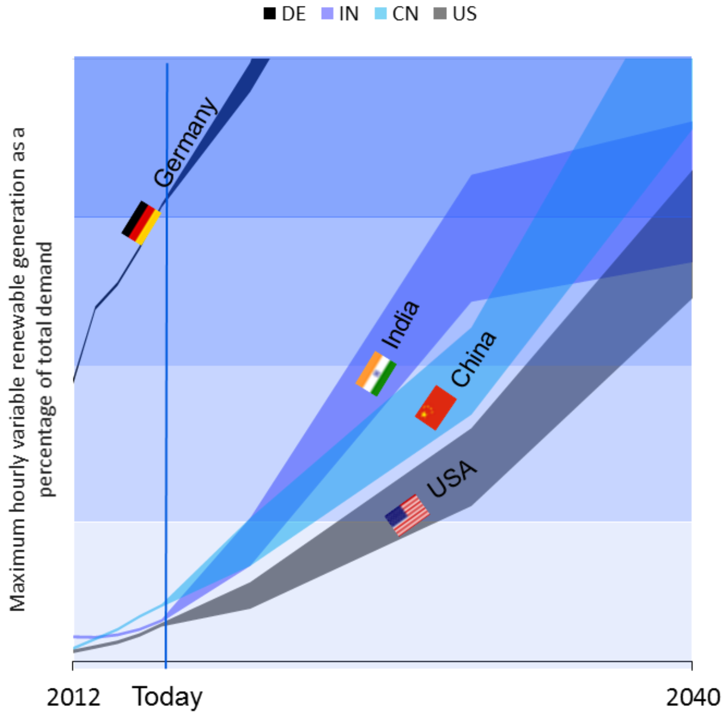


New business models

UBER
airbnb
NETFLIX

Big shift in power

Technical challenges of renewable energy grid integration



*Source: ABB evaluation

Technical challenges*
Conventional operation
Grid capacity & reserve
+ system inertia & grid voltage
+ short circuit power & significant variable RES curtailment

* Percentages are dependent on system characteristics

Grid investments and technologies required to address above challenges

Power systems of the future
Grid interconnection

Opportunities

Renewable integration across regions

- Fluctuations during the day
- Seasonal variations

Optimal use of reserve and peaking capacities

Diversification of electricity supply

Reduction of wholesale electricity price volatility

Strengthening grid operation in case of fault conditions

Increase capacity utilization factor of conventional generation

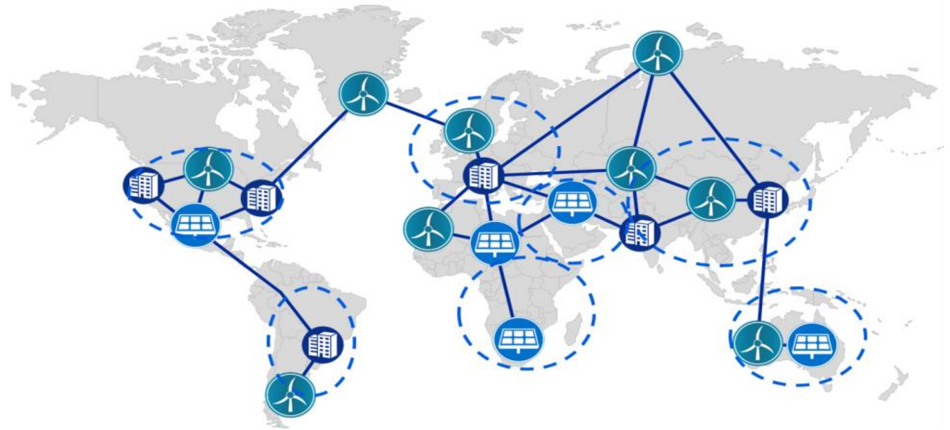
Challenges

Political factors

Economic framework

Technological capabilities

Coordinated operation (global harmonization of standards, grid codes and operational practices)



Power systems of the future

Grid interconnection: Ultra High Voltage

World's most powerful UHVDC link

Chiangji-Guquan, China

1100kV DC

12000MW

>3000km

World's first multi-terminal UHVDC link

North-East Agra, India

800kV DC

6000MW

>1700km

UHVAC transmission

Bina Substation, India

1200kV Circuit breaker & transformer

Power systems of the future
Microgrids and integration of renewables

Resilient and cost-effective technology

Grid code compliant integration of wind & solar

Stabilizing weak grids

Microgrids acting as one controllable generator or load

Access to power in remote locations

Marble Bar, Australia

- PV* (300 kW)
- Diesel (1280 kW)
- Flywheel (500 kW)

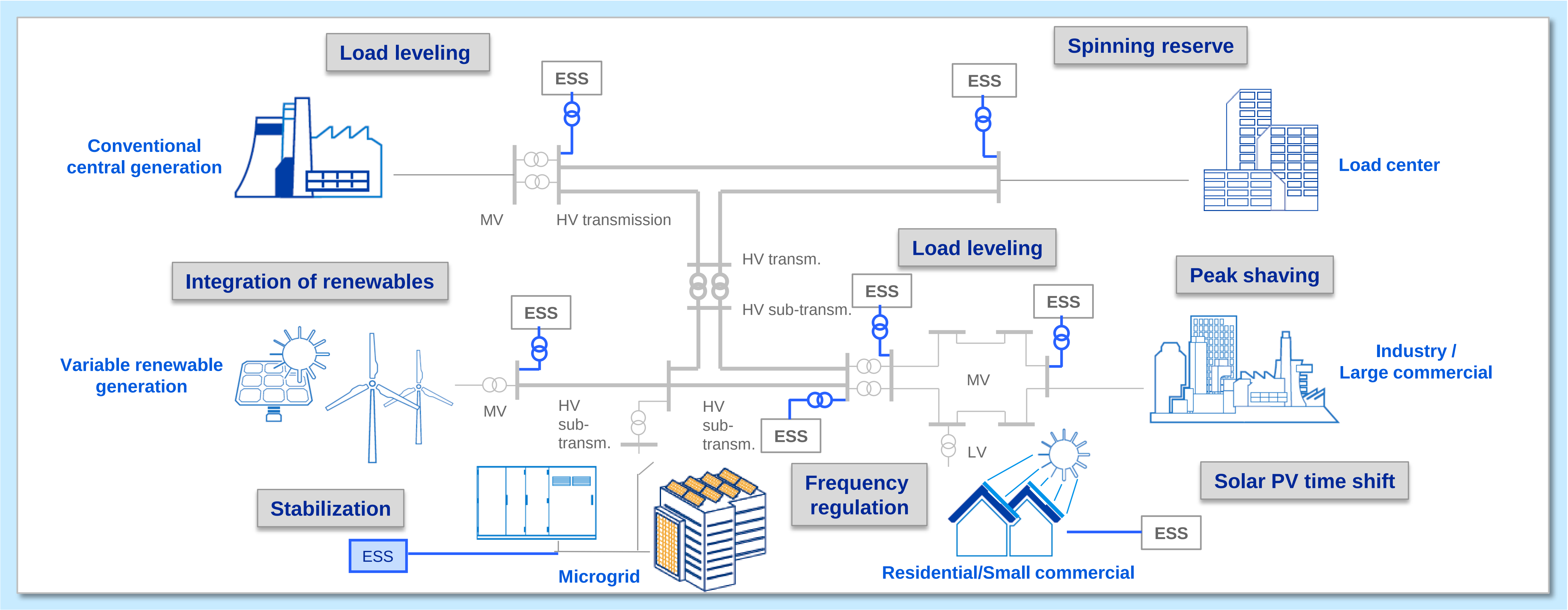
Johannesburg, South Africa

- PV* (750 kW)
- Diesel (2x600 kW)
- Battery (1 MVA/380 kWh)

 *PV -Photovoltaic

Power systems of the future

Energy storage – a key element across the power value chain



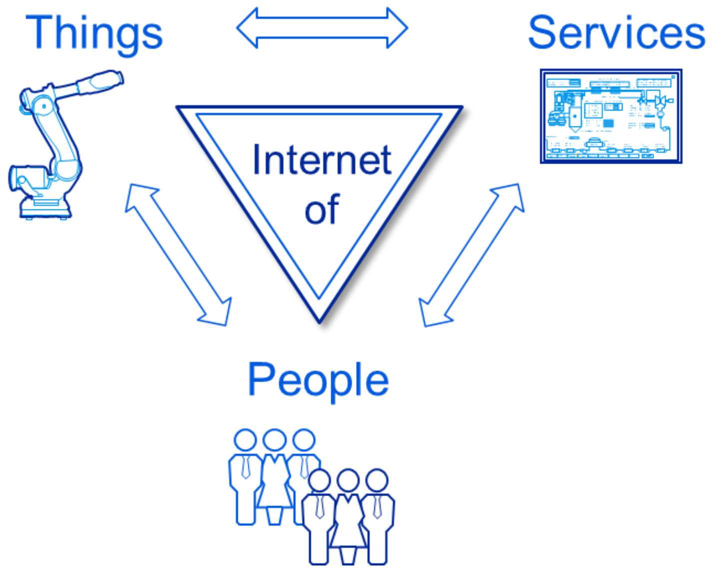
Power systems of the future
Power quality & demand management

Distributed renewables	Line voltage regulator On-load tap-changers for distribution transformers Extended control algorithms	Line voltage regulator for medium voltage grids with RESIBLOC® technology 
Bulk renew-ables	Extremoz substation (BR): Static Var Compensator to connect wind energy (>1000 MW) to 230kV level	
Demand response manage-ment	Frequency regulation through short term balancing of supply and demand Smart home and building management Electric vehicle (charging) infrastructure	

Power systems of the future

Digitalization trend – Internet of Things, Services & People

Design and build	Optimized design through simulation Faster configuration process Lower lead times and higher quality manufacturing & assembly processes Reduced on-site installation & commissioning
Operate	Virtual power plants Power generation forecasting & scheduling Electricity market management Ownership of assets and business model
Maintain	(Big) Data analysis – continuous learning Remote access – communication Monitoring, asset management & service aligned with expert knowledge Workforce management



Power systems of the future

Evolution from a conventional to a digital substation

Fit for future grid requirements

Standardized digital signal transfer

- Compatibility & interchangeability
- Signal supervision
- Fast communication
- Data acquisition for monitoring

Reduced cabling

Reduced footprint (AIS)

Safety

Reduced installation times

Flexibility for changes

Queensland, Australia

275kV digital substation including NCIT[1] & 61850 process bus communication in operation since 2011

Relevant for new and existing substations

[1]NCIT – Non Conventional Instrument Transformers

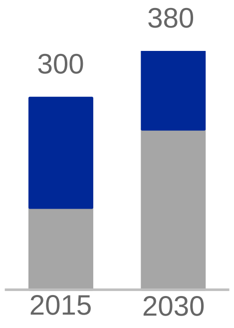
Market undergoing significant change

Demand drivers remain attractive

Shift in growth of electricity sources

Gross power capacity additions (GW)

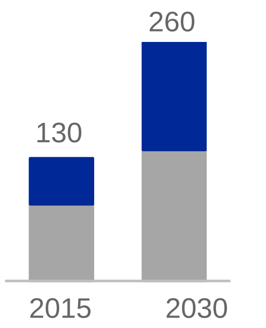
CAGR ~1.6%



Conventional
Renewable

Bulk vs. distributed renewable capacity additions (GW)

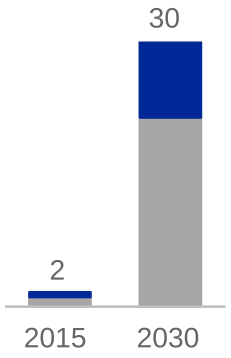
CAGR ~5.0%



Bulk
Distributed

Flexible capacity and Microgrid additions (GW)

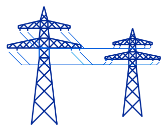
CAGR ~20%



Microgrids
Flexible Capacity[2]

Customers & consumers: more diverse, more grid feed-in & take-out points

Utilities



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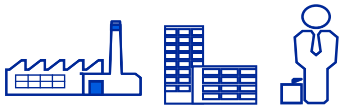
Industry, developers, new players[1] …



Suppliers: shift in differentiation

Power
Infrastructure enabling flow of electrons

+

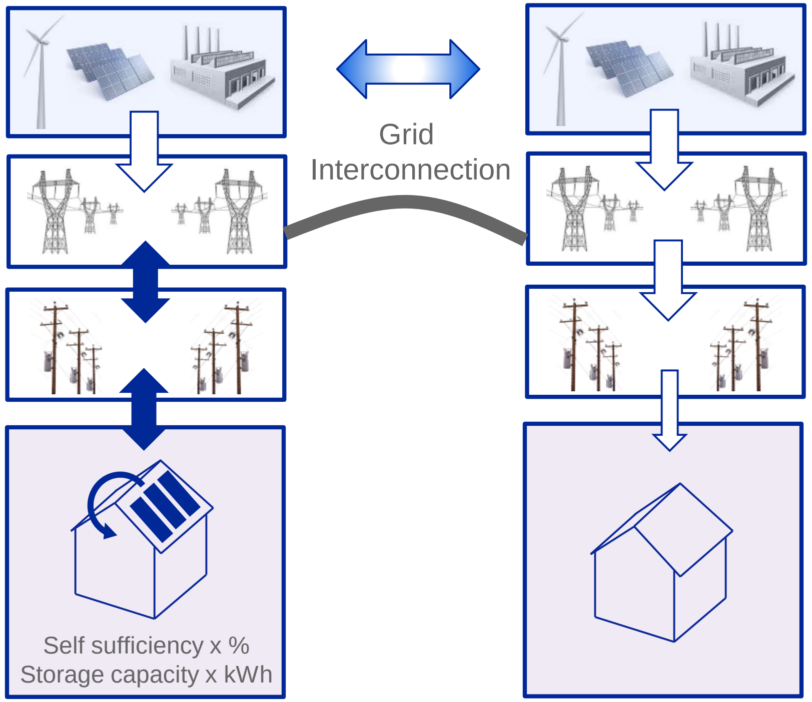
Automation
Design, control, optimization

Shift in generation mix, customer diversification and supplier differentiation

[1]E.g. Virtual Power Plants, local consumers, …;
[2] Flexible capacity includes Virtual Power Plants and battery storage capacity.
Source: Bloomberg New Energy Finance

Power systems of the future – an evolutionary vision

Interconnected system of regional grids with fluctuating demand and generation patterns



Renewables will take major share in electrical power generation

- Disruptive elements
  - Photovoltaics
  - Batteries
  - Digitalization
- Distributed generation with changing consumer & producer patterns
- Distribution grid role changing
- Transmission backbone essential
- New business & operational models

New opportunities & challenges require new ideas – evolutionary & revolutionary

Thank you