Standardization of grid integration of renewable energy generation

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5 December, 2019   London, UK

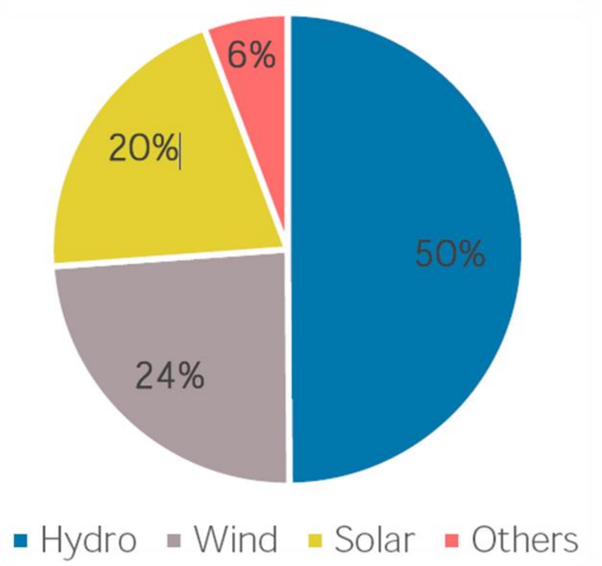
1 Impact of high penetration of RE generation

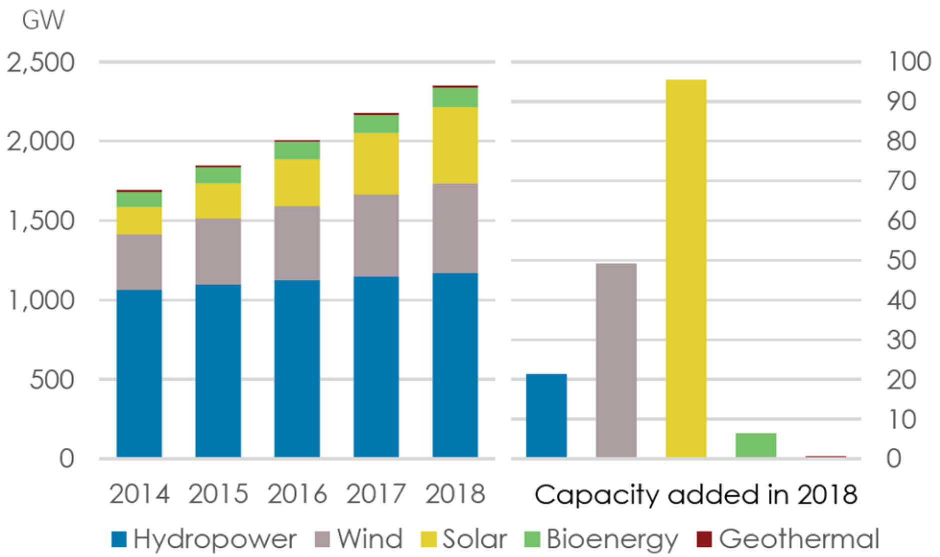
2 Grid requirements and technical works

3 IEC International Standardization on RE Grid Integration

1. Impact of high penetration of RE generation

- At the end of 2018, global RE capacity amounted to 2,351 GW. Hydro accounted for the largest share of the global total, with an installed capacity of 1,172 GW. Wind and solar energy accounted for most of the remainder, with capacities of 564 GW and 486 GW respectively.
- RE capacity expansion continues to be driven mostly by new installations of solar and wind energy. These accounted for 84% of all new capacity installed in 2018, finally pushing the overall share of hydro to just under 50%.



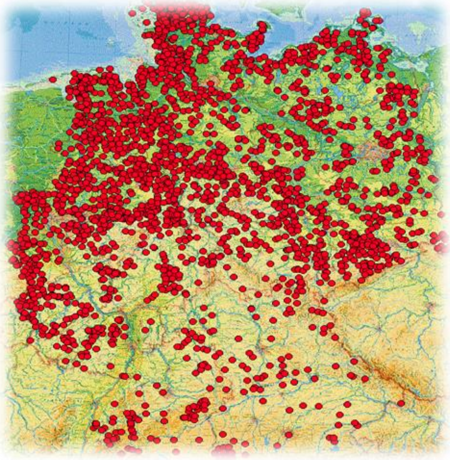


Data Source：IRENA, Renewable capacity highlights, 2019.03.31

1. Impact of high penetration of RE generation

- With the penetration of RE growing, the interaction between RE and the bulk power system caused many issues influencing the grid security and stability, the system performance dramatically changed.

1989



2017

Germany: wind and solar energy accounts for around 50% in capacity , 29% in electricity, by 2017.

Renewable energy distribution and UHVDC projects in China

1. Impact of high penetration of RE generation

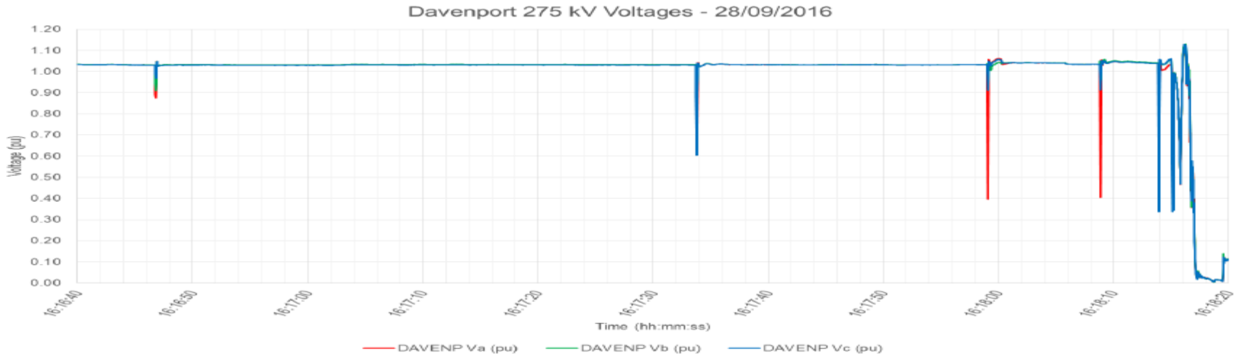
Issue of 50.2 Hz in Germany

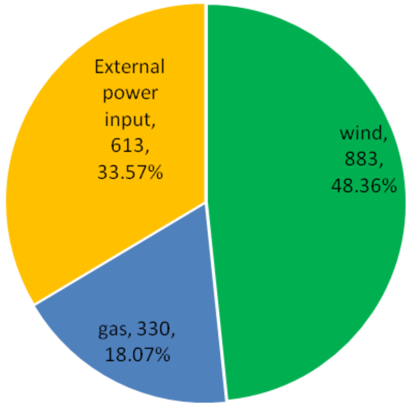
- Technical background：
  - ✓ The distributed PV generations are required to disconnect in case of system frequency over 50.2 Hz, in German old grid code.
  - ✓ The affordable disconnection of power sources in UCTE is 3 GW defined by system reserves.
- The amount of 38 GW (data of year 2013) distributed PV disconnection in case of system over-frequency, may lead to severe frequency drop and instability, need to modify the grid requirements with respect to distributed PV in this situation.

1. Impact of high penetration of RE generation

- Successive FRT during system faults under extreme weather condition in Australia
  - Sep 28, 2016, strong rain and storm hit south Australia grid which with 50% penetration of RE, caused 6 times grid voltage drop and wind generation tripping, 950MW in total. (16:18:15) ,
  - Load flow increased to 900 MW after the faults, caused overloading and disconnection of tie line and system collapsed for a 50 hour blackout.

No.	time	event
1	16:16:46	Northfield – Harrow 66kV line. tirpped.
2	16:17:33	275kV Brinkworth-Temlers West. 2 phase to ground fault, damaged towers bypassed.
3	16:17:59	275kV Davenport-Belalie. single phase fault, 1s auto-reclosed.
4	16:18:08	275kV Davenport-Belalie. single phase fault, no auto-reclose.
5	16:18:13	275kV Davenport-Mt Lock. Single phase fault. Auto-reclosed, then locked out.
6	16:18:14	275kV Davenport-Mt Lock failure of auto-reclosed. 3 275kV line out of services.



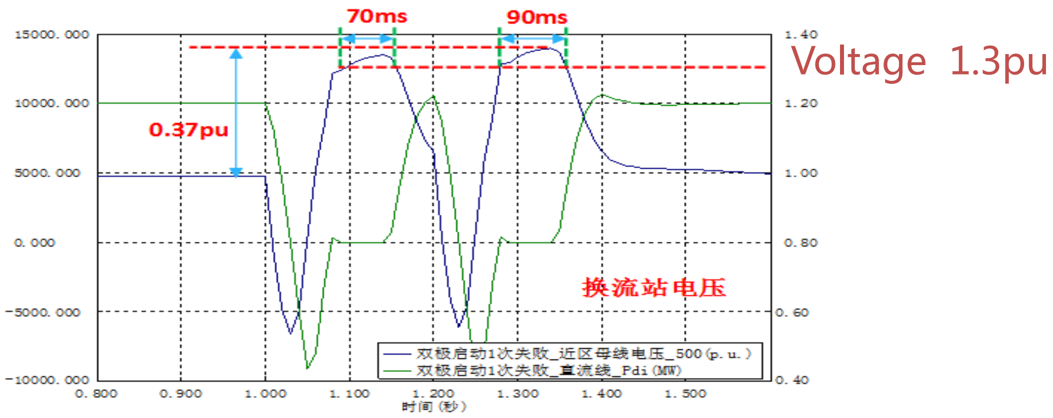


Heywood 275kV tie line (Max 600MW) connected to Victoria

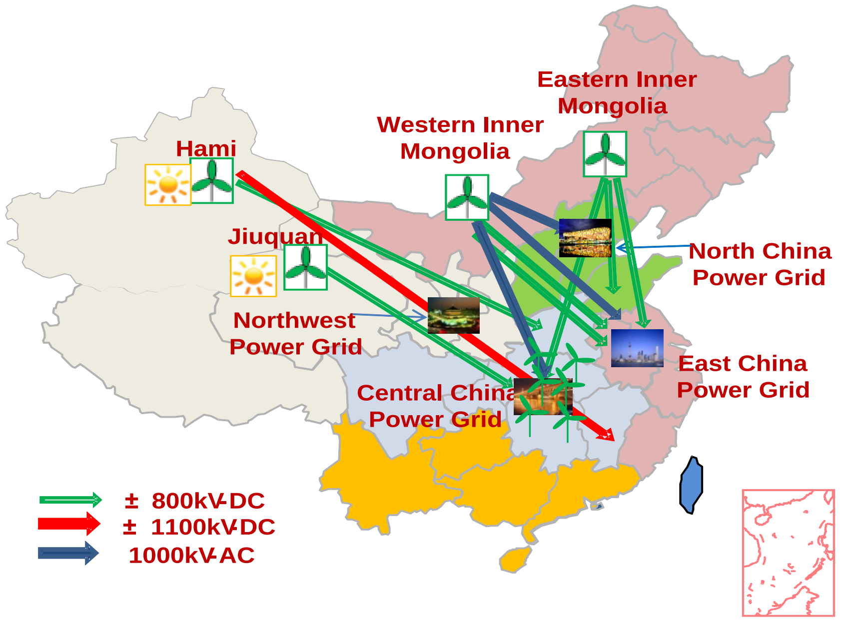
1. Impact of high penetration of RE generation

HVRT caused by UHVDC commutation failure in China

- Main reasons of LCC-HVDC system commutation failure are the low grid strength or system short circuit at the receiving end ac system. Commutation failure also causes an over-voltage at the sending end ac system with a 60-100ms duration, 2 times successive commutation failure will last for 400-500ms.
- If the HVRT function not equipped with, the wind turbines shall be disconnected due to the high voltage caused by HVDC system commutation failures.



Voltage profile of sending AC system caused by 2 successive commutation failures



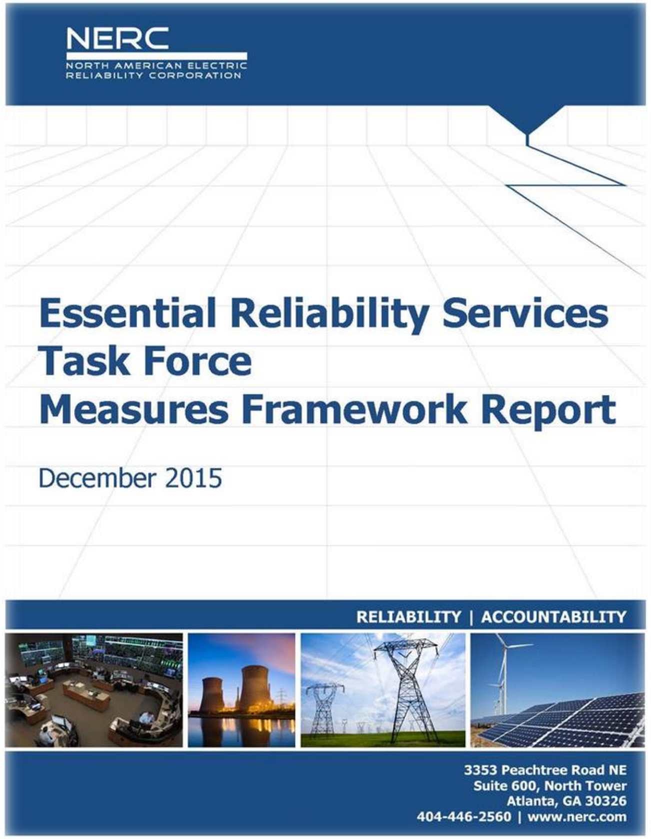
1 Impact of high penetration of RE generation

2 Grid requirements and technical works

3 IEC International Standardization on RE Grid Integration

2. Grid requirements and technical works - USA

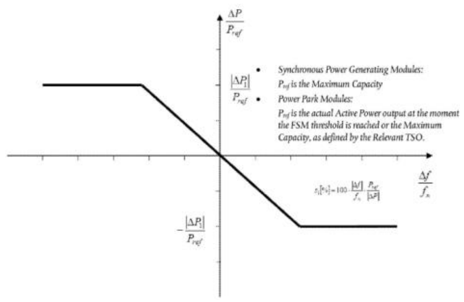
- December 2005, USA federal energy regulatory commission (FERC) issued order No.661A- Interconnection for Wind Energy, presented requirements to wind farms, including power factor, fault ride through and SCADA system.
- 2015, NERC published *Essential Reliability Services Task Force Measures Framework Report*, addressing inertia response, frequency regulation as well as other requirements on controllability.
- 2017, IEEE 1547-2018 published, technical requirements on distributed power sources put forward, including LVRT, frequency response and power quality.

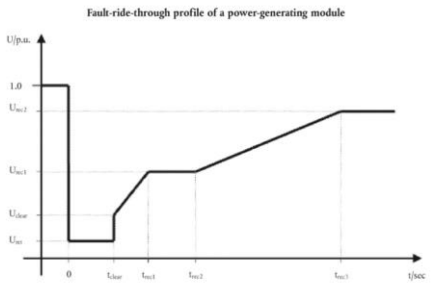


2. Grid requirements and technical works - Europe

- ENTSO-E: European Network of Transmission System Operators for Electricity
  - ENTSO-E, represents 43 electricity transmission system operators (TSOs) from 36 countries across Europe, aims at further liberalizing the gas and electricity markets in the EU.

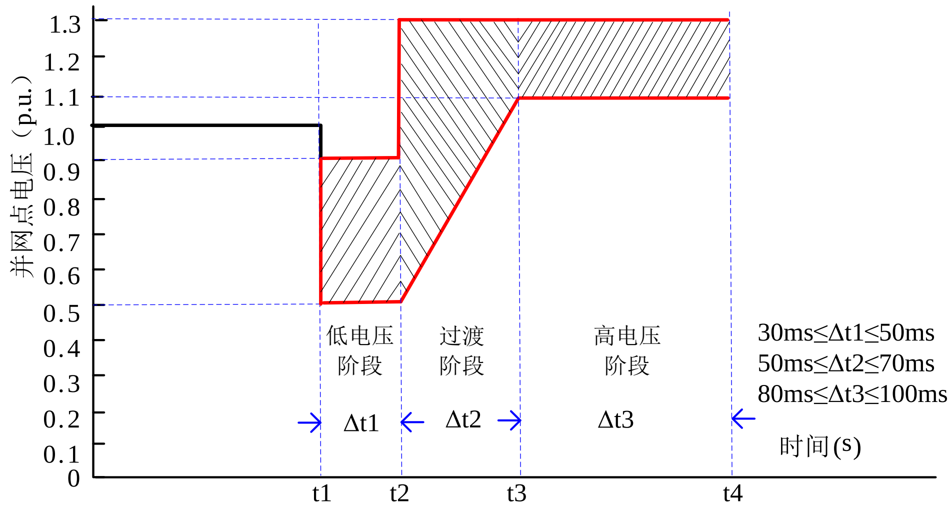
- The Network Code on Requirements for Generators
  - Harmonizing standards that generators must respect to connect to the grid. These harmonized standards across Europe will boost the market of generation technology and increase competitiveness.
  - Those requirements that contribute to maintaining, preserving and restoring system security in order to facilitate proper functioning of the internal electricity market within and between synchronous areas, and to achieve cost efficiencies, should be regarded as cross-border network issues and market integration issues.

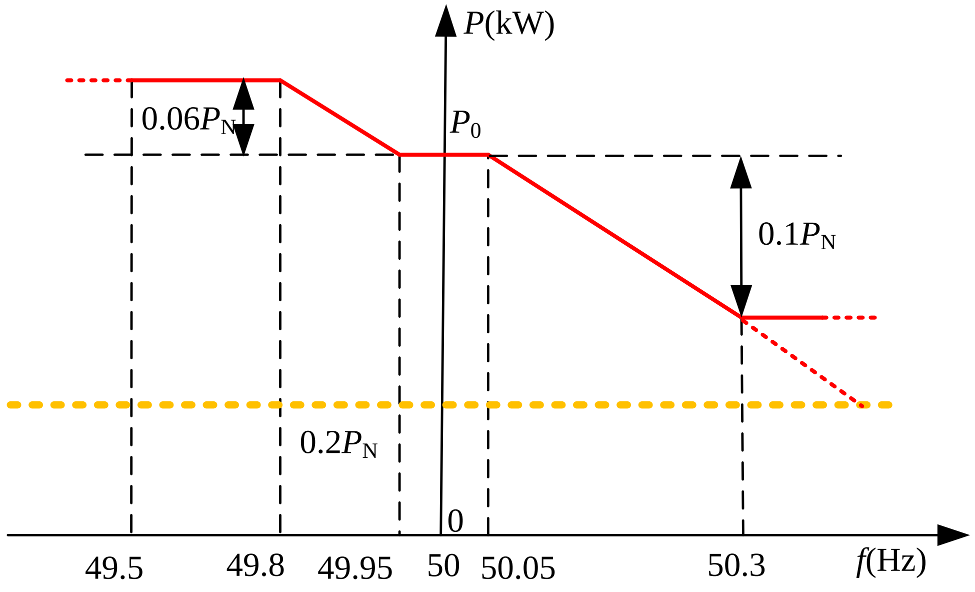




2. Grid requirements and technical works - China

- UHVDC commutation failures cause over-voltage to 1.30 pu at the sending end of AC system, requirement of successive fault ride through are discussed and may be included in the new grid codes.
- Inertia response and primary frequency regulation are new added in grid code, wind farms shall be capable of participating system frequency regulation, with 6% headroom as the reserve for up-regulation.





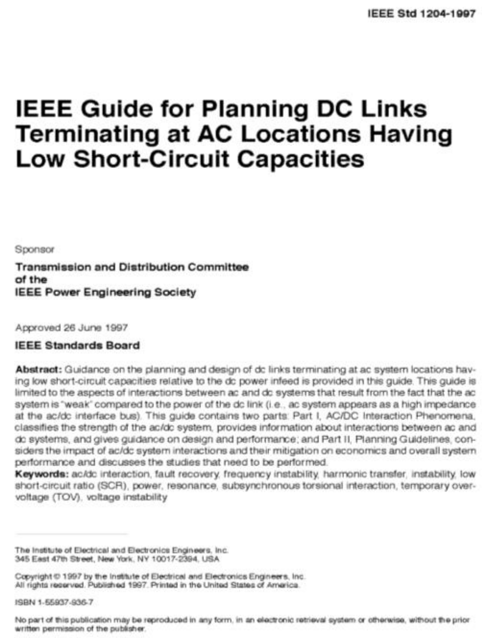
2. Grid requirements and technical works – Weak AC Grid

Strength characteristics of power system integrating renewable energy

- The "strength" of the power system is a measure used to describe the ability of the power system to maintain the main characteristics.
- The "strong" or "weak" of the power system is a relative concept: when the impedance of the power system is large from the POI, the power system is weak; when the inverter capacity is relatively large, the power system is relatively weak.

IEEE Std 1204-1997   Definition of weak power system

- A high SCR ac/dc system — SCR value greater than 3.
- A low SCR ac/dc system — SCR value between 2 and 3.
- A very low SCR ac/dc system — SCR value lower than 2.



IEEE Std 1204-1997

IEEE Guide for Planning DC Links Terminating at AC Locations Having Low Short-Circuit Capacities

Sponsor

Transmission and Distribution Committee of the IEEE Power Engineering Society

Approved 26 June 1997

IEEE Standards Board

Abstract: Guidance on the planning and design of dc links terminating at ac system locations having low short-circuit capacities relative to the dc power infeed is provided in this guide. This guide is limited to the aspects of interactions between ac and dc systems that result from the fact that the ac system is "weak" compared to the power of the dc link (i.e., ac system appears as a high impedance at the ac/dc interface bus). This guide contains two parts: Part I, AC/DC Interaction Phenomena, classifies the strength of the ac/dc system, provides information about interactions between ac and dc systems, and gives guidance on design and performance; and Part II, Planning Guidelines, considers the impact of ac/dc system interactions and their mitigation on economics and overall system performance and discusses the studies that need to be performed.
Keywords: ac/dc interaction, fault recovery, frequency instability, harmonic transfer, instability, low short-circuit ratio (SCR), power, resonance, subsynchronous torsional interaction, temporary overvoltage (TOV), voltage instability

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

ISBN 1-55937-936-7

2. Grid requirements and technical works – Weak AC Grid

- Technical Brochure *Connection of wind farms to weak AC networks*
  - CIGRE B 4.62 working group ;
  - Time schedule：Jan 2013~Dec 2016.
- Technical challenges in weak grid situations
  - Risk of fault ride-through failure: The frequency, phase, and high / low voltage changes during the FRT may cause the wind farm to fail to meet the FRT requirements;
  - Control interactions and oscillation instability of multiple power electronic devices: HVDC inverters, SVCs, STATCOMs, etc. near wind farms have strong interactions;
  - The voltage of POI is significantly affected by the wind turbine, and the control mode is dynamically coupled through the POI. The traditional transient stability model is no longer applicable.

WG B4.62

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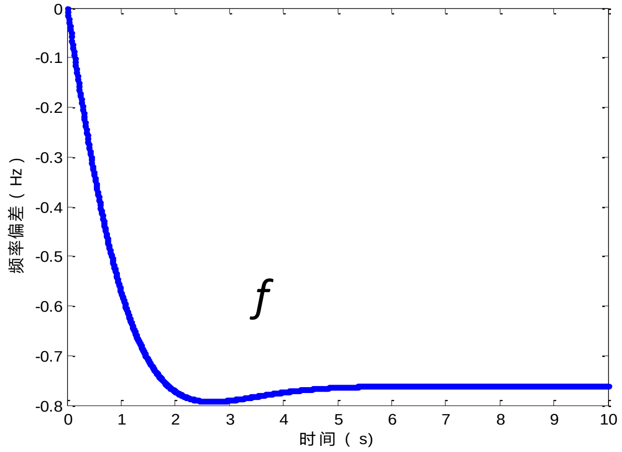
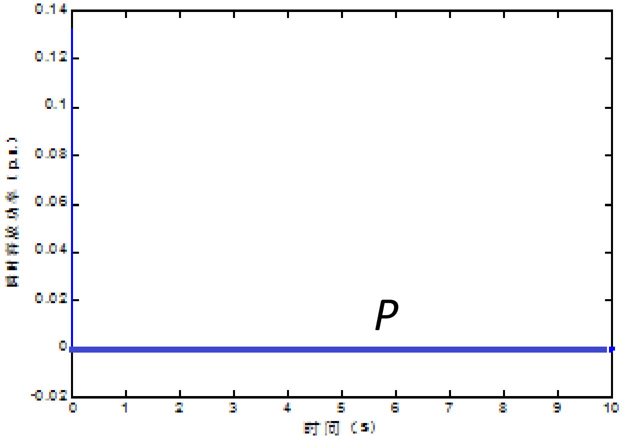
2. Grid requirements and technical works – Frequency Response

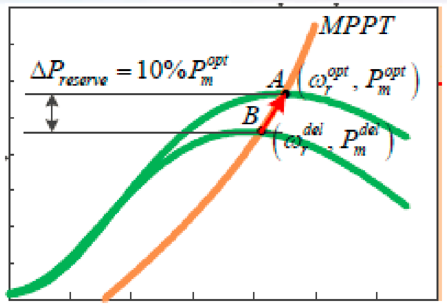
Frequency response characteristics of RE generation units

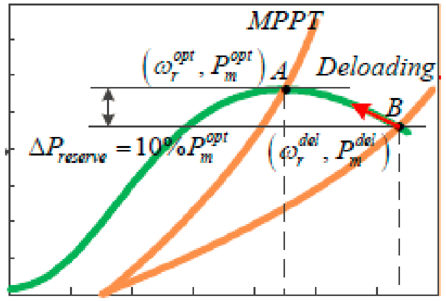


System frequency



Active power





- Variable-speed wind turbine or PV inverter decoupling the power from the system frequency, the unit will not respond to grid frequency changes, and the unit ′s rotational kinetic energy is “hidden”. It does not contribute to the system frequency deviation.
- If the RE generation unit want participate in the system's primary frequency regulation, it must have a certain reserve capacity, and it can also be realized by energy storage.

2. Grid requirements and technical works – Frequency Response

- **CIGRE JWG C2/C4.41 working group ‘Impact of high penetration of inverter-based generation on system inertia of networks’**
  - Time schedule：July 2018~November 2020
  - Convenor：Mpeli Rampokanyo (South Africa)
  - Main work scope：
    - ✓ Investigate the existing primary frequency regulation requirements;
    - ✓ Define the operation measures of low-inertia power system;
    - ✓ Quantify major frequency requirements as renewable energy penetration increases;
    - ✓ Establish a frequency change rate constraint method;
    - ✓ Study the control strategy of inverter-based power supply.

CIGRE Study Committee C2

PROPOSAL FOR THE CREATION OF A NEW WORKING GROUP[1]

JWG N° C2/C4.41	**Name of Convenor:** Mpeli Rampokanyo (South Africa) **E-mail address**: mrampokanyo@csir.co.za
Strategic Directions #[2]: 1, 2	**Technical Issues #[3]: 5, 10**

The WG applies to distribution networks[4]: Yes

Potential Benefit of WG work #[6]: 2, 3, 4

Title of the Group: Impact of high penetration of inverter-based generation on system inertia of networks

Scope, deliverables and proposed time schedule of the Group:

Background:

The worldwide drive to reduce carbon emissions in the environment has led to the global community looking for alternative sources of energy that are less polluting and cheaper to harness than traditional primary energy sources that are currently widely used such as fossil fuel sources. This has led to the widespread introduction of renewable energy sources (RES) as alternative energy sources for the future. While the introduction of RES generation onto the electrical grid brings with it some major benefits, it is certainly not without challenges.

Not all RES are non-synchronous but a majority of them are and this is expected to have a significant impact on the way the power system is operated. One major challenge with the introduction of non-synchronous generation on the grid is the reduction of natural inertia that is provided by conventional synchronous machines on the grid. This natural inertial response from synchronous generating sources helps in damping frequency excursions during system disturbances such as generator trips or sudden loss of a large load. With depleting inertial energy, the rate of change of frequency (RoCoF) increases substantially, leading to a lower nadir, such that Primary Frequency Response (PFR) systems and even defence schemes such as Under Frequency Load Shedding Schemes (UFLS) may fail to protect the system during major frequency excursions. This has become a big challenge for system operators across the globe as penetration of inverter-based renewable sources is increasing tremendously and RES are seen as an imminent replacement of conventional generating sources. System operators have to be prepared for a more dynamic system, not only operating the system within tight security constraints, but also performing congestion management and facilitating a competitive electricity market.

Scope:

The objective of this WG is to advise and formulate philosophies for system operations in order to prepare the on-going energy transition. Primary Frequency Response studies will be carried out (or existing studies will be reviewed) in order to analyse and mitigate against the impact of the reduction of synchronous inertial energy on the power system as a result of integration of non-synchronous renewable generation using various networks around the globe as case studies. The integration of the existing knowledge between system operation and system performance, as well as the interaction with system planning, is crucial to achieve the proposed goals.

The JWG will address amongst others the following issues:

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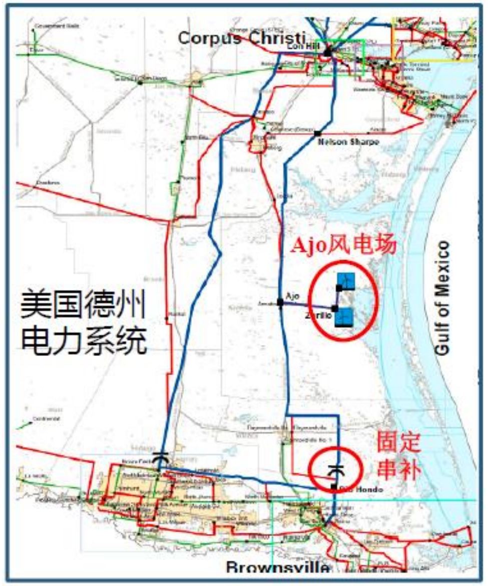
WG form 2017-V5

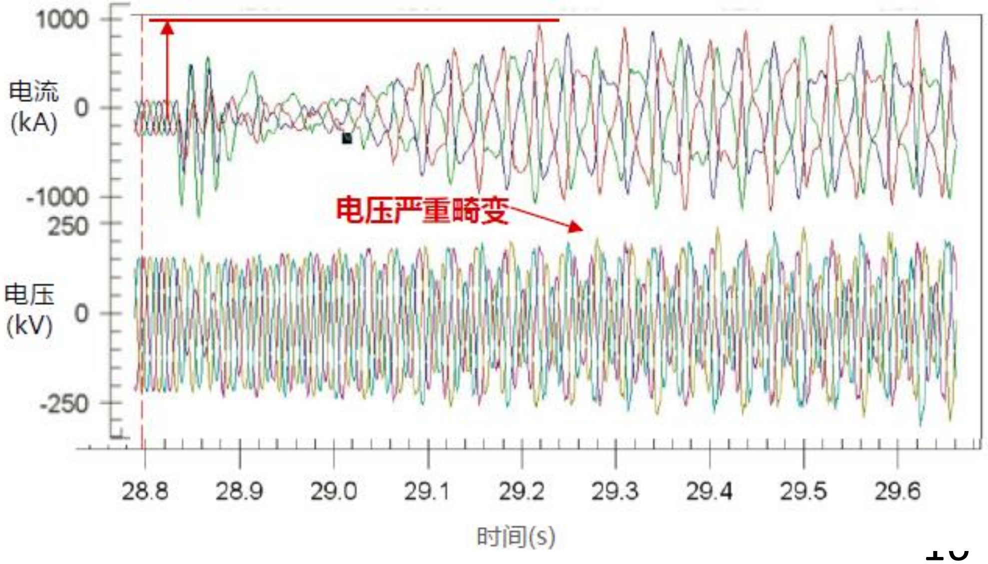
2. Grid requirements and technical works – SSR or SSCI issues

Sub-synchronous oscillation of a wind farm in Texas, USA

- In October 2009, the first sub-synchronous oscillation of about 20 Hz occurred in the Texas Ajo wind farm.

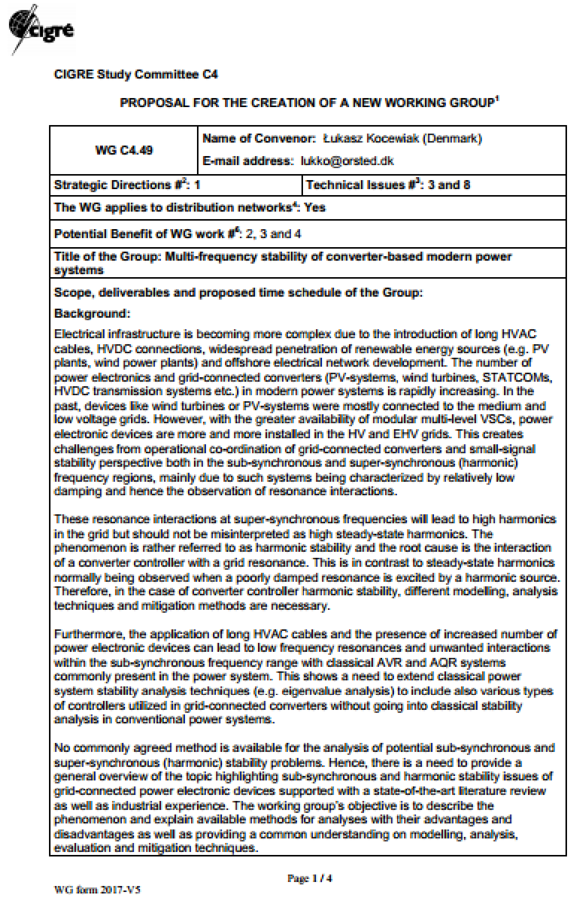


- ✓ Ajo-Netson line is cut off due to maintanance, and the double-fed wind farm is directly connected to the grid through the high series compensation line;
- ✓ The sub-synchronous oscillation around 20Hz in the system voltage/current increases, causing the system voltage to exceed 2 p.u., and the series compensation is bypassed;
- ✓ The accident caused a large number of wind turbines to be cut off and the crowbar circuit to be damaged.



2. Grid requirements and technical works – SSR or SSCI issues

- **CIGRE JWG C4.49 working group "Multi-frequency stability of converter-based modern power systems"**
  - Time schedule：June 2018~June 2021
  - Convenor：Łukasz Kocewiak (Denmark)
  - Main work scope：
    - ✓ Review of existing literature regarding converter stability issues;
    - ✓ Definition of stability phenomenon including harmonic stability and sub-synchronous stability;
    - ✓ The impact of grid-connected converter controllers on sub-synchronous and harmonic stability phenomenon;
    - ✓ Overview of linear modelling and analysis methods to perform small-signal stability studies and the description of mitigation methods.



CIGRE Study Committee C4

PROPOSAL FOR THE CREATION OF A NEW WORKING GROUP[1]

WG C4.49	Name of Convenor: Łukasz Kocewiak (Denmark) E-mail address: lukko@orsted.dk
Strategic Directions #[2]: 1	Technical Issues #[3]: 3 and 8
The WG applies to distribution networks[4]: Yes	
Potential Benefit of WG work #[4]: 2, 3 and 4	
Title of the Group: Multi-frequency stability of converter-based modern power systems	

Scope, deliverables and proposed time schedule of the Group:

Background:

Electrical infrastructure is becoming more complex due to the introduction of long HVAC cables, HVDC connections, widespread penetration of renewable energy sources (e.g. PV plants, wind power plants) and offshore electrical network development. The number of power electronics and grid-connected converters (PV-systems, wind turbines, STATCOMs, HVDC transmission systems etc.) in modern power systems is rapidly increasing. In the past, devices like wind turbines or PV-systems were mostly connected to the medium and low voltage grids. However, with the greater availability of modular multi-level VSCs, power electronic devices are more and more installed in the HV and EHV grids. This creates challenges from operational co-ordination of grid-connected converters and small-signal stability perspective both in the sub-synchronous and super-synchronous (harmonic) frequency regions, mainly due to such systems being characterized by relatively low damping and hence the observation of resonance interactions.

These resonance interactions at super-synchronous frequencies will lead to high harmonics in the grid but should not be misinterpreted as high steady-state harmonics. The phenomenon is rather referred to as harmonic stability and the root cause is the interaction of a converter controller with a grid resonance. This is in contrast to steady-state harmonics normally being observed when a poorly damped resonance is excited by a harmonic source. Therefore, in the case of converter controller harmonic stability, different modelling, analysis techniques and mitigation methods are necessary.

Furthermore, the application of long HVAC cables and the presence of increased number of power electronic devices can lead to low frequency resonances and unwanted interactions within the sub-synchronous frequency range with classical AVR and AQR systems commonly present in the power system. This shows a need to extend classical power system stability analysis techniques (e.g. eigenvalue analysis) to include also various types of controllers utilized in grid-connected converters without going into classical stability analysis in conventional power systems.

No commonly agreed method is available for the analysis of potential sub-synchronous and super-synchronous (harmonic) stability problems. Hence, there is a need to provide a general overview of the topic highlighting sub-synchronous and harmonic stability issues of grid-connected power electronic devices supported with a state-of-the-art literature review as well as industrial experience. The working group's objective is to describe the phenomenon and explain available methods for analyses with their advantages and disadvantages as well as providing a common understanding on modelling, analysis, evaluation and mitigation techniques.

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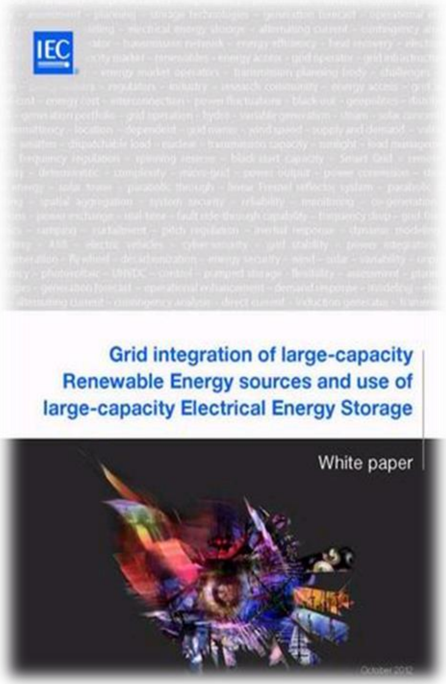
WG form 2017-V5

1. Impact of high penetration of RE generation
2. Grid requirements and technical works
3. IEC Standardization on RE Grid Integration

3. IEC standardization on RE grid integration



- Purpose and main analysis:
  - To explore "what is needed to integrate large quantities of renewables into existing electricity grids, given various characteristics and difficulties which necessarily accompany such a change."
- Main Conclusions:
  - In the area of integration of large renewables, many elements are not yet in place and much effort will be required.
  - In addition to continuing the development of device-level standards, the IEC should make an effort to develop performance-oriented RE integration standards.
  - Besides interconnection standards, standards for modeling, testing, communications, monitoring, control, generation forecast, scheduling and dispatching are also needed.

3. IEC standardization on RE grid integration

- Title : Grid Integration of Renewable Energy Generation
- Secretariat :

China NC

Role	Name	Nationality
Chair	Mr. Bernhard Ernst	DE
Secretary	Mr. Yongning CHI	CN
P-Member: 17	Australia, Canada, China, Germany, Denmark, Spain, Finland, France, United Kingdom, Italy, Japan, Malaysia, Netherlands, United States of America, Russian Federation, Switzerland, Sweden.	
O-Member: 13	Austria, Belgium, Czech Republic, Hungary, Israel, Mexico, New Zealand, Norway, Poland, Portugal, Thailand, Korea, Republic of, South Africa	

- Focus on the impact of a high percentage of renewables connected to the grid, considering that their variability and predictability impact the functioning of the whole electricity grid.

- Include requirements for interconnection and related tests for grid code compliance, as well as standards or best practice documents for planning, modeling, forecasting, assessment, control and protection, scheduling and dispatching of renewables with a grid level perspective.

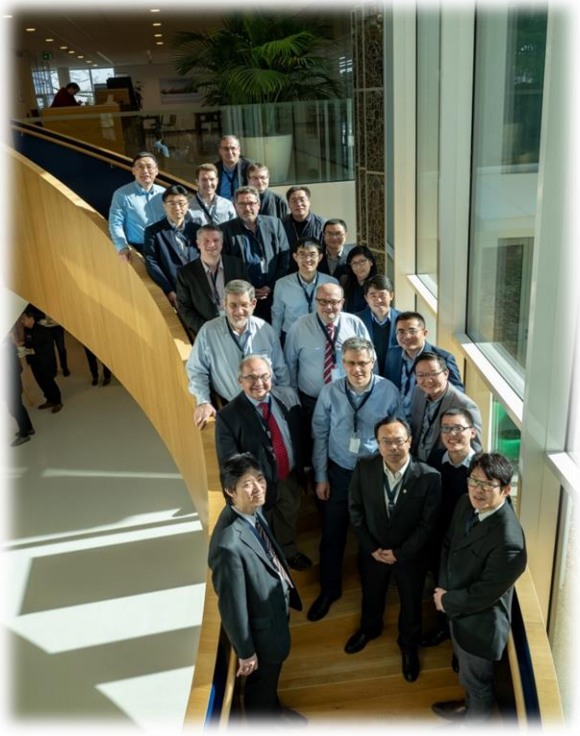
3. IEC standardization on RE grid integration

- Existing Working Groups in IEC SC 8A

WG No.	Title	Convener	No. of std
WG 1	Terminology of RE grid integration	Mr. Lingzhi ZHU	1 (IS)
WG 2	Renewable energy power prediction	Mr. Shuanglei Feng	1 (TR)
AHG 3	Roadmap of grid integration of renewable energy generation	Mr. Bernhard Ernst Mr. Yongning Chi	1 (TR)
JWG 4	Grid code compliance assessment for grid connection of wind and PV power plants	Mr. Qing LI	1 (TS)
JWG 5	System issues regarding integration of wind and PV generation into bulk electrical grid	Mr. Jason MacDowell Mr. Hu Jiabing	4 (TR)

3. IEC standardization on RE grid integration

- IEC SC 8A/JWG 5 - System issues regarding integration of wind and PV generation into bulk electrical grid
  - Project 1: Interconnecting Inverter-Based Resources to Weak AC Networks
  - Project 2: Sub- and Super-synchronous Control Interactions
  - Project 3: Fast Frequency Response and Frequency Ride-Through from Inverter-Based Resources during Severe Frequency Disturbances
  - Project 4: Behavior of Inverter-Based Resources in Response to Bulk Grid Faults



IEC

Administrative Circular	8A/43/AC
	2018-04-27

INTERNATIONAL ELECTROTECHNICAL COMMISSION

TO ALL NATIONAL COMMITTEES

Technical committee 8: Systems aspects of electrical energy supply

Subcommittee 8A: Grid Integration of Renewable Energy Generation

Set up Joint Working Group (JWG 5): System issues regarding integration of wind and PV generation into bulk electrical grid and call for experts.

This document is also made available to TC 82, TC 88, TC 95, TC 114, TC 115, TC 117 and TC 120.

Dear Sir/Madam,

Background

During the 2017 IEC SC 8A plenary meeting in Vladivostok, Russian Federation, a decision was made to set up a new Joint Working Group, with title JWG 5 "System issues regarding integration of wind and PV generation into bulk electrical grid", covering a series of possible projects within the following scopes:

(1) Weak AC Grid Connection and Special Application Issues
(2) Plant Level Interaction and Coordination Issues
(3) Voltage and Frequency Ride Through and Control Issues

After consulting with TC 82 and TC 88, it was agreed to set up the JWG 5, managed by SC 8A with the cooperation with TC 82 and TC 88, also nominate Mr. Jason MacDowell and Mr. Hu Jiabing as the co-conveners of JWG 5.

Title of JWG 5: System issues regarding integration of wind and PV generation into bulk electrical grid

Task of JWG 5: To develop a series of projects within the following scopes of weak AC grid connection and special application issues, plant level interaction and coordination issues, voltage and frequency ride through and control issues.

Membership:

- Co-convenors of JWG 5: Mr. Jason MacDowell (US)
  Mr. Hu Jiabing (CN)
- Representatives from each P-member country of IEC SC 8A

Action

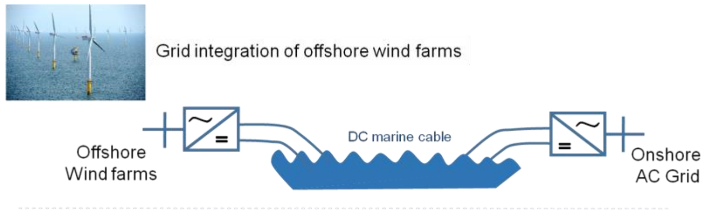
(1) National Committees are kindly invited to appoint experts, who should have expertise in the field of renewable energy grid integration and could make an effective contribution to the work of JWG 5. The appointed experts should be entered into the IEC Experts management system by the National Committees **no later than 2018-06-22**.
(2) The kick off meeting of JWG 5 was determined to be held in Wuhan, China on 20-21 June, 2018. Mr. Hu Jiabing are responsible for organizing the meeting and the logistics.

3. IEC standardization on RE grid integration

- Preliminary Work Item (PWI) 1 : "Operational behavior and coordinated control between renewable energy and HVDC systems"
  - Convener: Dr. Li Yan from CEPRI

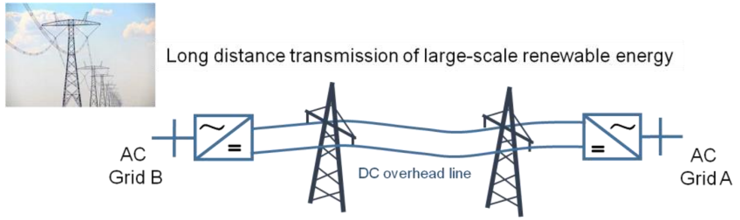
Operational behavior

- RE power output behavior based on HVDC system integration
- RE behavior analysis during HVDC system emergency period
- RE integration using HVDC technology in start-up and shut down



Coordinated control

- Inter-support between RE Station & DC in voltage and frequency
- Voltage cooperate control
- Fault response, including fault control and recovery
- Protection for system including RE Station & DC



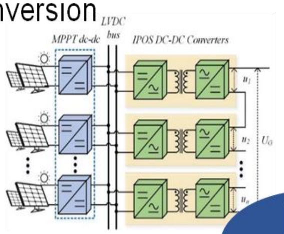
3. IEC standardization on RE grid integration

- Preliminary Work Item (PWI) 2 : " Integrating distributed PV into LVDC/MVDC systems and use cases"
  - Convener: Prof. Zhu Miao from Shanghai Jiaotong University

Key Issues

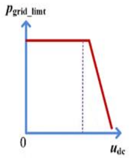
– DC Interface for RE integration

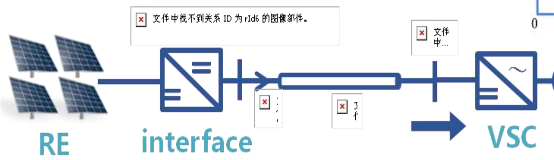
- Wide-range operation
- High-efficiency power conversion
- Fault isolation capability
- Power quality
- Electrical isolation



– Regulation of power and DC voltage

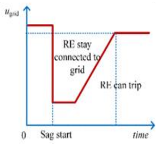
- Power regulation capability
- Secondary DC voltage regulation

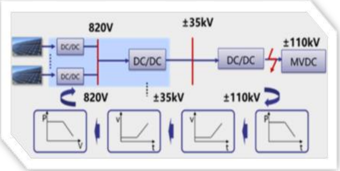




– Fault response of DC integrated RE

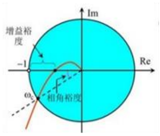
- Emergency power control
- Low-voltage and high-voltage ride-through

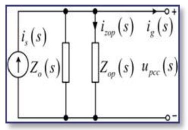


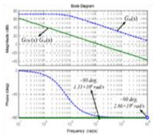


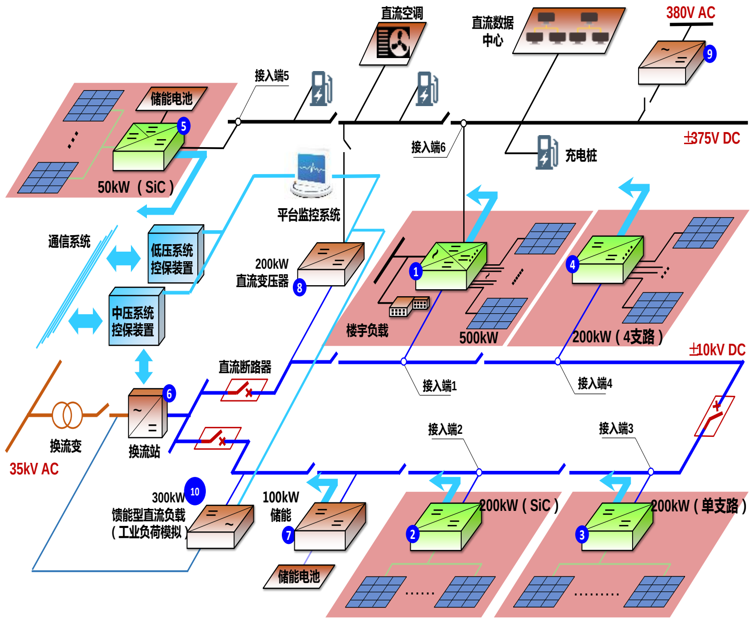
– Stability and Oscillation Suppression

- System stability with wide-range fluctuated RE
- Impedance reshaping for oscillation suppression









Project "Experimental DC Network for MW-Level PV Integration (2017-2020) in SGCC

3. IEC standardization on RE grid integration

- New evaluation task "Modeling of converter-based renewable energy generation for stability study" within AHG 3
  - Convener: Prof. GENG Hua and Dr. ZHU Lingzhi

EMT	RMS
Slow, typical time step <50 µs	Fast, typical time step > 1ms
typical frequency range up to several k Hz	Typical frequency range < 10 Hz
detailed model of inverters with switching elements	Equivalent rms voltage/current source, average models
includes nonlinear V/I characteristic (saturation, ...)	Limited to linear V/I characteristic
Bottom-level controller included	Few bottom-level controller
Top-level controller included	The same as EMT

- Develop generic full-function RMS models (with controller) of IBGs with different primary sources for small and large disturbance stability studies.
- Develop generic static and RMS model for distributed IBGs adapted to different requirements and wide accepted aggregation methodology.
- Guideline or use case for EMT model of IBGs considering different types of studies.

Thanks！

Chief Engineer, renewable energy research center, CEPRI
Secretary, IEC SC 8A – Grid Integration of RE Generation

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