**Association Grand Projects**

# Workshop TGEG'18

## Technologies for Global Energy Grid

*Organization: Association Grand Projects'21- AGP'21*
*President: Lucien Deschamps*
*With Technical and Scientific support of:*

*CIGRE, International Council on Large Electric Systems,*
*Jicable, International Conference on Insulated Power Cables*
*SEE, Society of Electricity, Electronics and Information Technologies and Communication*

**Wednesday, 29 August 2018 - 9:00 am to 5:00 pm**
Palais des congrès de Paris, Room 341
2 place de la Porte Maillot
75017 Paris

***André Merlin** : Chairman Workshop TGEG'18*
***Gerald Sanchis** : Workshop Coordination*

*L: Lecture  SI: Short Intervention*

## 9:00 Opening Ceremony

André Merlin, Past President CIGRE, Former Founding President RTE, AGP'21

André Merlin welcomed the participants and introduced briefly the scope of the Workshop organized by the AGP21 association.


André Merlin et Gerald Sanchis

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## Session 1: Global electricity network feasibility

Wednesday 29 August, 9:15 – 10:45

**Chairman** : André Merlin, Past President CIGRE, Former Founding President RTE

**Rapporteur**: Gérald Sanchis, RTE, Secretary of CIGRE WG C1.35

**1.1 L – Global electricity network feasibility study.**
by Gérald Sanchis, RTE, Secretary of CIGRE WG C1.35.

From 2016 to 2018, CIGRE WG C1.35 has performed a feasibility study on the concept of a global electricity network. The time horizon selected is 2050, the data on energy are coming mainly from international studies, particularly from the World Energy Council. The model used by CIGRE splits the world in 13 regions. The simulations performed address 20 interconnections, selected according to a potential relevance among the combinations of all links between the 13 electrical nodes.
The study includes sensitivity analysis to different factors: the capacity factors, the technology costs, the flexibility of the demand.
Finally, the results show the profitability of a global grid, mainly centered on the region of Mongolia region, at the crossroads of three densely populated regions: China, India and Europe.
All the results should be soon available in a CIGRE Technical Brochure.

**1.2 SI – European infrastructure, Supergrid for 2050.**
by Spyros Chatzivasileiadis, DTU, University Technical of Denmark.

The presentation addressed the results related to the development of the European Supergrid infrastructure for 2030 and 2050, through two European projects, “Best Paths” and “IRENE-40”.
The appropriate infrastructure measures for the integration of over 80% renewable power have been highlighted. Using an 8,000 node European model, together with a single-node per country model, a study has been performed showing the interactions between AC and DC grids, the impact of the new infrastructure on the successful integration of RES, and the resulting effect in operating costs.
The results highlighted the benefits of controllable flows that HVDC links offer, putting forward the concept of a “Fully Controllable Power System”.

**1.3 SI – HVDC Technology key issues for energy grids.**
by Marcio Szechtman, CEPEL, Brazilian Power research Centre.

The presentation provided a good overview of the HVDC technologies in the perspective of long-distance transmission grid. Indeed for Energy Grids involving long distance transmission lines and different countries/markets, HVDC seems to be the most suitable technological alternative.
Two main technologies are considered: LCC (Line Commuted Converter) and VSC (Voltage Source Converter).
LCC advantages may be considered as of fundamental importance for Energy Grids. However for a complex HVDC Grid with multiple terminals, it may show limitations.

The Hybrid LCC/VSC approach seems to repesent a State-of-the-art technology application and could be a reference point, mainly when the power flow will be predominantly unidirectional.

**1.4 SI – Sahara Wind HVDC project's integrated acesse to the North Atlantic trade winds.**
by Khalid Benhamou, Sahara Wind Morocco.

Introduced in 2002, the Sahara Wind 5 GW-HVDC transmission project's objective was to scale-up wind energy in order to compete against fossil fuels on price parity and create a more inclusive renewable energy economy. By powering Africa and Europe at record-low electricity prices, the project's 5GW-HVDC transmission line extensible to 10GW boosts local development through regional integration.
Overmatching Morocco's 52% renewable electricity targets in 2030 by a large extent, Sahara Wind's integrative pathway was consolidated by the Atlantic trade wind's paleontological footprints which, by shaping ocean surface currents for millions of years led to the accumulation of 71% of the world's known sedimentary phosphates deposits on North African shores. As 90% of Phosphates are used as fertilizers, wind powered electro-chemical processes can substitute fossil fuels in phosphate upgrades and ammonia synthesis. The latter consume up to 3% of the world's primary energy demand. Scalable, direct wind-hydrogen reduction plants can also upgrade Mauritania's iron-ore exports into value-added steels in a carbon-dioxide-free process. Hence, the world's largest emitting fertilizer and steel industries can transition into carbon-free processes. Backed by significant reserves, the aforementioned business cases not only enhance local access to wind-electricity, but also empower state-owned mining conglomerates in becoming stakeholders of a much broader energy transition.

**1.5 SI – Interconnection of electricity networks between regions and continents.**
by Antonio Iliceto, TERNA, Italy.

The Mediterranean Transmission System Operators (MedTSO) has launched a master plan of transmission grid, with the objective to demonstrate that exchanging energy is beneficial to both shores of the Mediterranean Region.
The Northern and Southern shores of the Mediterranean basin present different characteristics that offer potentialities and complementarities. Countries of both banks have realized that these synergies can become key to exchange energy and meet the targets of the energy transition in the next decades.
Finally, the proposed Mediterranean Master Plan provided a reference planning document for the interconnection Projects in the Mediterranean Area – Target 2030, consistent with four macro economic scenarios, compatible with the National development plans of Med-TSO Members, and a concrete plan for 14 projects, made both viable by market studies and feasible by network studies.

## Session 2: Keynote

Wednesday 29 August, 11:00 – 11:30

**Chairman**: Jean Kowal, ex Medgrid, and CIGRE.

**Rapporteur**: Petru Notingher, Université de Montpellier 2, CNRS.

### 2.1 L: "Technologies for the Global Energy Grid"

**Mingli Fu,** Electric Power Research Institute of China Southern Power Grid, China

In its keynote lecture, Dr Mingli Fu addressed three main topics:

- Challenges of large bulk offshore wind power connection from South China Sea
- Specific Considerations for HVDC Cable Insulation Evaluation under Temperature Gradient
- Environmentally friendly gas insulated line and technology development

After an overview of the West to East Power Transmission corridors of China and the China Southern Power Grid Company, Dr Fu presented the planned offshore wind power project in the South China Sea, which should comprise 23 offshore wind farms with a total installed power capacity of 67 GWh, for an investment of 80 billion US dollars. He addressed the topics of the electricity collecting and transmission systems, pointing out the challenges in terms of topological structure, voltage levels, output mode (DC or AC) and submarine cables to be designed and used, with a focus on the investments needed by the cable system and its impacts on the marine environment.

In the second part of the lecture, the speaker described the increasing needs of HVDC cables in the future networks, with an illustration of the VSC-HVDC projects in China. The concerns over extruded HVDC cables have been pointed out, showing the necessity to assess space charge behavior and electric field distortion in full-size cable setups under operating-like conditions in term of temperature gradient. Results of several studies on this matter have been presented and discussed, showing that space charge can double the field at the insulator/semicon interface, and underlining the importance of space charge measurements as tools to evaluate the electrical stress in HVDC cable insulation and the risk of cable failure.

The final part of the keynote speech has been devoted to the problematics of environmentally friendly GIL and GIS. The expected performance insulating gas mixtures using $C_3F_7CN$ in terms of breakdown strength, decomposition and compatibility with metals have been addressed, in view of their use by China South Grid as an alternative to $SF_6$ in projects similar to the 1000 kV/3000 MW $SF_6$-insulated GIL laid under the Yangtze River.

At the end of the lecture, Dr Fu answered questions from the audience regarding the financial impact of the different projects and the implication of local utilities and authorities.

## Session 3: Insulated Power Cables

Wednesday 29 August, 13:45 – 14:30

**Chairman** : Ray Awad, Independent Consultant

**Rapporteur**: Gilbert Teyssedre, Université Paul Sabatier, Toulouse.

The session dealt with two main technologies: Cables with synthetic insulations (1plenary presentation) and superconducting cables (1 plenary lecture and 2 keynotes).

**3.1 L: Superconducting cables: status and drivers for market penetration**

Jean-Maxime Saugrain, presented status of Super-Conducting cables, mainly focused to ac cables. The historical evolution of superconducting materials, critical properties and related technologies was reviewed. Typical cable structures to maintain operational temperature low were described. The virtually unlimited carried current – beyond 100kA – enables working under relatively low voltage. Numerous projects over the world demonstrated the readiness of the technology. However, still the market is low, the reasons being linked to the cost, the lack of return of experience and the unconventional stress conditions compared to HV insulated cables. Several application cases were given as remote transformer station in Essen, Germany in operation since mars 2013 (10kV cable starts from the remote station instead of 110kV); Substation connection ring in Chicago, 2.5km long, or Retrofitting pipes or tunnels when cannot add more XLPE insulated cables inside.

**3.2 L: State of the art and new technologies AC & DC of insulated cable systems, and submarine cables**

An overview of application range for cable insulation ranging from XLPE to thermoplastic insulation (HPTE) and oil-filled insulation is presented by S Cotugno as Prysmian representative. Technologies are declined function of power, stress form (HVAC vs HVDC), transmission distance and voltage. When the highest powers are still transmitted with oil-filled cables, polymeric insulations tend to broaden their range, and thermoplastic material brings an advantage on the working temperature for HVDC (90C vs 70C for XLPE). DC becomes interesting above 150 km distance and oil filled systems have limitations in length with pumping units. The future is with submarine cables with deeper installation and related mechanical issues (pulling forces), and the market demand is with longer length and ever higher voltage, with ensuring repair easiness and reliability.

**3.3 SI : HVDC Superconducting MgB2 cables: Best paths EU project**

CE Bruzek presented the development and demonstration project of a long length (>300km) superconducting HVDC cable within the Best Paths project, using $MgB_2$ wires. Both cable and terminations are developed and tested. Superconducting cables offer very efficient transmission and moderate voltage. A power of 3.2 GW/pole, 10kAmps 320kV is targeted.
More complex design of housing envelopes is implemented compared to the first presentation by Saugrain. Tests on a 120-meter-long cable are ongoing. Specific tests have been designed for validating this technology like e.g. space charge measurements at cryogenic temperature and mechanical withstanding of the cables.
Among question raised, the installation conditions as with radius of curvature were addressed. The cables and housing are relatively adaptive and do not represent real issues.

**3.4 SI : Superconducting transmission lines**

T Rjabin described two projects with superconducting links in megacities. The Ishikari HTS DC project, 1000m long, Japan is a data center power supply with a cable 10 kV, 2500 A. Very efficient cryostat system as developed that permits to foresee long transmission distance with superconducting cables. The second project in St Petersburg is with a HTSC DC link of 50MVA, 20kV, 2500m long, connecting two major substations of different voltage classes 220 kV and 330 kV in the heart of the city. The development and testing of the line is underway. The full system is to be tested on a remote site before installation. The successful experimental operation of the first HTSC cable can constitute a significant accelerator of the introduction of such equipment into the electric power industry.

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## Session 4: Overhead power lines

Wednesday 29 August, 13:45 – 14:30

**Chairman** : Jose Henrique Machado Fernandes, Independent Consultant, Brazil

**Rapporteur**: Bernard Dalle, BMD - Consulting, France

### 4.1 L - A situation of the state of the art and the innovations of the overhead electric power lines, in Brazil.

by Carlos Alexandre M. do Nascimento, CEMIG, Brazil

Brazil, a continental extension country, has a large and robust interconnected system of overhead transmission lines (230 to 765 kVac and 600 to 800 KVdc) and subtransmission (69 to 138 kV), which it was built from the beginning of the 1960, and will continue to grow steadily in the coming decades as generation increase 1.5GW per year.
Basically, the expansions of these interconnected systems occurred through national development plans, with ambitious engineering projects, but adapted to the restrictive financial conditions of an economic developing country such as Brazil. HSIL lines have been developed to optimize as much as possible the global cost of long AC lines and the return of experience is very good; no trouble on these expanded bundled conductors have been observed
In this context, with a developmental vision with high economic and social value, Brazil has several projects in operation in the state of the art. Technological innovations are required for an increasingly interconnected and aging system. To continue the expansion of the overhead transmission lines, untraditional projects will be required, with a strong presence of intermittent renewable generation, and associated with the various restrictions imposed by a society increasingly concerned with environmental preservation. Key words for the future are new materials (HTLS Conductors), use and share of fiber optics inside the conductor and the shield wire for answering the social demand of a digital society in the new concept of synergic network, for monitoring OHL, for increasing ampacity, use of robots for operational efficiency; decentralized management, training of labor, converting AC to DC, thus seeking to continue providing good services to the new digital society.
The fruitful discussion during which questions raised by JOAO NOLASCO, Dr. ALESSANDRO CLERICI, LLUIS-RAMON SALES CASALS,… dealed with HSIL lines (behavior and cost), with expanded bundled conductors, with HTLS, with fiber optic for the use of real time monitoring and social demand, with the transformation of AC to DC lines.

## Session 5: Advanced technologies, innovation

Wednesday 29 August, 14:30 – 15:15

**Chairman** : Timofey Rjabin, R&D Centre FGC UES, Russia.

**Rapporteur**: Olivier Boisard, Ecole Centrale Lille, France.

### 5.1 L – Factors for investment decision GIL-Cable.

by Hermann Koch, Siemens Erlangen, Germany.

In this presentation are exposed investment decision criteria identified for the selection of Gas Insulated Lines (GIL) *versus* extruded XLPE cables for underground high voltage AC transmission. The work pursued in the CIGRE JWG B3/B1.27, developed in the Technical Brochure 639, addresses the relevant aspects of this comparative analysis – economic parameters, maintenance cost factors, security, or environmental impact, ... – using a matrix approach to compare and evaluate the characteristics of each alternative.

Keys specificities of GIL are emphasized - especially better voltage ratings at AC (up to 800 kV for GIL, compared to 500 kV for cable), current ratings (up to 8000 A for GIL, and 2675 A for cable), temperature limits for materials used (up to 120°C for GIL, and 90°C pour XLPE cables), or materials used (aluminum and sulfur hexafluoride / nitrogen gaz mixture at a pressure of 6/7 bars for GIL). Many projects application examples are given in the TB, providing practical elements of comparison.

As a conclusion, it is pointed out that, beyond the specificities of each project, cost drivers and criteria for investment decision GIL vs. cables are now clearly identified.

### 5.2 SI – Superconductivity associated with Liquid $H_2$.

by Christian-Erik Bruzek, Nexans, France.

In a low or zero-carbon economy, hydrogen has a high potential of development as a storage and distribution vector for energy. Mature technologies are already available for H2 production and transportation - in aerospace industry for instance, or for fuel cells use. But physical characteristics of H2 at cryogenic temperatures are also particularly appropriate for electrical power transmission : 1°/ at 20 K, liquid hydrogen optimizes performances of superconducting material, like REBCO or BISCCO tapes, 2°/ gas H2 has good insulation properties, and research are currently ongoing on liquid and superfluid H2 insulation characteristics, probably similar to liquid nitrogen, and 3°/ with a high heat capacity, liquid or supercritical H2 is an excellent cooling fluid.

Different concepts of “cable-pipes” are presented, combining H2 transfer and electric power transmission. A typical design is a flexible cable, 30 cm diameter, for an electric power transmitted from 100 MV to 1 GW, using a 14 mm diameter cable conductor inside a first envelop of liquid H2, both in a second envelop containing cold gas H2.

Further studies have to be launched, especially on security and maintenance issue, but none of these issues appears insurmountable, and the conclusion message of the presentation is that “superconductivity and cryogenic communities are ready to build and test a first demonstrator”

## Session 6: Storage

Wednesday 29 August, 15:50 – 16:40

**Chairman**: Khalid Benhamou, Sahara Wind, Morocco

**Rapporteur** : Pierre Denuelle, Feedering, France

**6.1 L: "A Survey of Energy Storage Technologies".**
**Robert B. Tanner,** Nature & People First, USA

Robert Tanner highlighted the rationale for energy storage which needs to grow with solar and wind energy developments, because they are intermittent. He focused on California's duck curve, where solar generation may soon overmatch loads in mid-day soliciting severe ramping-up needs of existing means thereafter.
Greenpeace's installed power capacity prediction shows that 0.2 TW of storage for a total of 3TW in 2020 affects the system's overall efficiency. By 2050, out of 13TW of global installed capacity, storage will therefore be comprised between 1 to 10 TW depending on alternatives and technologies.
Hydro pumped storage makes 95% of today's storage capacity at 187 GW. Compared to installed production capacities, Japan leads with 7%, Europe has 4,3%, China plans to reach 4% in 2020, USA is at 2% only. In the USA – where development depends on profitability and private finance, renewables get funded because they produce billable watt-hours, whereas storage is rarely economically viable. An arbitrage to leverage a business case ROI to buy low and sell high is therefore missing, in spite of its important benefits.
Other technologies: compressed air, flywheel, batteries, capacitors, electrochemical etc. have been shown along with their technological readiness levels and diverse applications.

**6.2 SI : "Case Study of ESS (Energy Storage System)"**
**by Danny Kim,** Hyosung, Korea

The South Korean government and industry decade-long support for ESS led Hyosung to deploy 300 MW/1,000 MWh in 110 ESS sites for various applications. These range from frequency regulation, peak shaving and renewable integration to micro-grids (10 island projects). In the last two categories, standardizing solutions were developed to simplify systems and reduce costs. The company has also gained experience in matching tailored operational constraints as well as tight frequency needs.
But even with government incentives, diesel savings hardly justify hardware investments. The trend goes therefore towards multi-functional (ie multi-applications) systems in non-regulated Power markets such as UK, USA or Australia (targeted by Hyosung) as PV integration provides several revenue stacks enabling amortization of ESS investments. Although still expensive, Li-Ion batteries costs have been divided by 4 in 6 years. Hyosung therefore looks at behind-the-meter ESS market applications, for example in the UK.

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## Session 7: Financial and regulatory aspects

Wednesday 29 August, 16:15 – 17:00

**Chairman**: Pierre Denuelle, Feedering, France.

**Rapporteur** : Jacques Horvilleur, SEE, France

7.1 - **Operate / Finance World Energy Grid**
**Jean Kowal,** ex Medgrid and CIGRE. France

**How to create, finance and operate the Worldwide Electric Grid?**
Two main preconditions have been demonstrated:

- The global benefit (*social welfare*) of a Worldwide grid is higher than its cost.
- A global electricity network is technologically feasible.

Still the development of such a project is a complex process with many challenges:

- Intergovernmental agreements.
- Selection of routes, environmental integration, detailed feasibility.
- Long term international project management.

On top of that, two main system wide prerequisites need to be solved:

- Which economic model of electricity market and minimal set of common rules will govern the operation of the global grid? Which authority to regulate a global grid?
  Can it be compatible with different models : vertically integrated monopoles, unbundled companies, partly or fully liberalized electricity markets ?
  Access to the interconnection grid to be organized for bunches of systems, with unbiazed rules : guarantee of transit ; fair tariff ; right of access for countries crossed by the grid.
  Capacities allocation to be based on market basis : auctions, reservations, trading.
  Can we assume a common carbon price ?
- How to finance the development of such a global grid, since the global benefit is distributed between its users (grid owners, producers, distributors, consumers)?
  Who will invest, and with which return on his investment?
  For the vertically integrated utility or for the regulated TSO: investment in the grid and energy import must be payed by surplus on consumers + gains on generation.
  For the private investor, the return comes from the use of the interconnection.

To build on these fundamental questions and promote convergence of policies and with other projects, we recommend deeper studies, to be taken on board by international organizations, like CIGRE for instance.

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**Conclusion of the Workshop:**

André Merlin thanked all the speakers, all the participants for the quality of the presentations and of the exchanges, with a special thanks to Lucien Deschamps for the organization of the fruitful Workshop.
He highlighted the wish of follow-up, through for instance another Workshop in the future.

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