Latin American Workshop 2013

CE – B1 CABOS ISOLADOS

Achievement and experience in service of long length High Voltage AC electrical links by insulated power cables

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Introduction to Long length AC Cable systems

Why is there now such a significant interest in Long Length AC transmission Power Transmission by insulated cables.

- Now possible with new cable designs and materials
- Transfer power from renewable energy sources to the grid
- Need to provide electric power to remotely located plants
- Difficulties in obtaining approvals for OHL
- Quicker implementation time than using OHL
- Lower cost differential between Underground and OHL
- Need for lower losses
- Environmental issues

Long Length HVAC insulated cable system

- At power frequencies cables behave as capacitors therefore they generate reactive power – hence some inductive reactance may be required in the system.
- Conversely overhead lines because of their spacing generate inductive reactance – hence some capacitive compensation may be required at substations.
- It can be seen that a mixture of AC Cables and AC Overhead lines might be quite compatible.
- Proposed definition of **A long length of insulated cable:-**
  - is one where the load due to the capacitive current needs to be taken into account in the system design.
  - typically this would be 40 km for voltages less than 220 kV and 20 km for voltages above 220 kV

CURRENT STATE of DEVELOPMENT

- **Modern HVAC cables**
  - Today's 400kV XLPE cable have very low dielectric losses
    - Many times lower than the old oil-filled cables
  - The operating temperature of XLPE cable significantly higher
    - Hence ratings are much improved compared to SCFF cable
  - XLPE cables can be made and installed in long lengths
    - No concerns about changes in ground level and oil pumping
- **Surge protection**
  - Cables need protection from flashovers
    - Now we can install ZnO arrestors at terminations
- **Reactive compensation**
  - Today there are more capacitor banks and coils in the system along with power electronics such as SVCs etc.
    - Inclusion of reactive compensation is not so much of an issue.
- **Installation**
  - Today we can use HDD to cross under rivers, roads and rail.
    - In the past such crossing could only be done with overhead lines

Technical performance & Practical examples of HVAC a link

- For technical performance of HVAC cable systems reference can be made to the report by WG C4.502
  - "*Power System technical performance issues related to the application of long HVAC cables".*
- Question should the link be AC or DC – Economics
- General Cable design & Installation Issues
- Practical examples and experience of HVAC links
  - Long length AC links now used in more than 20 countries

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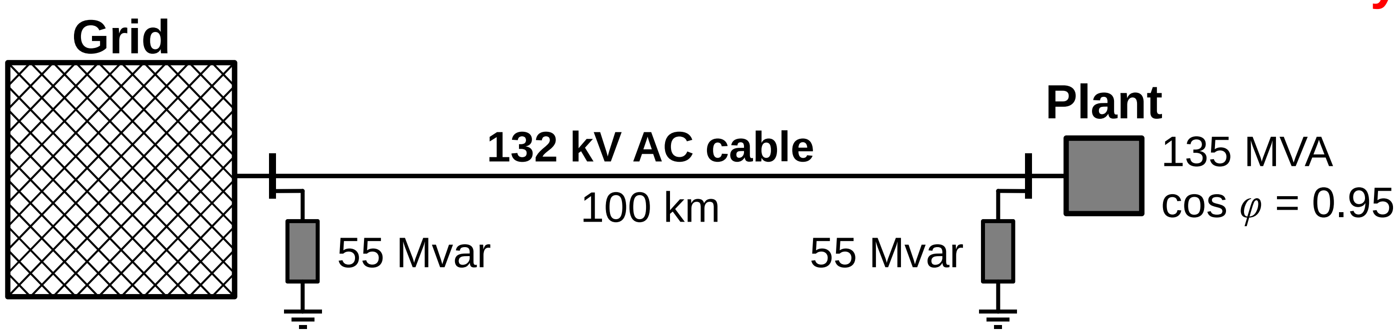
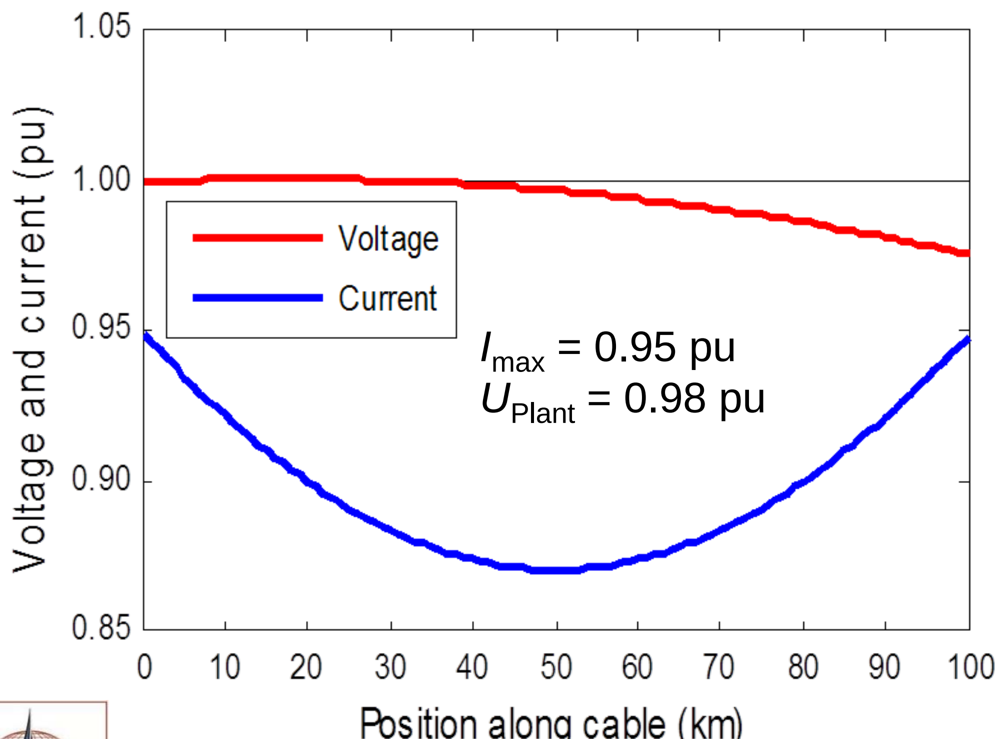
AC1- a 100km link with 132 kV AC cable system

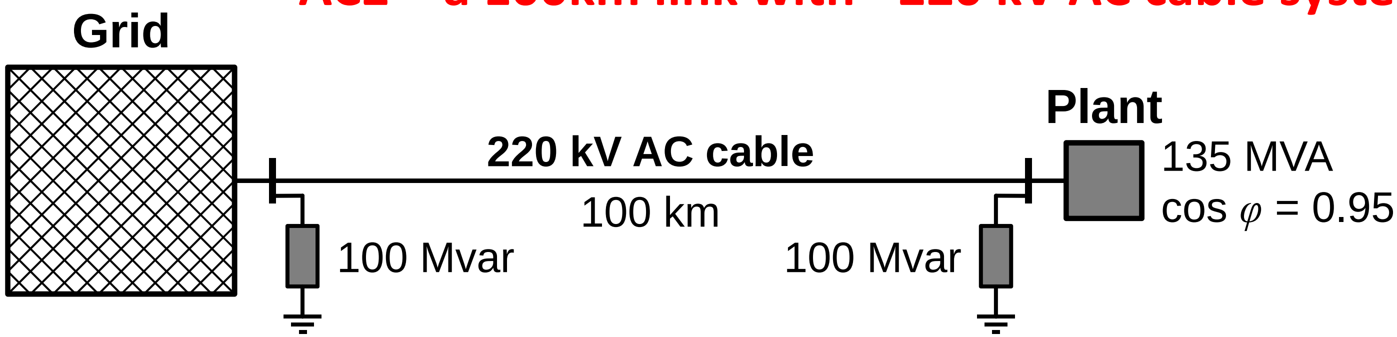


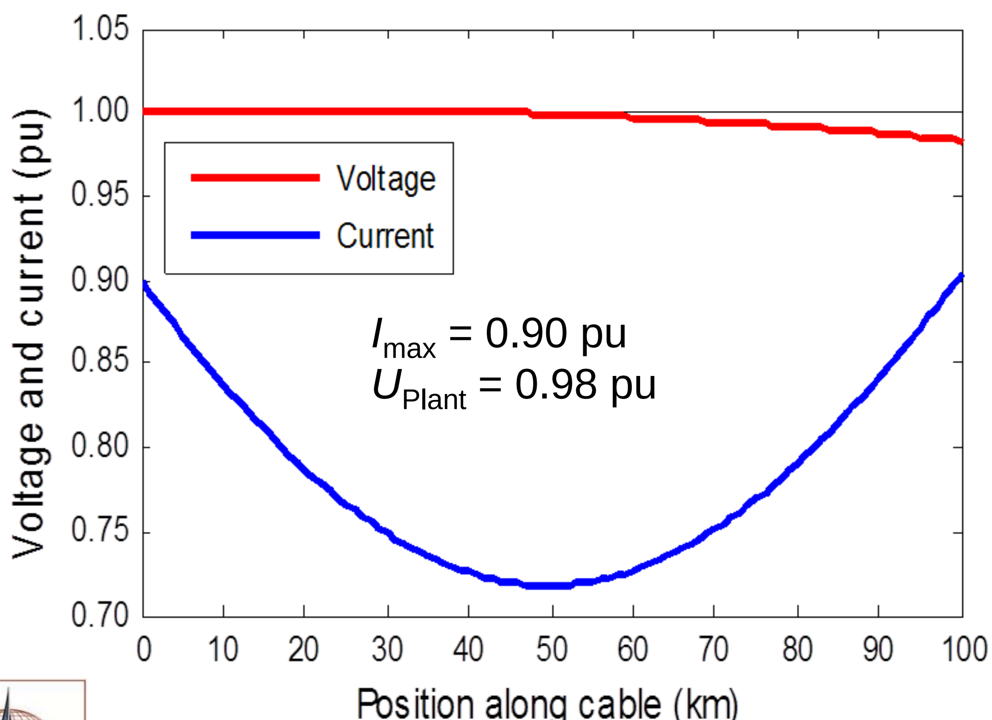


Losses (MW)	
Cable System	3.4
Compensation	0.2
Total	3.6

As reported at WETS 11

AC2 – a 100km link with - 220 kV AC cable system



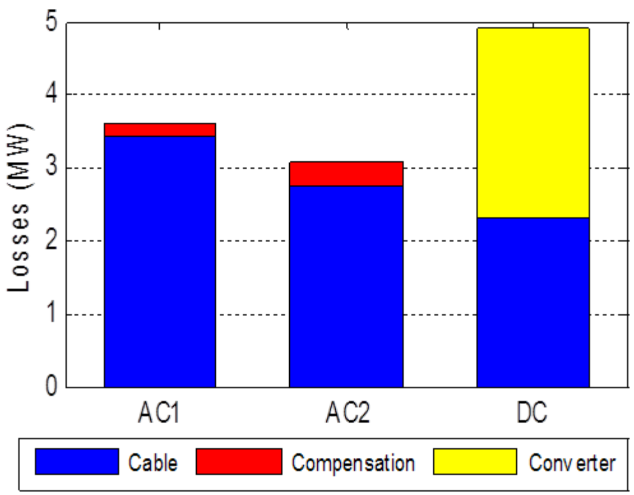


Losses (MW)	
Cable System	2.8
Compensation	0.3
Total	3.1

As reported at WETS 11

Comparison of AC – DC link

- Feasibility of 100 km UGC systems to connect remote plants
  - 132 kV and 220 kV AC options and ± 150 kV DC option
- Lower total losses in AC systems compared to DC system
  - Cable losses slightly higher for AC but converter losses higher
- Investment cost advantage for AC systems over DC system
  - Higher cable and installation cost for AC offset cost for converters

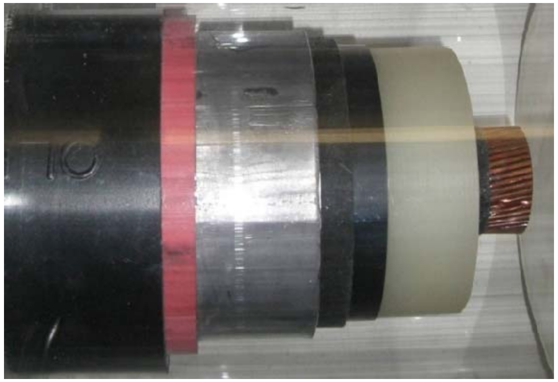


Cost	AC1	AC2	DC
Cable	25 M€	26.5 M€	17.5 M€
Civil works and installation	25 M€	25 M€	17 M€
Accessories and installation	3 M€	3.5 M€	2.5 M€
Reactors and installation	2 M€	3 M€	-
VSC terminals and installation	-	-	40 M€
Project management	5 M€	5 M€	5 M€
Total	**60 M€**	**63 M€**	**82 M€**

As reported at WETS 11

Cable design

- Very important when considering long lengths of AC underground cable
- Compromise between lowest cost and robust design
  - Enabling ease of installation with long service life
- Copper or aluminum conductor
  - Cost, weight, supply lengths, installation, joints



Cable installation

- Long cable length is key factor
  - Reducing number of joints and jointing cost
  - Reducing transportation and installation costs
- Cable laying
  - Trench excavated by conventional means
  - Trench excavated by trenching machines with rock saws
  - Direct ploughing

REVIEW of Current LONG LENGHT AC LINKS

- More than 50 AC cable links listed in the WG 1.07 report
  - However less than 5 of these met the new criteria for the definition of a long length AC link.
- At WETS 11 a total of 29 AC links were reported
  - But at that time only 5 of these met the criteria for a long length AC link
- More recently in TB490 "Testing of AC submarine cable" a total of 30 AC links were reported
  - Of these 13 meet the criteria for a long length AC link
- Since in June 2013 we have found
  - More than 40 projects that meet the new criteria
  - **Clearly much progress is being made**

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Long length high voltage links by AC insulated power cables in France & Belgium

Item no	Country of the link	System	Power Voltage Length	Cable type & line characteristics	Comments & Compensation
1	France	RTE Suburb of Paris Nanterre - Nourottes	530 MW 225 kV 21 km	l = 499,84 μH/km c = 229,2 nF/km 1600 mm^2 Cu - XLPE	Referenced WETS 11 No compensation
2	France	Boutre –Trans (commission 2015)	.......MW 225 kV 65 km (+25km +20km)	2000/2500 mm2 CuE XLPE	New Project under construction
3	France	Merlatière-Recouvrance (Commission 2015)	450 MVA 225 kV 38km	2000/2500mm^2 Al XLPE	New Project
4	Belgium	Avernas- Bois L'image – (Koksijde- Slijkens & Tihange - Avernas) (2002)	350MVA 150kV 1 x 33 km 2 x 30 km	2000mm^2 Al XLPE (1 Single Circuit and one Double circuit)	Referenced in WG B1.07 as SP06
5	Belgium	Thornton Banks Wind Farm (2008)	325 MW 170 kV 2 x 38km	1000mm2 Al 3 core XLPE - Submarine	Complete offshore wind farm.

These are circuits <40km below 220 kV or < 20 above 220 kV

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Long length high voltage links by AC insulated power cables in U.K.

Item No	Country of the link	System	Power Voltage Length	Cable type & line characteristics	Comments & Compensation
6	UK	Isle of Mann Interconnection (Installed 2000)	60 MW 90 kV 104 km	300mm^2 Cu 3 core XLPE – Submarine (2000)	Compensation at each end. Was the worlds longest AC power cable link.
7	UK	London Array	630 MW 150 kV 53 Km	630 & 800 mm^2 Cu 3 core , XLPE - Submarine	
8	UK	New Cross 1	800 MVA 275 kV 21.0 km	1613mm^2 Cu SOFF	
9	UK	St Johns Wood	1600MVA 400 kV 25.5 km	2500mm^2 Cu XLPE Tunnelled	Compensation at one end.
10	UK	New Cross 2	800 MVA 275kV 21.2 km	1613mm^2 Cu SOFF	
11	UK	West Duddon Sands Wind Farm	389 MW 155kV 41 km	1000mm^2 Cu 2 x 3 core XLPE - Submarine	New Project

Long length high voltage links by AC insulated power cables in Denmark

Item No	Country of the link	System	Power Voltage Length	Cable type & line characteristics	Comments & Compensation
12	Denmark	Aarhus-Aalborg (In operation since 2004)	2x 1,000 MVA 380 kV 2 x 14.7km	Double circuit hybrid . 3 siphons total length of 14.7 km. Rating OHL per circuit 2,000MVA, cable 1,000MVA+ (cyclic rating. 1,200mm2 Al – XLPE	3 reactors, 70, 100 & 140 Mvar, See WG B1.07 SP01
13	Denmark	Horns Rev 2 (2009)	215 MW 170 kV 42 km	630 mm2 Cu 3 Core XLPE - Submarine	
14	Denmark	Lolland-Zealand (2010)	200 MW 145 kV 4.6 + 14.6 km land + 28 km Submarine = 47km total	Land ....mm2 Al. XLPE Submarine ......mm2 Al XLPE Dble-crt, XLPE, land+sub	
15	Denmark	Connection of the Anholt Wind Farm to the grid (land cable) (2012)	400 MW 235 kV 59 km + 24.5 km	Land 2000 mm² Al, 5 sectors XLPE (0,226 µF/km). Submarine 1600 mm2 AL (Solid) XLPE - Submarine	Compensation at both ends.

These are circuits <20km above 220 kV

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Long length high voltage links by AC insulated power cables In Netherlands and Corsica

Item No	Country of the link	System	Power Voltage Length	Cable type & line characteristics	Comments & Compensation
16	Sardinia - Corsica	SARCO	150 MVA 150 kV 31 km (11 + 15 + 5 km)	Land 400 mm2 Cu XLPE Submarine 400 mm2 Cu – 3 core XLPE – Submarine	See WG 1.07 SP 20
17	Netherlands	Randstad 380kV (In operation since may 2013)	2 x 2,640 MVA 380 kV 2 x 10km	Double circuit hybrid .Total length 20 km (2x 10 km) and 2 cable/phase 2,500 mm2 Cu. XLPE	Both ends 3 x 100 Mvar, (compensation at 50kV) Reported at WETS 11
18	Netherlands	Alphen-Gouda (In operation since 1982)	300 MVA 150 kV 22.6km	800mm2 Cu SCOF	Single side 1 x 50 Mvar at 50kV

These are circuits <40km below 220 kV

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Long length high voltage links by AC insulated power cables Italy & Spain

Item No	Country of the link	System	Power Voltage Length	Cable type & line characteristics	Comments & Compensation
19	Italy	"Sorgente-Rizziconi" (Calabria-Sicily)	2000 MW 380 kV 41 - 43Km 2 Circuits	Each cct: 3 km land - 2500 mm^2 Cu, XLPE 36–38 km sub - 1500 mm^2 Cu, SCFF PPL 2 km land - 2500 mm^2 Al - XLPE (single core)	Line-connected. Each cct: 285 Mvar at each terminal (ratings @420 kV) Currently under construction
20	Italy	Malta	225 MW 220 kV 118 km	20 km land - 1000 mm^2 Al XLPE (single-core) 98 km sub. 630 mm^2 Cu 3-core XLPE – submarine.	Line-connected. 220 Mvar Sicily, 60 ÷120 Mvar Malta (ratings @245 kV) Currently under construction
21	Tunisia	Tunis Rades Grombalia 2 (2005)	…….MVA 225 kV 24.7 km	1000 mm2 Cu XLPE	
22	Spain Mallorca - Ibiza	Interconnection Red Electrica (2014)	……MVA 145 kV 117 km	300 mm2 Cu 3 core XLPE – Submarine (2014)	Currently under construction

Long length high voltage links by AC insulated power cables Sweden & Norway

Item No	Country of the link	System	Power Voltage Length	Cable type & line characteristics	Comments & Compensation
23	Sweden	Aland Interconnection (1973 – 2015)	35 MW 84 kV 55 km 80 MW 110 kV 63 Km	185 mm2 Cu 3 x ! Core XLPE Submarine (1973) 240mm2 Cu 3 Core XLPE Submarine (2000)	This was one of the first XLPE submarine cables
24	Sweden	Bornholm Interconnection (1979)	…MW 72kV 43 km	240 mm2 Cu 3 core XLPE – Submarine	
25	Norway – Sweden	Gjoa (2010)	40MW 115 kV 100 km	240 mm2 Cu 3-Core XLPE – submarine,	
26	Norway - Sweden	Goliat (2013)	75MW 123 kV 106 km	........mm2 ......3-core XLPE - submarine	

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Long length high voltage links by AC insulated power cables USA & Korea

Item No	Country of the link	System	Power Voltage Length	Cable type & line characteristics	Comments & Compensation
27	USA	Middletown-Norwalk	600 MW 345 kV 38 km	Dbl-crt; 1500 mm2 Cu, XLPE	
28	USA	Bayonne	512 MW 345 kV 11 km	………..mm2 ……. XLPE sub + land	150 Mvar
29	Korea	Nam Pusan-BukPusan	520MW 345 kV 21.9 km	2000 mm2 Cu SOFF PPL C= 0.37 uF/km 3 cts	2 X 200 Mvar
30	Korea	Sin Sungdong	520MW 345 kV 17.0 km	2000 mm2 Cu SOFF PPL C= 0.37 uF/km 3 cts	2 x 200Mvar

These are circuits < 20 above 220 kV

Long length high voltage links by AC insulated power cables N. Africa, Australia, NZ. & China

Item No	Country of the link	System	Power Voltage Length	Cable type & line characteristics	Comments & Compensation
31	Saudi Arabia - Bahrain	GCC – GRID Interconnection (2006)	1200 MVA 400 kV 40 + 7 = 47 km	……….mm2 Cu SCFF - 7 km Land + 40 km Submarine	Awarded in 2005
32	Saudi Arabia	Oil Platform (2013)	…..MVA 245 kV 45 km	500 mm2 Cu, 3 Core XLPE - submarine	
33	UAE	Delma Island Interconnection (2006)	…….MW 145 kV 42 Km	300 mm2 Cu 3 Core XLPE – Submarine	
34	Australia NSW	Transgrid (200)	600MW 330 kV 27 km	1600mm2 Cu SCFF	Inn WG 1.07 report
35	Australia Victoria	Victorian Desalination supply	>130 MW 245 kV 88 km	400 & 500 mm2 Cu XLPE	2 x 52 Mvar, One 38km and other 75km from the desalination plant. Completed in 2012
36	China	Hainan-Guangdong	740 MVA (Cosφ=0.98) 525 kV 31km	800 mm² SCFF cable Charging current: 22.8A/km	320 Mvar at each end.

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Victorian desalination plant project

- 150 billion liters of water per year
- 90 MW of power required by plant
- 87 km distance to grid connection
- Underground 220 kV AC cable system
- Compensation units at two locations

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Long length high voltage links by AC insulated power cables in Japan

Item No	Country of the link	System	Power Voltage Length	Cable type & line characteristics	Comments & Compensation
37	Japan	Shin-Toyosu Line (TEPCO)	900MW/cct(final power 1200MW/cct) 500 kV 40 km 2 circuits (final circuits 3)	2500mm2 Cu XLPE	See WG 1.07 SP 13 Compensation
38	Japan	Katsunan - Setagaya Line (TEPCO)	480 MW/cct (final power) 275 kV 32.5 km 3 circuits	1200,1400,1600mm 2 Cu XLPE	Compensation
39	Japan	Yokohama-Kohoku Line (TEPCO)	3000 MW 275 kV 20km(3circuts)&16km(1circuit)	2000,2500mm2 Cu XLPE	Compensation
40	Japan	Kawasaki-Toyosu Line (TEPCO) 2012 – 2015 & 2016	1900 MW 275 kV 22 km 3 circuits	2500mm2 Cu XLPE	Compensation

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Long length high voltage links by AC insulated power cables in Japan (cont.)

Item No	Country of the link	System	Power Voltage Length	Cable type & line characteristics	Comments & Compensation
41	Japan	Chiba-Katsunan Line (TEPCO) 2012 & 2014	660 MW/cct 275 kV 30 km 2 circuits	2000 ,2500mm2 Cu XLPE	Compensation
42	Japan	South- Route by CEPCO (Chubu)	590 MW/circuit 275 kV 26.8 KM 2 Circuits	2,500 mm2 Cu XLPE	Compensation
43	Japan	West-Route by CEPCO	660 MW/circuit 275 kV 23.1 km 2 Circuits	2,500 mm2 Cu XLPE	Compensation
44	Japan	NishiOsaka-Ozone Line by KEPCO 1995 & 2005	322MW 275kV 19.0km	1500mm2 Cu XLPE	Compensation
45	Japan	Matsushima-Narao Line by Kyushu 2005	60MW/circuit 66kV 53km 2 circuits	325mm2 Cu. 3 core XLPE - Submarine	

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Long length high voltage links by AC insulated power cables in rest of world

Item No	Country of the link	System	Power Voltage Length	Cable type & line characteristics	Comments & Compensation
46	Africa - Zanzibar	Pemba (2010)	25MVA 36kV 78 km	........mm2 Cu 3 core XLPE - Submarine	
47	Africa - Tanzania	Zanzibar 2	100 MW 145 kV 37 km	300 mm2 Cu 3 core XLPE Submarine	
48	Thailand	Koh Samui 3	.....MVA 115kV 54 km	500mm2 Cu 3 core XLPE - Submarine	
49	Vietnam	Phuc Quo	.......MVA 110kV 53km	400mm2 Cu 3 core XLPE - Submarine	

This are circuits <40km

Challenges for Implementation

- **System design issues**
  - Matching the power rating for hybrid circuits
  - Acceptance of cyclic ratings – thermal delay for cables
  - Protection system arrangements - Cable vs. OHL,
  - Lower power losses on the cable and no corona losses
  - Reliability - repair times for underground cable
  - Controlling EMF - easier for cable than OHL ,
  - Controlling future changes in route to ensure circuit rating
  - Amount of reactive compensation - location
  - Impact on other network components
  - Sheath bonding for long lengths - tolerances
  - Sheath voltage levels
  - Link box maintenance – inspection – monitoring
  - Thermal mechanical forces from long straight cable lengths

Challenges for Implementation (cont.)

- **Installation**
  - Right of way,
  - Remote areas transportation
  - Inductive coupling with OHL,
  - Commissioning – Testing
- **Monitoring**
  - Long distance Distributed Temperature Sensing
  - Control of route condition
- **Maintenance**
  - Fault location
  - Access to route information – GPS data
  - Methods to reduce repair times and outage in case of cable damage.

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How to address these challenges

- A CIGRE task force has recommended that a WG be formed to prepare a technical brochure
  - this would address these challenges and other issues.
- It would also include practical examples
  - from each member country on the WG.
- Given the limited information at this time it is felt this document would be of value to any organisation
  - considering the installation of a long length AC cable link.
- The target is to have more information available
  - for the Jicable conference & WETS 15 in June 2015
- We welcome your comments and questions !