ICC Fall Meeting 2010, Fort Dowell, AZ, October 17. -20.

Subcommittee F: Field Testing and Diagnosis

Field Testing of HV Extruded Cable Systems – The Experience with Frequency-Tuned Resonant Systems

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1.1. The Selection of Test Voltages for Field Testing of Cables

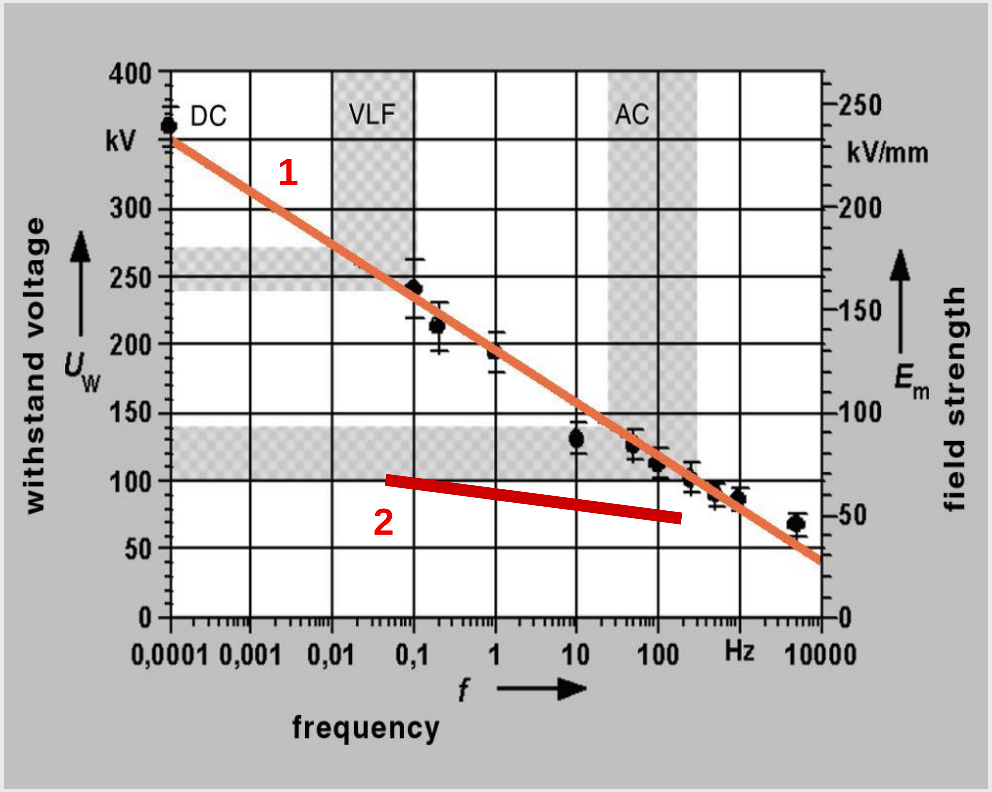
Principle: Representative withstand test voltages shall “produce the same dielectric effect in the insulation as voltages ... in service“ (IEC 60071)

Consequence: Also on-site withstand tests of HVAC XLPE cable systems shall be performed

not with DC voltage,
not with VLF voltage,
not with impulse or DAC voltage

but **with AC voltage of an appropriate frequency range**.
(IEC 62 067: 20 ... 300 Hz)

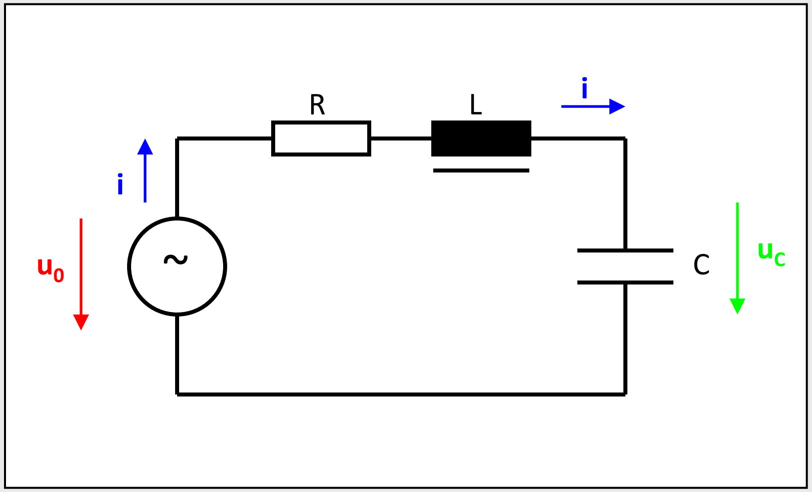
An AC voltage test completed by PD measurement is most efficient.



Ref.: Gockenbach/Hauschild:
IEEE Insulation Magazine 16(“000)pp.11-16

1 – perfect insulation, 2 – insulation with a certain large defect

1.2 The Generation of High AC Voltages by ACRF Test Systems



The only way to generate high AC voltages of appropriate frequency (20…300 Hz) for testing of HV cable systems is the application of resonant circuits. Mobile and lightweight resonant systems are tuned to resonance by the feeding frequency:

ACRF Test Systems

Main equations and parameters of single system:

Resonance condition: $$\omega L = \frac{1}{\omega C}$$

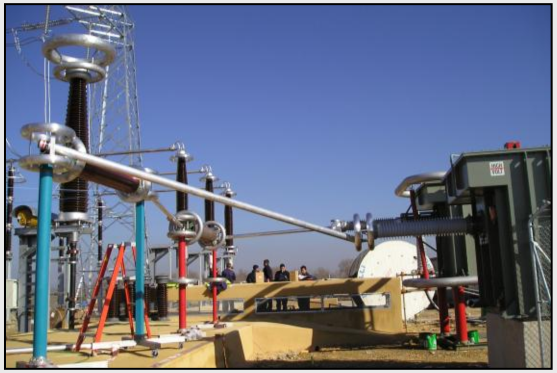
Test frequency $$f = \frac{1}{2\pi\sqrt{L \cdot C}}$$ **= 20 …300 Hz**

Test current $$i = u_C \cdot 2\pi \cdot f \cdot C = u_C \cdot \sqrt{\frac{C}{L}}$$ **≤ 100 A**

Quality factor $$Q = \frac{S_{test}}{P} = \frac{u_C}{u_o} \geq 100$$

Test voltage $$u_C = u_0 \cdot Q \geq 100 \cdot u_0$$ **≤ 300 kV**

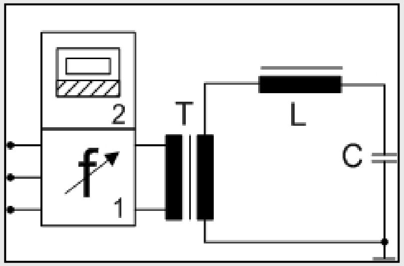
2.1 Situation of Cable Testing with ACRF Test Systems



1) Because of the higher insulation stress in HV and EHV cables, field testing for commissioning and diagnostics is required with AC voltage.
2) The IEC Standards 60840 and 62067 accept an AC voltage of a frequency range between 20 and 300 Hz. In practice, the test frequencies are mainly between 25 and 60 Hz.
3) At the moment more than 125 ACRF test systems for HV cable testing are operating worldwide (without China) and have demonstrated reliability under all climatic conditions.
4) AC voltage withstand testing is often completed by unconventional PD measurement via sensors in the joints.
5) With combinations of ACRF test systems, land cables have been tested up to 25 km length, there are requirements to test even much longer systems of submarine cables.

2.2 Required Test Power for On-Site Cable Testing

ACRF Test System:



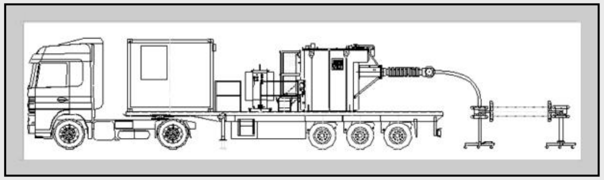
Test voltage U_t

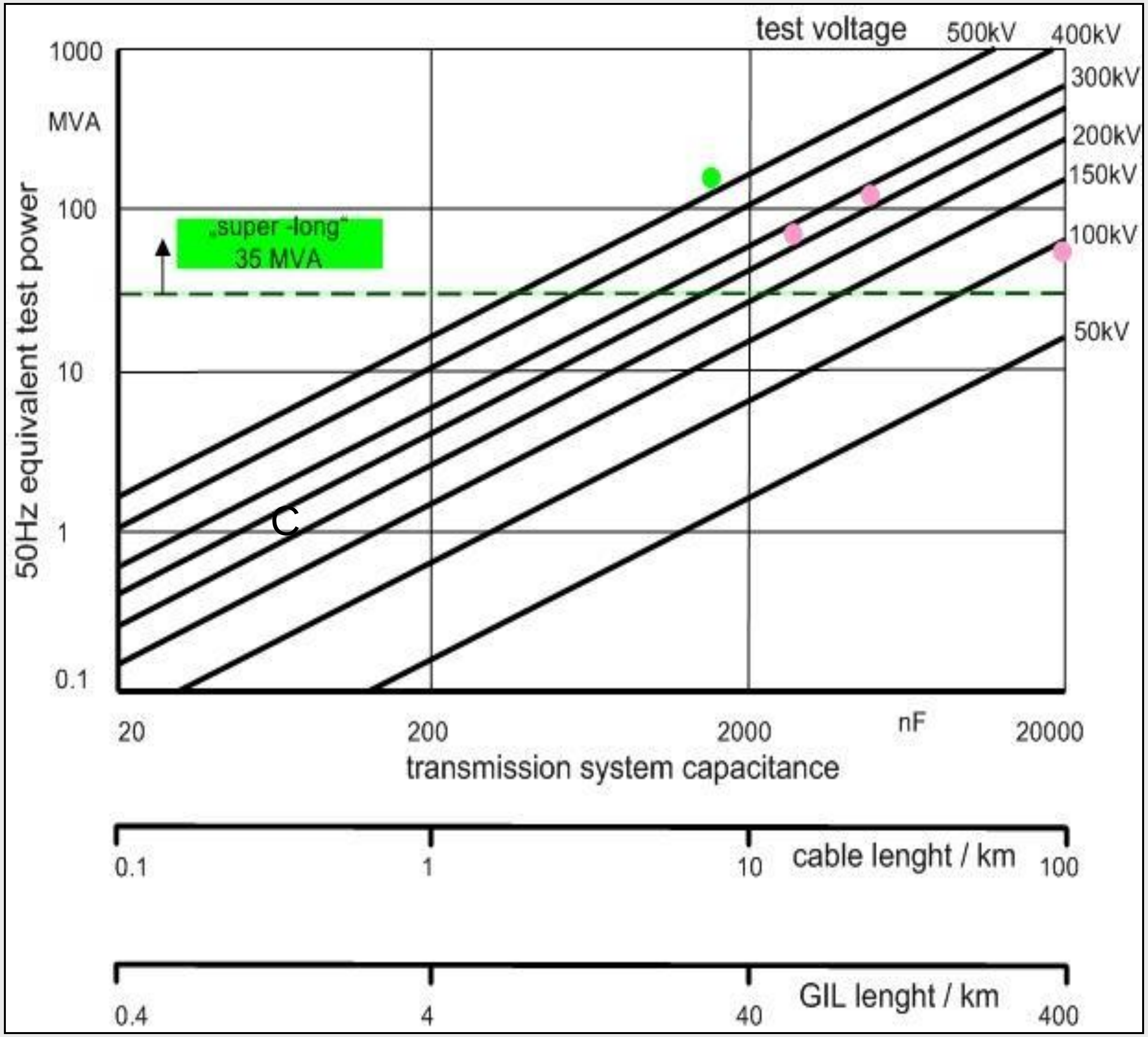
Test object capacitance C

Test power $S_{test} = 2\pi f_t C U_t^2$

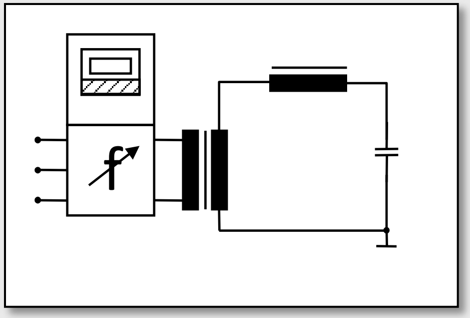
50 Hz equivalent power

$S_{50} = (50\ \text{Hz} / f_t) \cdot S_{test}$



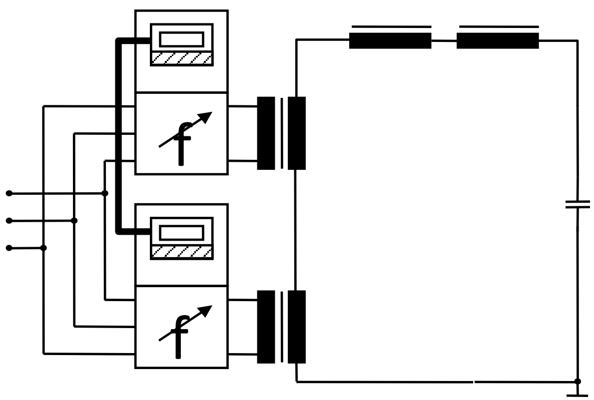


2.3 Extension of Test Voltage and Power with ACRF Test Systems

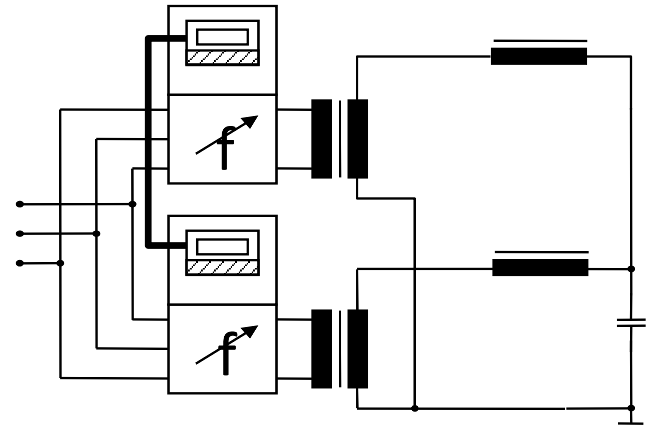


longer cables

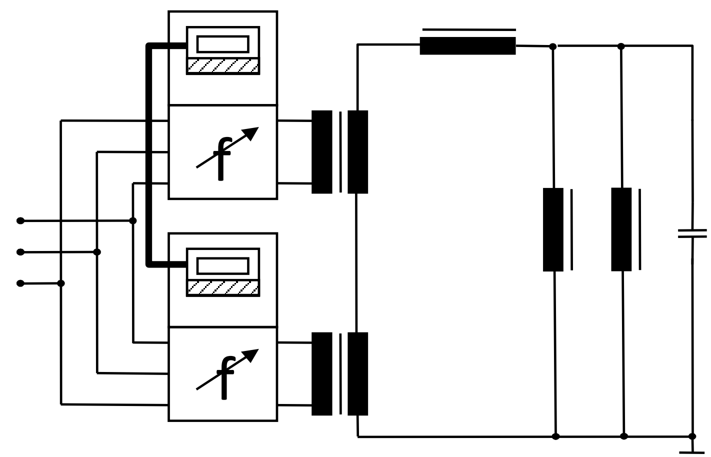
higher voltage



series connection of reactors



parallel connection of reactors



3.1 Real Setup for a Cable System Test in Doha/Qatar, January 2009

Test requirements:

Test voltage:	260 kV
Test duration:	1 hr
Cable type:	400 kV XLPE
Cable length:	16 km
Cable capacitance:	3600 nF

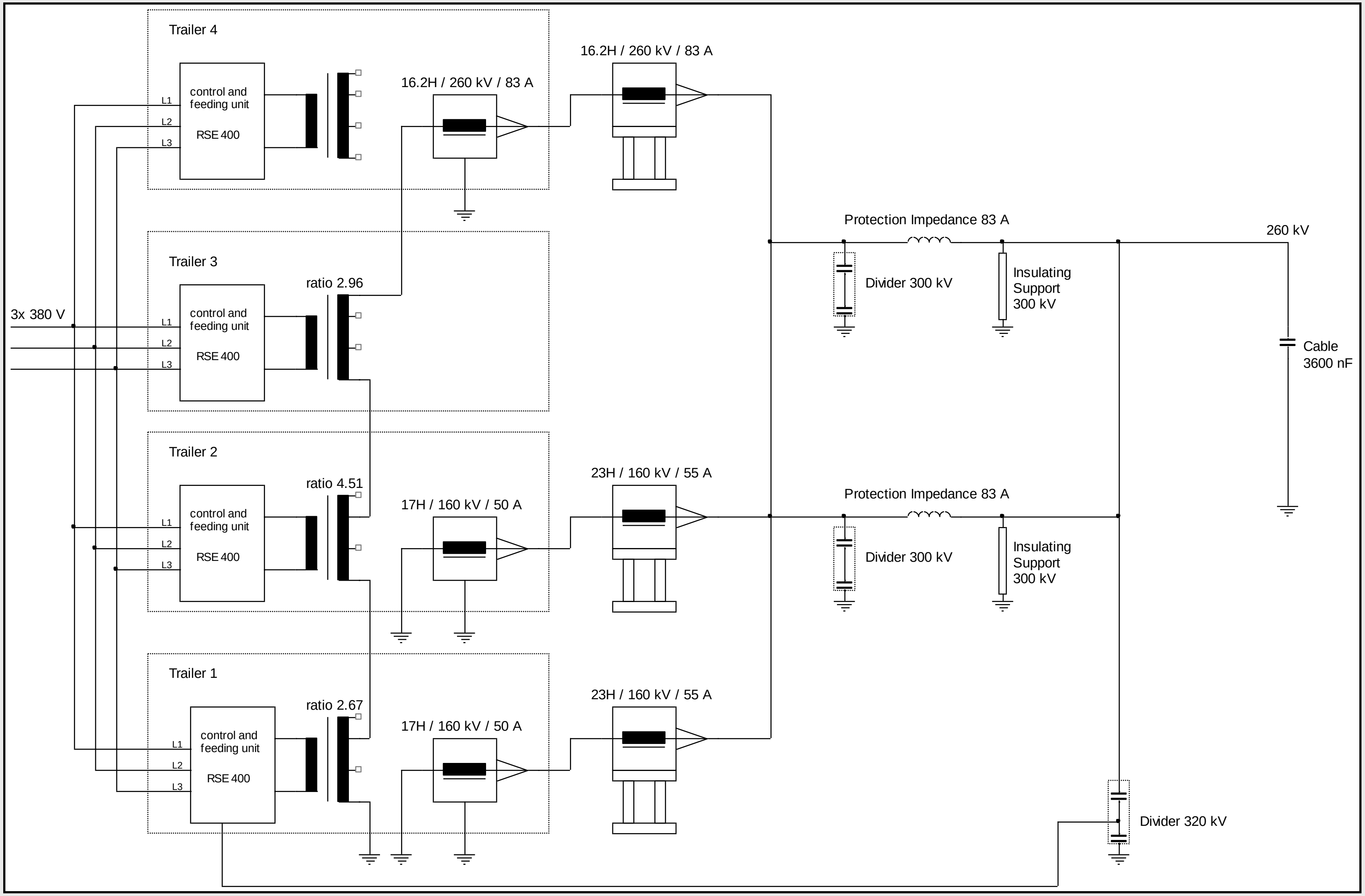
ACRF test systems:

4 trailers with
- 4 frequency converters (400A) (only 3 converters used)
- 2 reactors (260kV, 83A,16.2H),
- 2 reactors (160kV, 50A, 17H),
- 2 reactors (160kV, 55A, 23H).

Resulting further test parameters:

Resonant frequency:	23.8 Hz
Test current:	140.4 A
Reactive power of test:	36.5 MVA
50 Hz equivalent power	76.7 MVA

3.2 Circuit of a Cable System Test in Doha/Qatar, January 2009

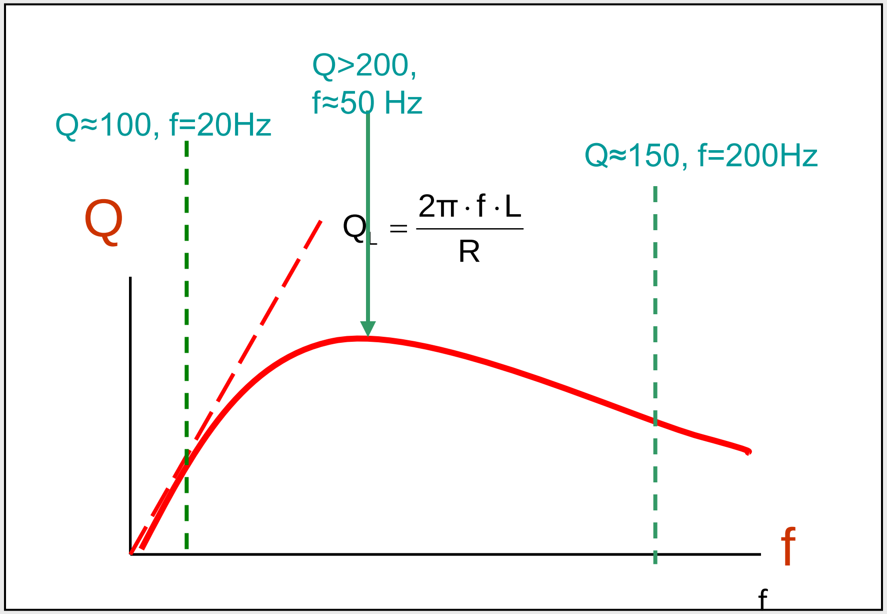


3.3 Feeding Setup for a Cable System Test in Doha/Qatar

The **active power losses P** in the test circuit must be supplied by the frequency converter. The **quality factor Q** of the whole circuit is the relation of the required reactive power for testing the cable $S_{test.}$ to the losses P.

$$P = \frac{S_{test}}{Q} = \frac{u_{test} \cdot i_{test}}{Q}$$

Q depends on current and frequency (low frequency means high current and vice versa), see principle diagram.



Doha test:

F_{test} = 23.8 Hz; S_{test} = 36.5MVA, assumption Q = 100: **P = 365 kVA**

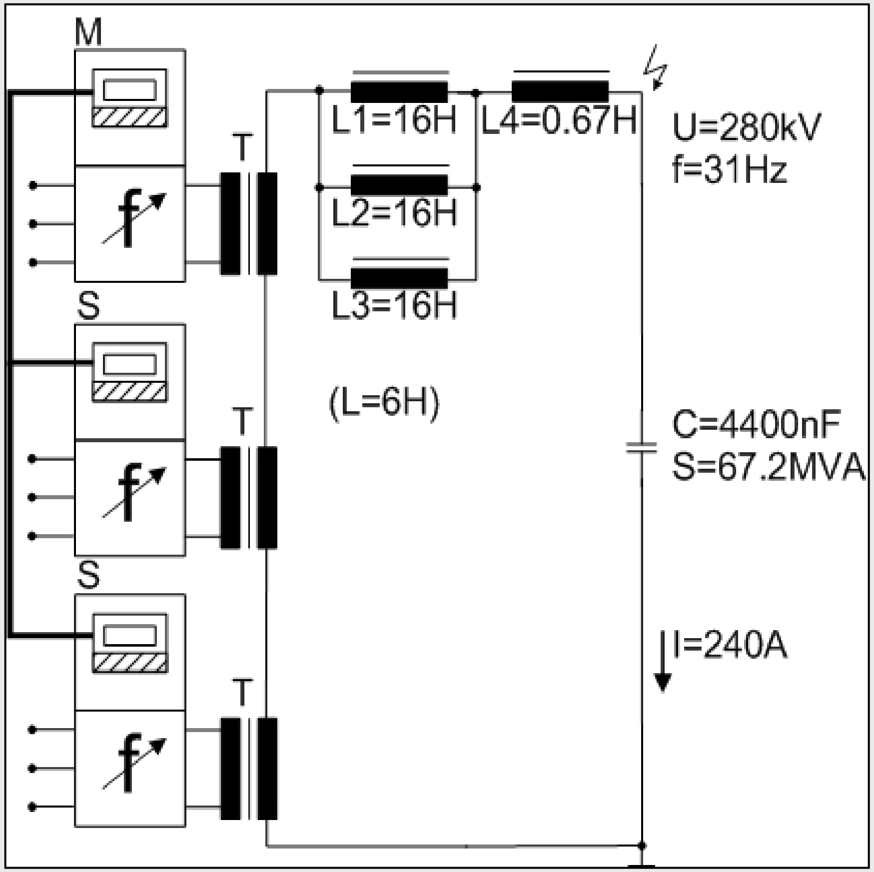
The limited number of taps of the exciter transformer does not allow a 100% **power adaptation**, therefore 75% are assumed. This leads to a power consumption of the frequency converter: $\mathbf{P_{feed} = P / 0.75 \approx 485}$ **kVA.**

When a **Diesel generator** is applied it should have a much higher rating: $P_{Diesel} \approx 2.5\ P_{feed}$

4. Setup for the Commissioning - Test of the SLC Project, London 2005

Principle circuit

Length of cable system 22 km, P_{50} = 108 MVA



Photos: Courtesy of IPH Berlin

Simulation of test at IPH Berlin

Real test in London

5.1 Increasing Application for Submarine Cable Testing

AC routine and field test
is applied for

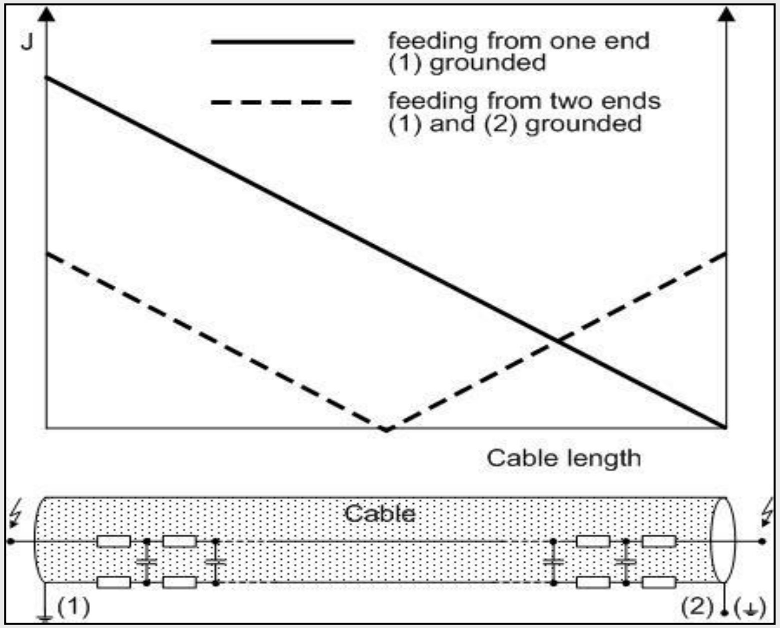
HVAC submarine cables and also
HVDC submarine cables according to a CIGRE recommendation

For both ACRF test systems are used..

HVDC submarine cables

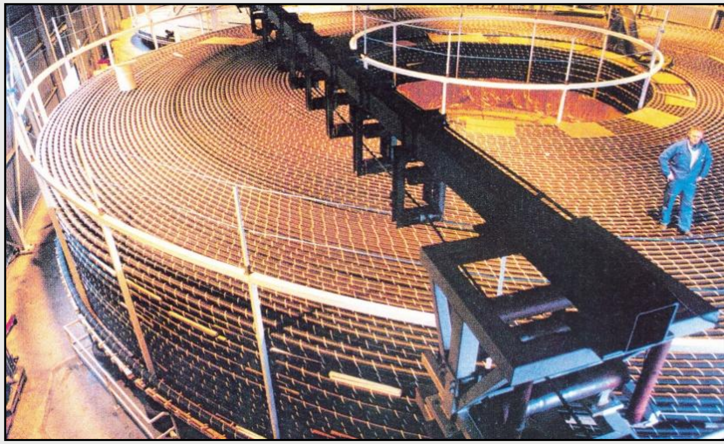
The relatively high resistance of cable sheet causes a remarkably lower quality factor than for HVAC cables. The current distribution must be optimized.

Photo: Courtesy of ABB Power Tech Products / Sweden



5.2 ACRF Test Systems for Submarine Cable Testing in Factory

Rating:
110/220 kV
388/194 A
15 ... 300 Hz



confi-guration	frequency Hz	max. voltage kV	max. current A	max. load nF	testable cable* km
parallel mode (L=1.3H)	35	110	388	16000	73
single mode (L=2.6H)	35	110	194	8000	36
series mode (L=5.2H)	35 25 15	220 158 95	194 194 194	4000 7800 21700	18 35 100

6. ACRF Test Systems for Medium Voltage Cables?

Why not ?

What is correct for HV cables cannot be wrong for MV cables. The much lower dielectric stress in MV cables enabled the application of other test voltages.

Test Voltage	**VLF (AC < 1Hz)**	**DAC (OSI)**	**AC (by ACRF)**
Volt. Distribution, Breakdown For withstand/PD test	Resistive at defect Similar to DC Both conditioned	Capacitive As OSI voltage No / Yes	Capacitive As AC voltage Yes / Yes
Main application, (Introduction)	Diagnostics, especially for water trees in MV cables (1985)	PD diagnostics of MV cables, (1995)	Multi-purpose, also for rotating machines (not yet introduced for MV)
Availability Weight, price	Very large number Both relatively low	Remarkable number Both relatively low	Only few, Both slightly higher
Conclusion	Long experience, but physically questionable	Only applicable for PD measurement	Suited for both, withstand and PD testing

6. Conclusions

1) The insulation of HV and EHV extruded cables is highly stressed and requires also on-site test voltages representing stresses in service, especially AC voltages. Then field test results are comparable with those in factory.
2) ACRF test systems generate such AC voltages (20…300 Hz, IEC60840&62067) well suited for field testing of extruded HV and EHV cable systems.
3) Both, the electrical and the mechanical design of these ACRF test systems, is very reliable. This has been shown by more than 120 systems operating worldwide. The field tests are more and more connected with PD measurement.
4) A modular concept for the combination of the components of several ACRF test systems is very helpful for testing with higher voltage and power. It has enabled the testing of the largest HVAC cable systems erected till now.
5) New challenges are expected with the testing of large submarine cable systems which are being prepared in several parts of the world.
6) For historical and price reasons, only very few ACRF test systems are applied in field testing of MV cables. They should have a chance for their physically correct test voltages, combination with PD measurement and multi-purpose application.