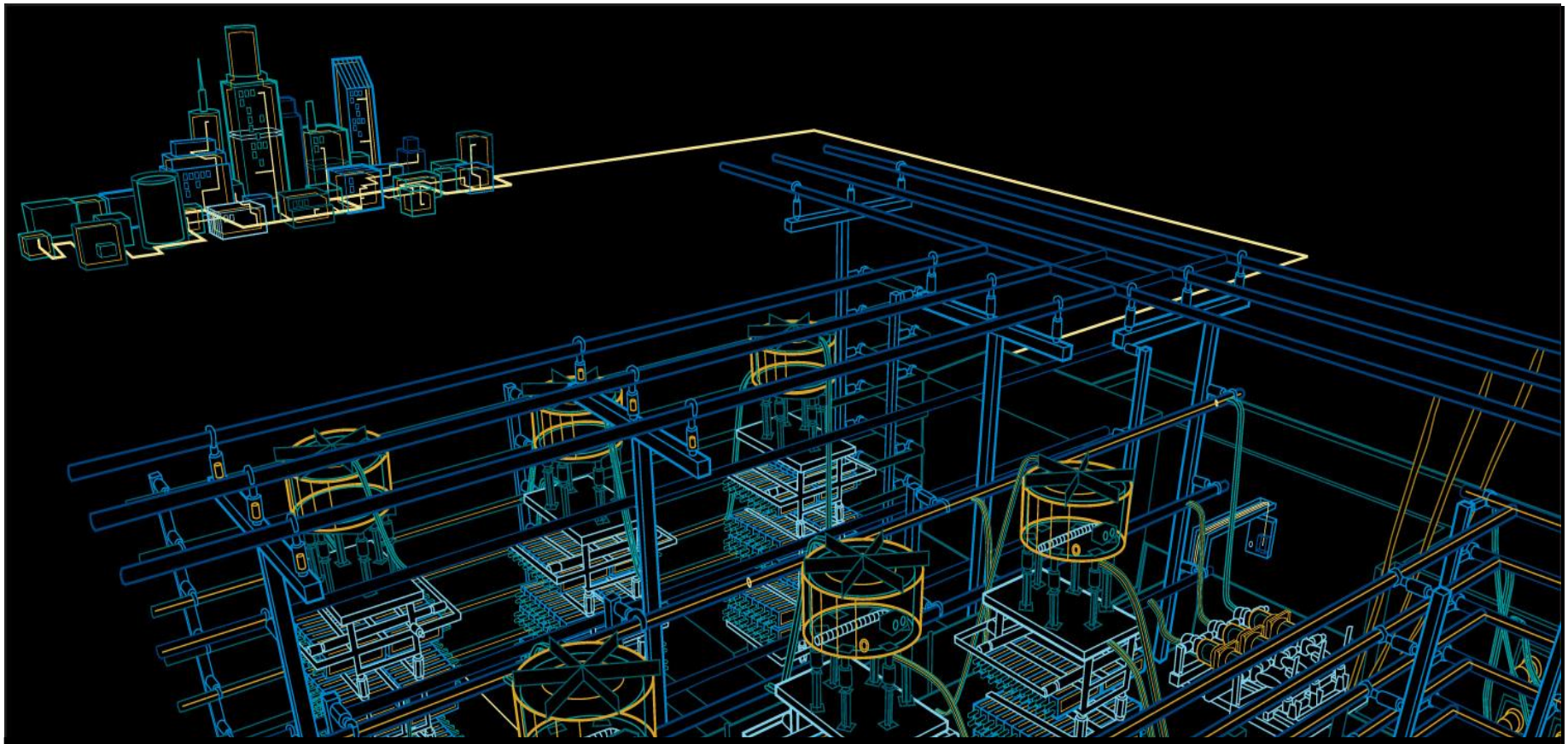


José Matias – High Voltage Components – ABB AB

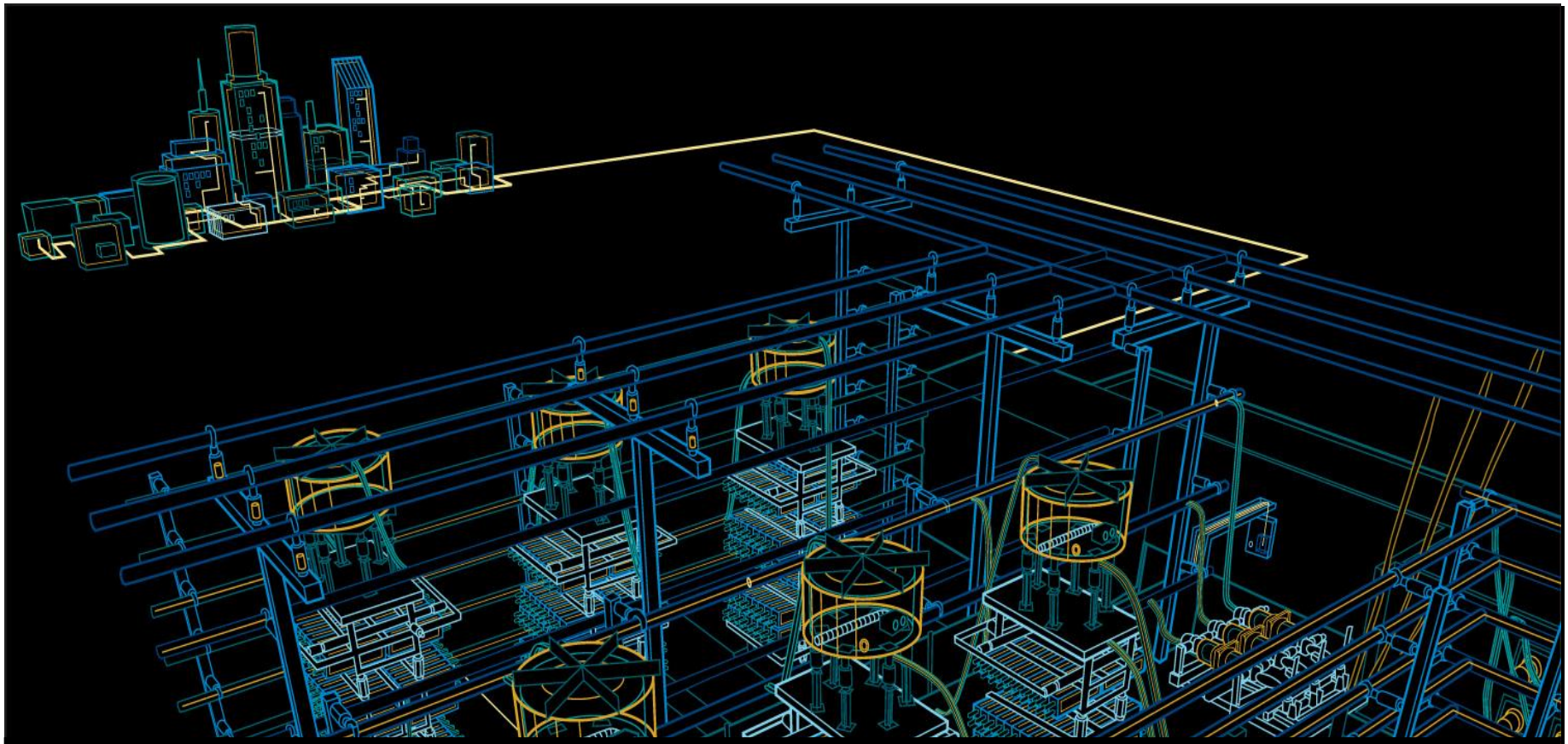
Santiago - Chile, 05-June-2013

Reactive Power Compensation

Reactive Power Compensation
Main Topics

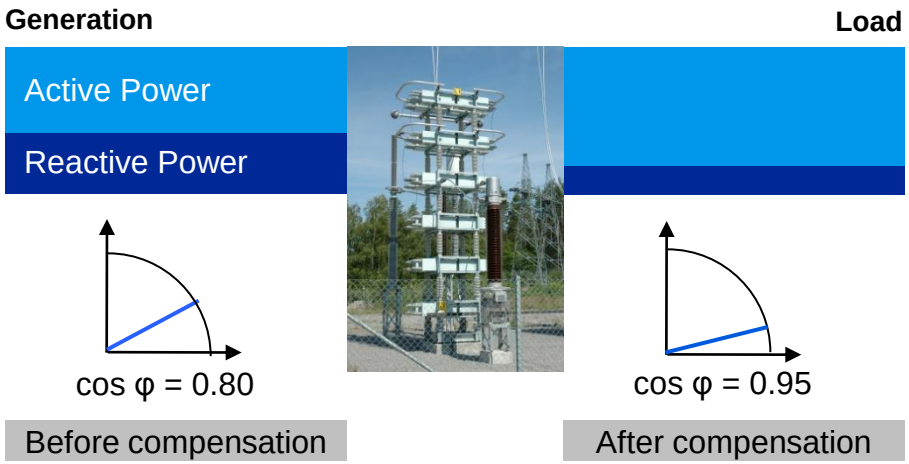
Topics

- **Introduction**
  - The need for capacitors
  - Reactive power
  - Effects of reactive power
  - Reactive power compensation
  - Implementing compensation in network
  - Benefits of reactive power compensation
  - Compensation solutions
- **Capacitors: Main components & Building blocks**
- **ABB Capacitors: History & background**
- **ABB Capacitors: Solutions & Portfolio**



Reactive Power Compensation Introduction

Power factor
Displacement factor (cos φ)

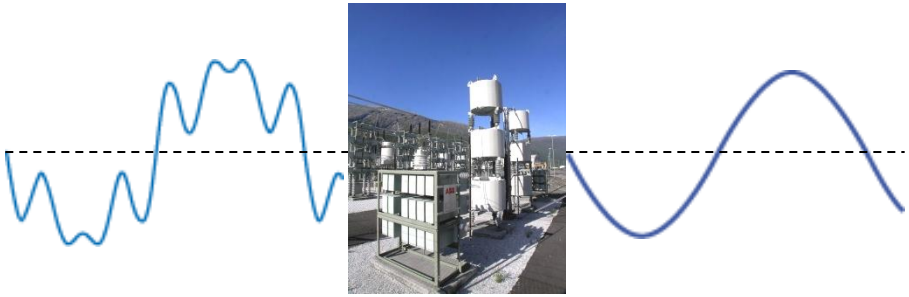


Reactive power compensation implies compensating the reactive power consumed by electrical motors, transformers etc.

Benefits

- Improves system power factor
- Reduces network losses
- Avoid penalty charges from utilities for excessive consumption of reactive power
- Reduces cost and generates higher revenue for the customer
- Increases system capacity and saves cost on new installations
- Improves voltage regulation in the network
- Increases power availability

Power factor
Harmonic distortion



Current waveform before harmonic filtering

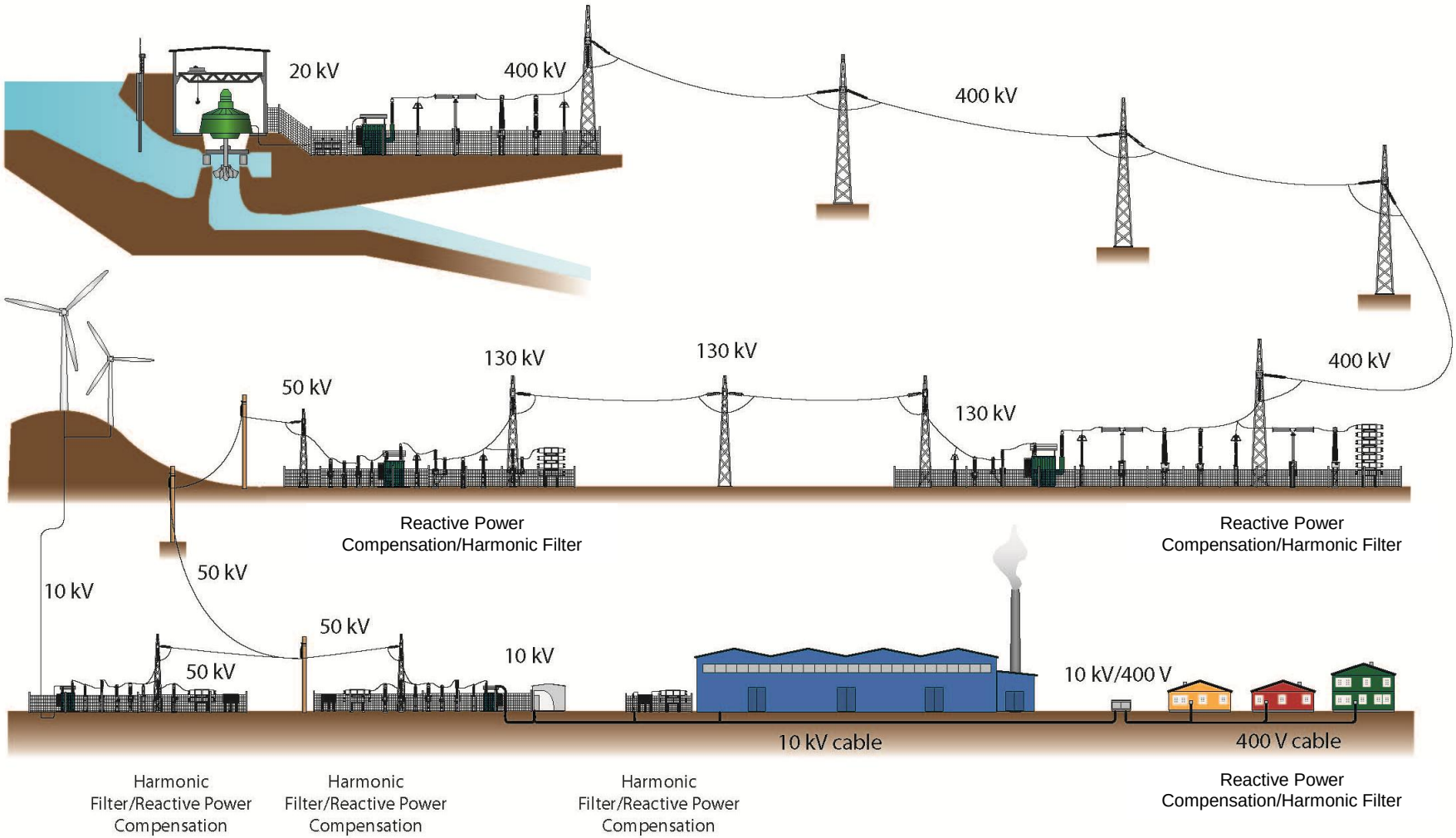
Current waveform after harmonic filtering

Harmonic filtering implies mitigating harmonic currents generated by the non-linear loads like rectifiers, drives, furnaces, welding machines, converters, HF lamps, electronic equipments etc in the network.

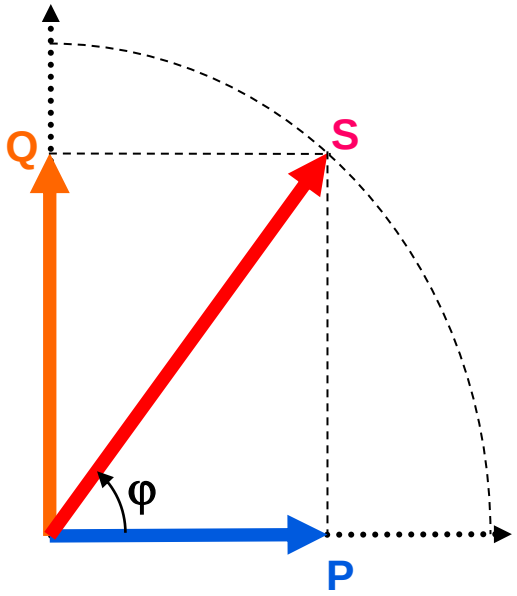
Benefits

- Reduces harmonic content in the network which further reduces disturbances in telecommunication network, misbehavior in control equipments and relay protections, measuring errors in metering system
- Reduces network losses
- Reduces equipment overloading & stress on insulation
- Reduces cost and generates higher revenue for the customer
- Reduces unplanned outages and increases power availability

The need for capacitors
We operate on all voltages in the network



Reactive power
Definitions



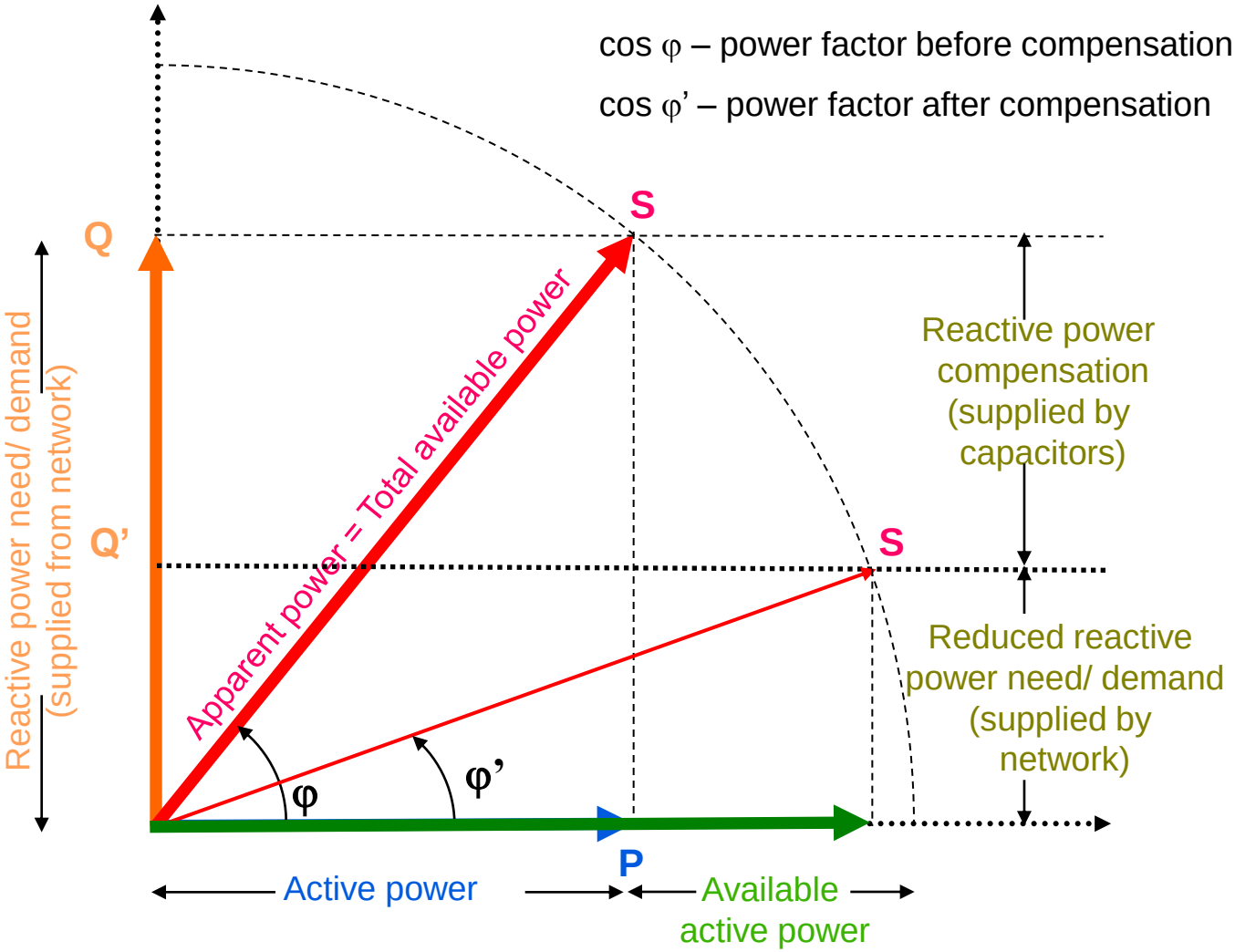
Active power (**P**)
It is the useful power that is doing the actual work. It is measured in W, kW, MW & calculated as, P = S x cos φ

Reactive power (**Q**)
It is a consequence of an AC system. Reactive power are used to build up magnetic fields. It is measured in var, kvar, Mvar & calculated as, Q = S x sin φ or P x tan φ

Apparent power (**S**)
Or total power (S) is the combination of active and reactive power. Apparent power is measured in VA, kVA, MVA

Power factor (**cos φ**)
It is a measurement of the efficiency in a system. Power factor describes the relationship between active (P) and apparent Power (S)

Reactive power
Compensation



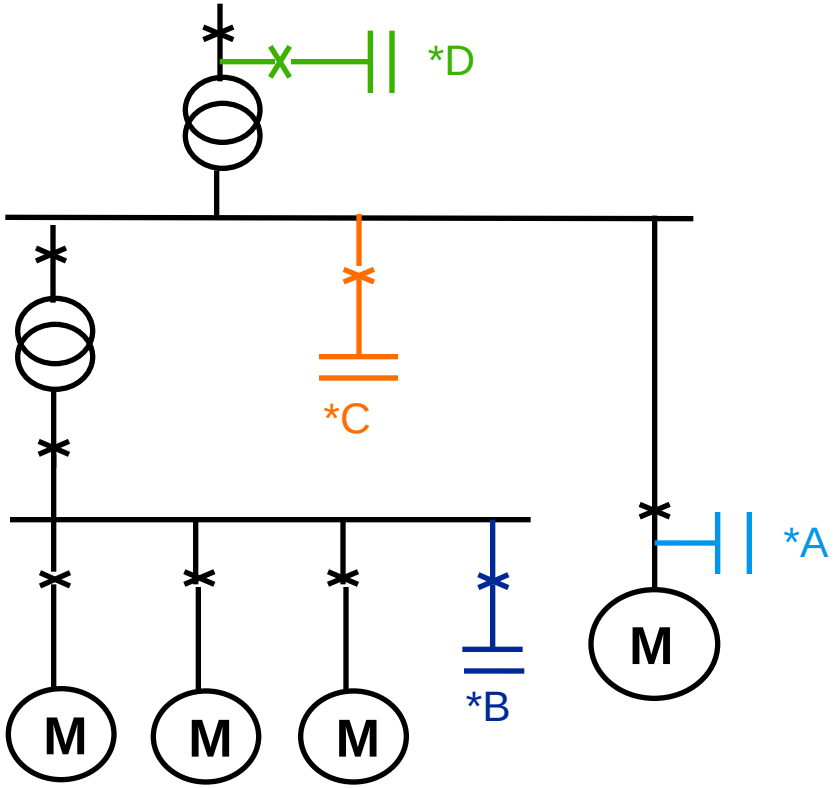
Reactive power
Implementing the compensation in the network

Shunt compensation of reactive power can be employed either at load level, substation level or at transmission level.

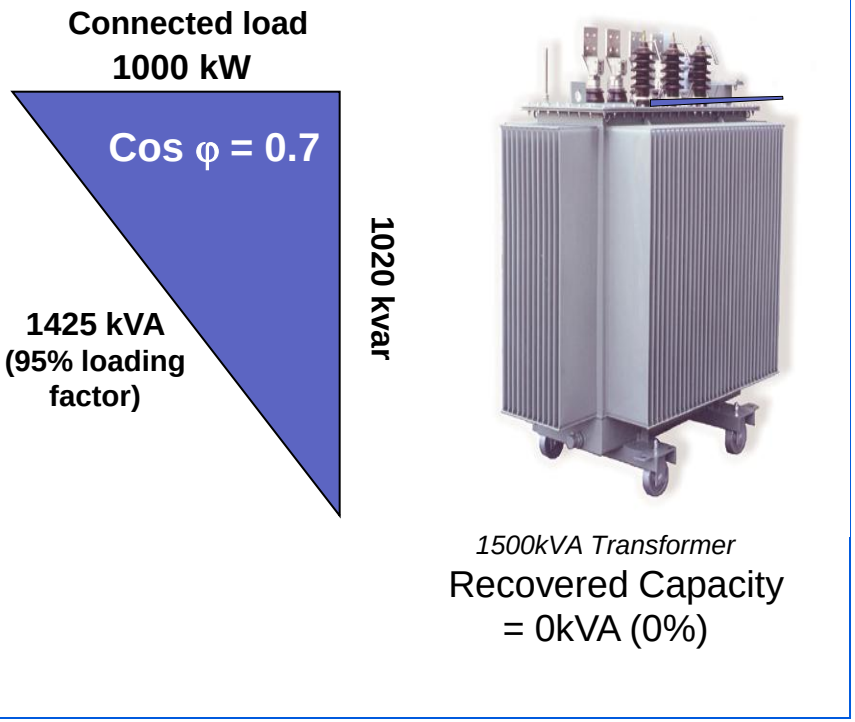
Compensation should be provided as close as possible to the consumption point to avoid having to distribute this power in the other part of network.

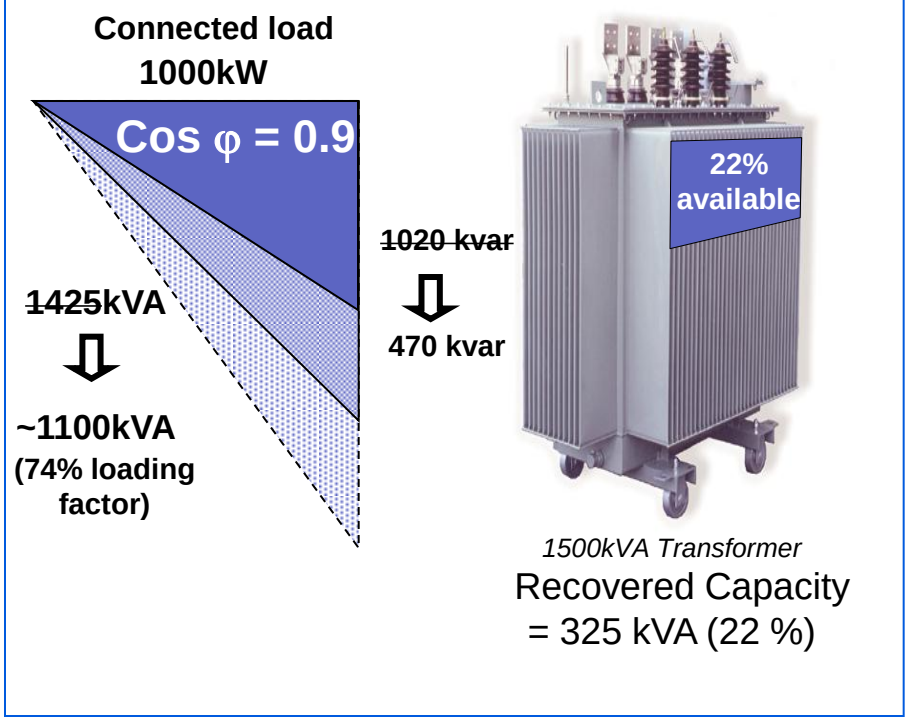
Location is primarily determined by the reason for compensation.

- *A : Direct Compensation
- *B : Group Compensation
- *C : Central Compensation at LV side
- *D : Central Compensation at HV side



Example of power factor correction
Relief in transformer loading

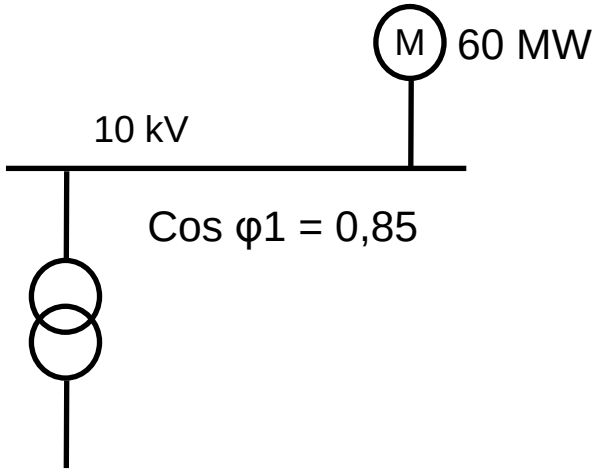




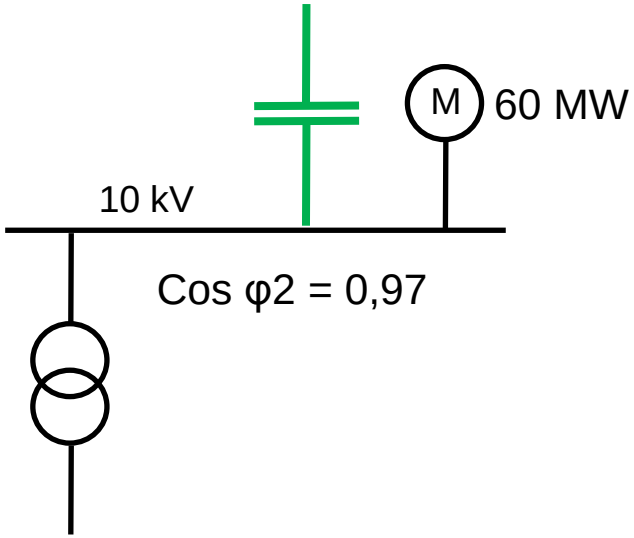
Power triangle of an installation running at low cos φ and for which the transformer is close to full load

Power triangle of the same installation where power factor correction has been applied reduces load on the transformer / releases capacity for additional loads

Reactive Power Compensation
Added value: optimizing power availability

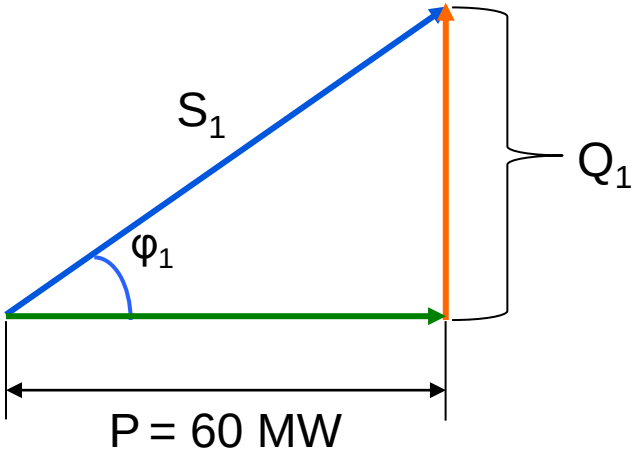


Compensation

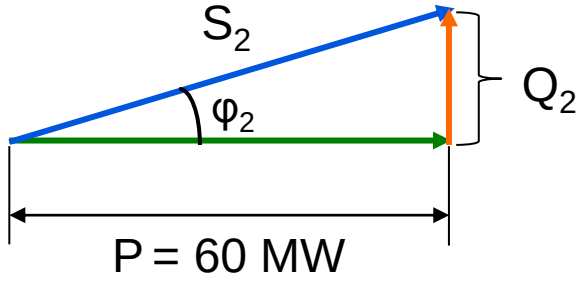


Q_{free} = % * P
according to tariff

Example
0.15 x 60 MW = 9 Mvar

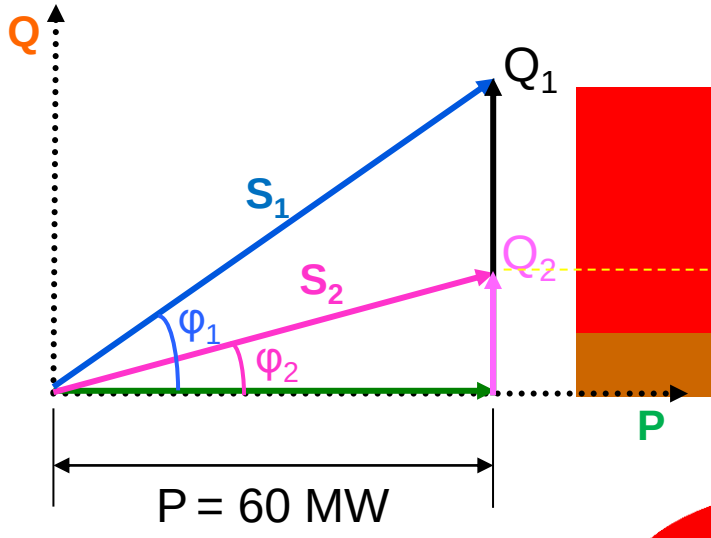


Compensation

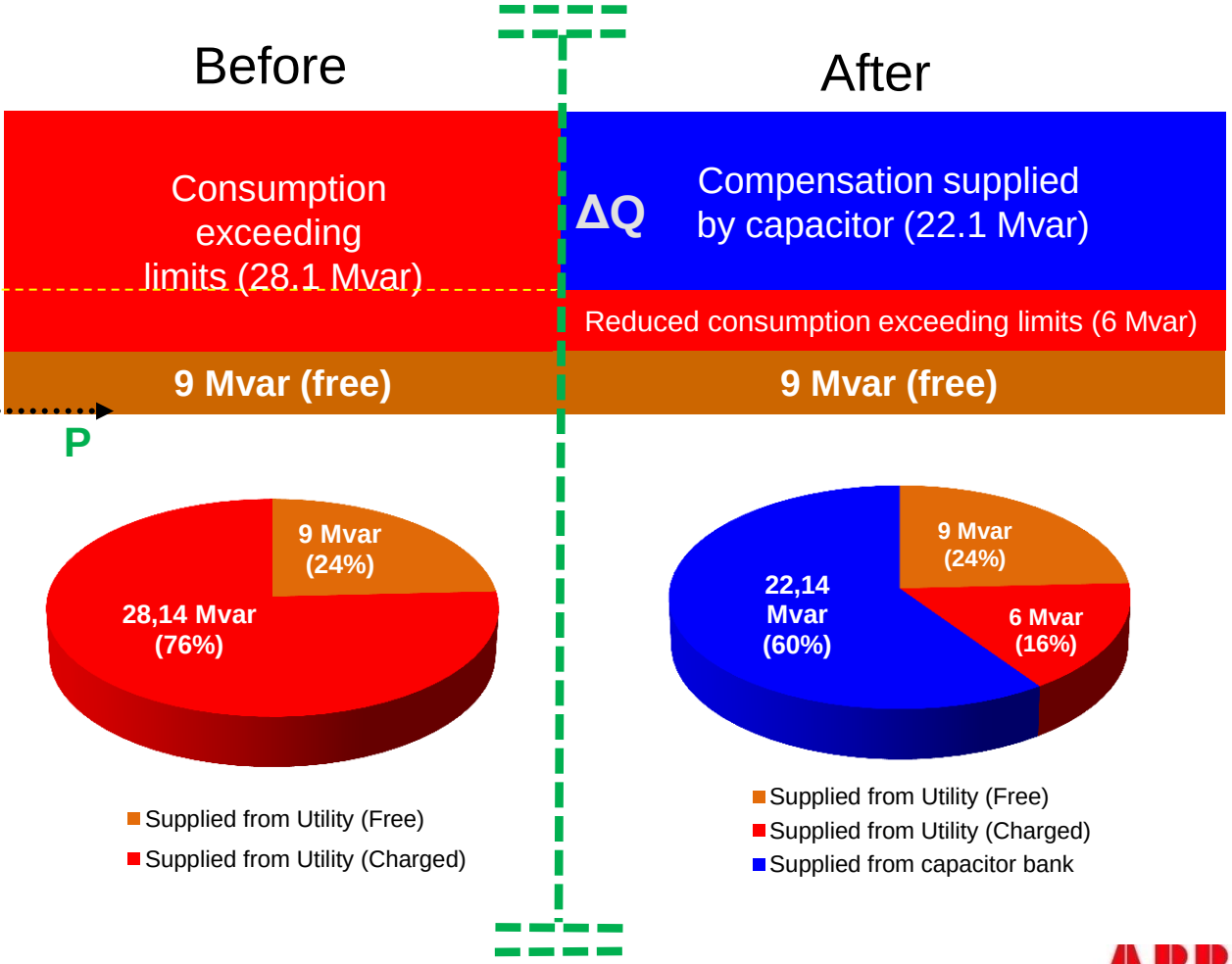


Reactive Power Compensation
Advantages: Summary/Conclusion

Q_{free} = X % x P according to tariff/utility regulation ⇨ Max. Q_{free} allowed from utility= 0,15 * 60 = 9 Mvar



Before	After
Cos φ_1= 0,85	Cos φ_2= 0,97
P= 60 MW	
S_1= 70,59 MVA	S_2= 61,86 MVA
Q_1= 37,19 Mvar	Q_2= 15,04 Mvar
ΔQ= 22,1 Mvar (cap. Bank power)	



Reactive Power Compensation
Purpose

Solution depends on aim:

Reactive Power need and no harmonics

Capacitor Banks

Reactive Power need and no distortion even if Harmonics are present

Detuned Filters

Reactive Power need and distortion problems

Tuned Filters

Reactive Power need and strong distortion problems such as fast voltage fluctuations and/or phase asimetry

Dynamic / SVC's

Reactive power
Apparent, Active & Reactive Power

REACTIVE POWER

Beer: Foam

Electricity - Unable to do work

APPARENT POWER

Beer: Full glass

Electricity - Available from utility

REAL POWER

Beer: Drinkable

Electricity = Able to do work

It is the Active Power that contributes to the energy consumed, or transmitted. Reactive Power does not contribute to the energy. It is an inherent part of the "total power" which is often referred as "Useless Power".

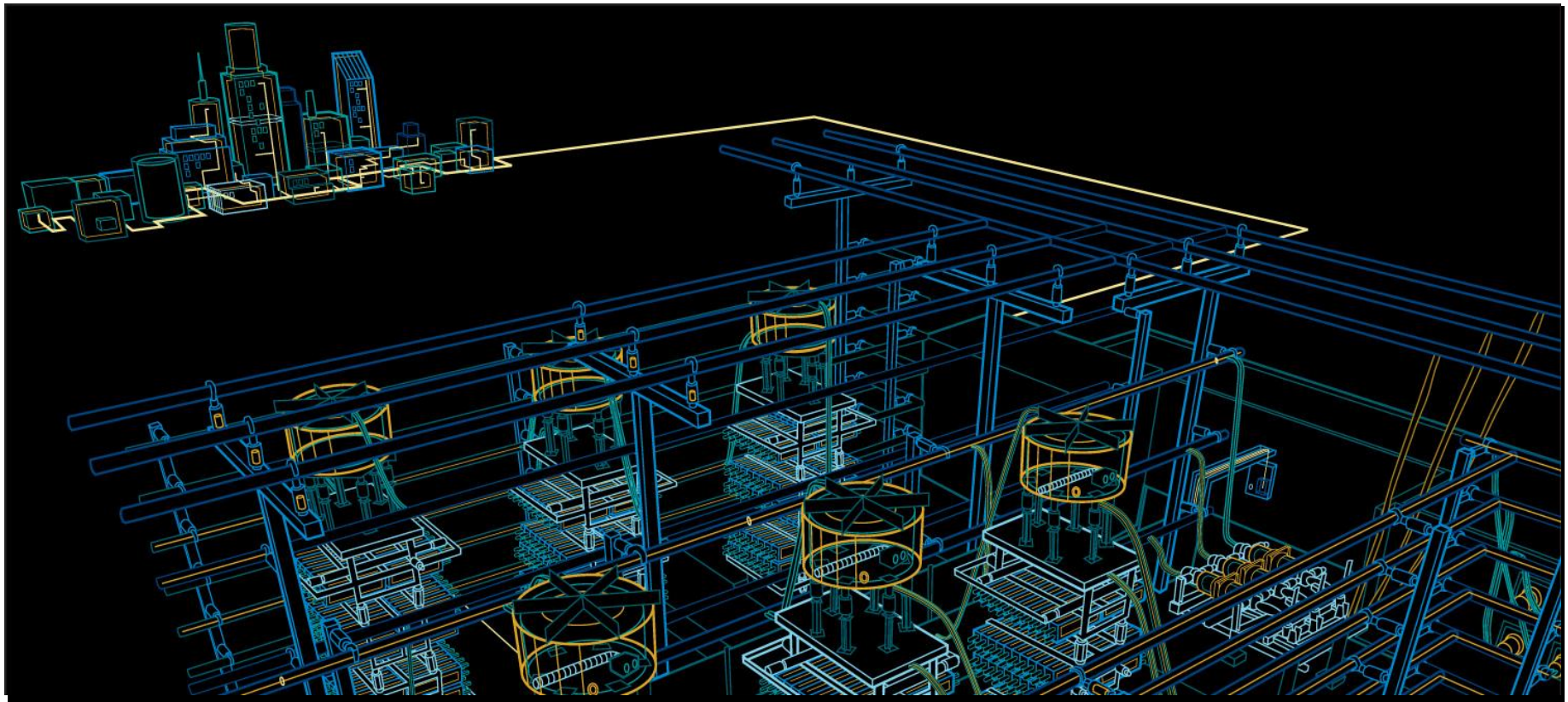
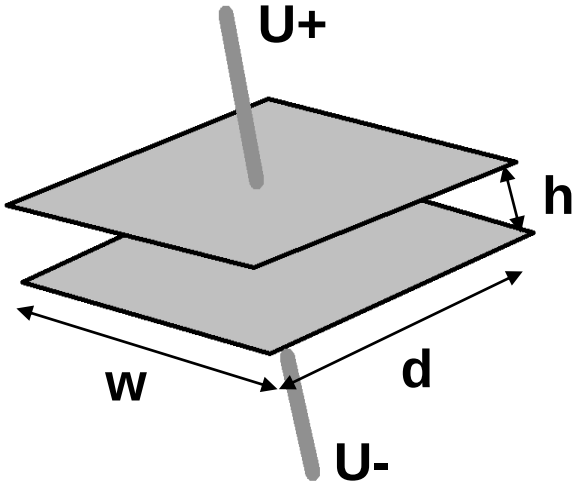


ABB Capacitors
Main components & Building Blocks

Main components and building blocks
Basic definitions: Capacitor & Capacitance

Capacitor

Two conductor layers separated by a insulating layer (dielectric)



Capacitance

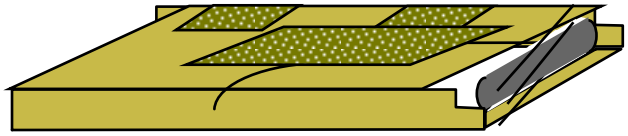
$$C = \varepsilon * \frac{A}{h}$$

- Area of the plates = w x d
- Distance between the plates (thickness of the dielectric)
- Permittivity of the insulating material (dielectric) or Dielectric constant

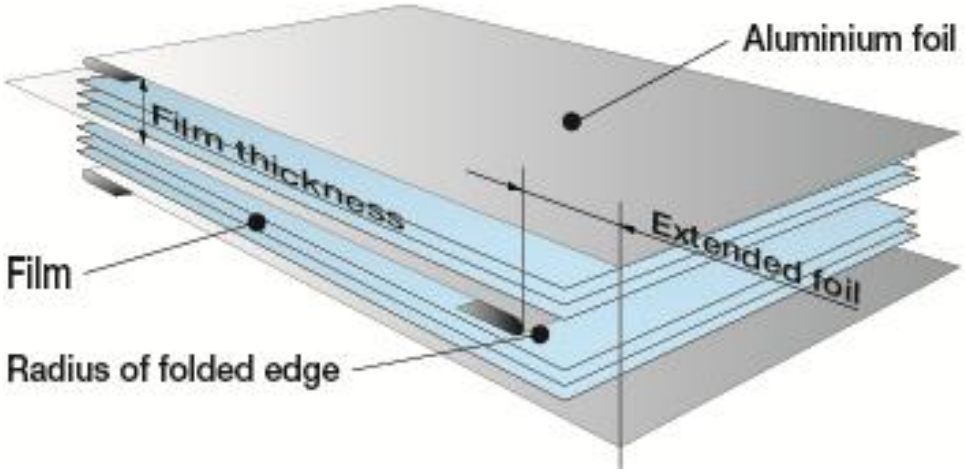
Reactive Power

$$Q = 2\pi f \times U^2 \times C$$

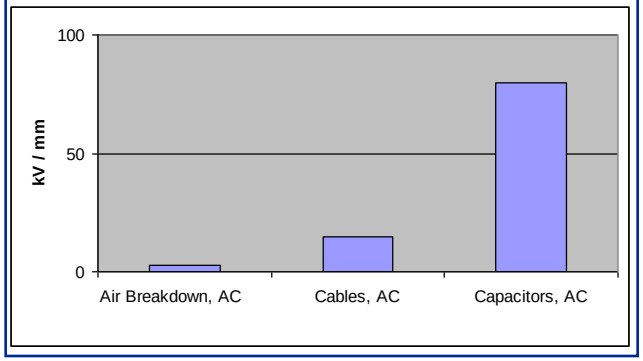
- Capacitance
- Voltage
- Frequency



ABB's unique features
Reliable and well utilized capacitor elements



Optimal electric field strength, well utilized insulation:

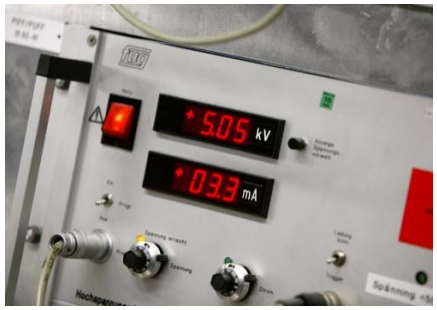


Design with safety margins:

- Several film layers (normally three)
  - High electrical withstand
- Folded foils at electrode edges
  - Low electric stress amplification
  - Minimized PD generation

Reliability
ABB Capacitors: well proven experience

We know that world-class products, requires top of the line personnel, careful selection of materials and most modern machinery.

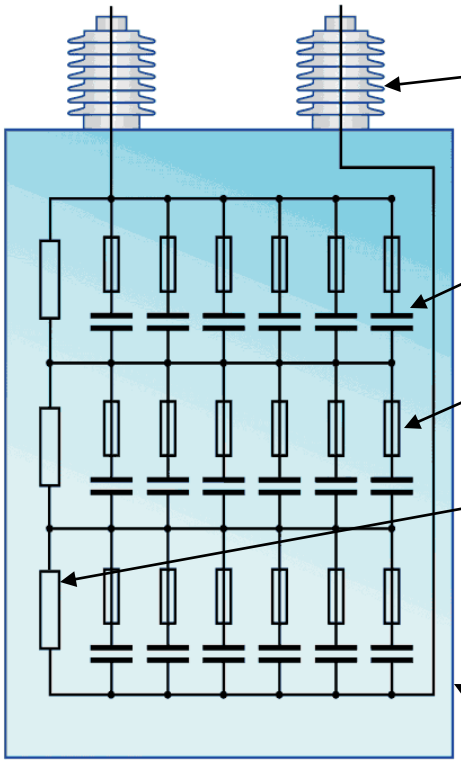


Our workshop has the most modern machinery and processes. These are often tailor made in order to satisfy the high demands of our customers.

Reliability
ABB Capacitors: Failure rates examples

Project (Installed)	Application	No. of units	Failure (%/year)
Itaipu (1985-93)	HVDC	15224	0.03
IPP (1986-91)	HVDC	13786	0.05
Pacific (1987-94)	Filter	1008	0.15
Itaipu (1990-94)	SC	5040	0.04
Rihand-Delhi	HVDC	6103	0.004

Power Factor Compensation & Filter Solutions
Basic definitions: Capacitor unit components



Bushing

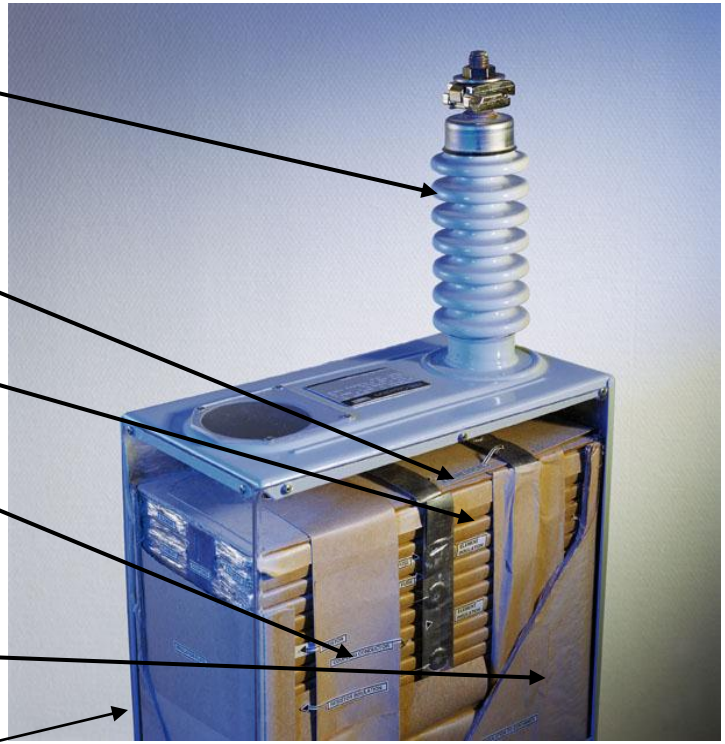
Elements

Internal fuse

Discharge resistor

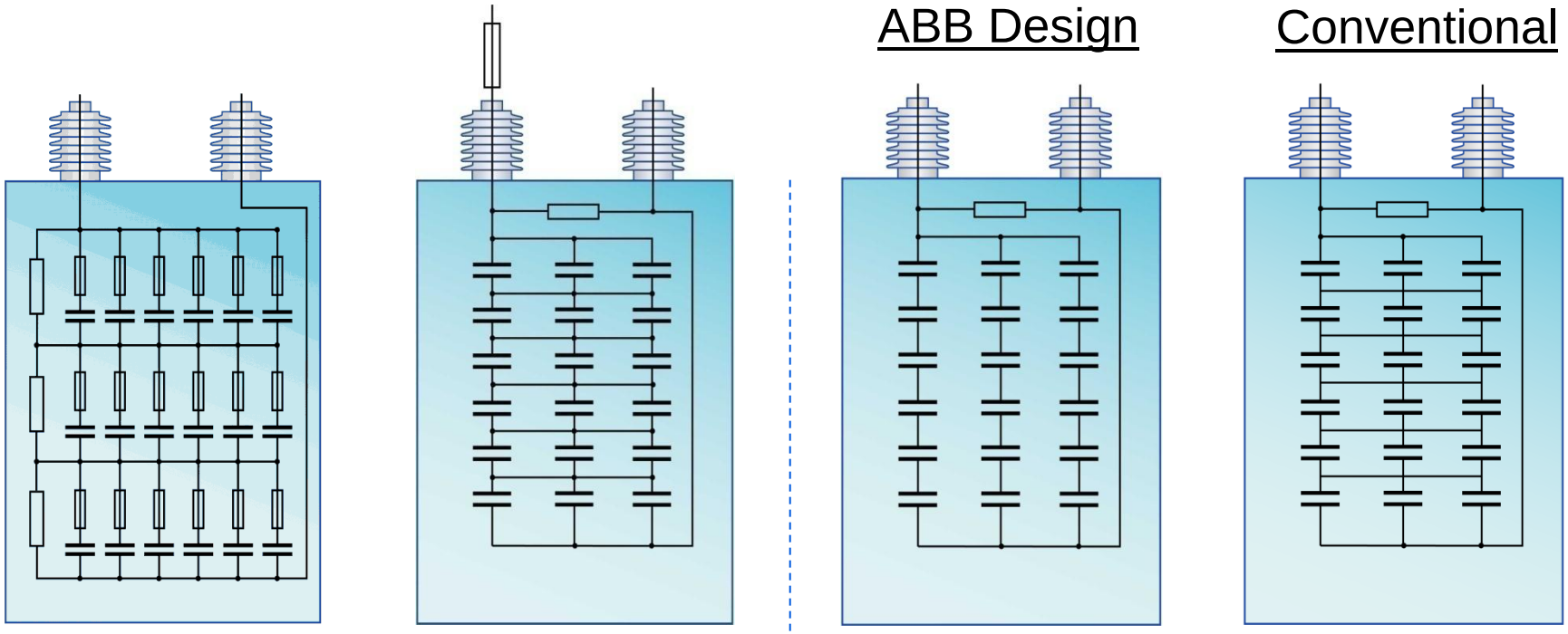
Internal insulation

Can
(stainless steel)



ABB's unique features

HiQ units available in all type of fusing technologies



ABB's unique features
Expertise in all type of fusing technologies

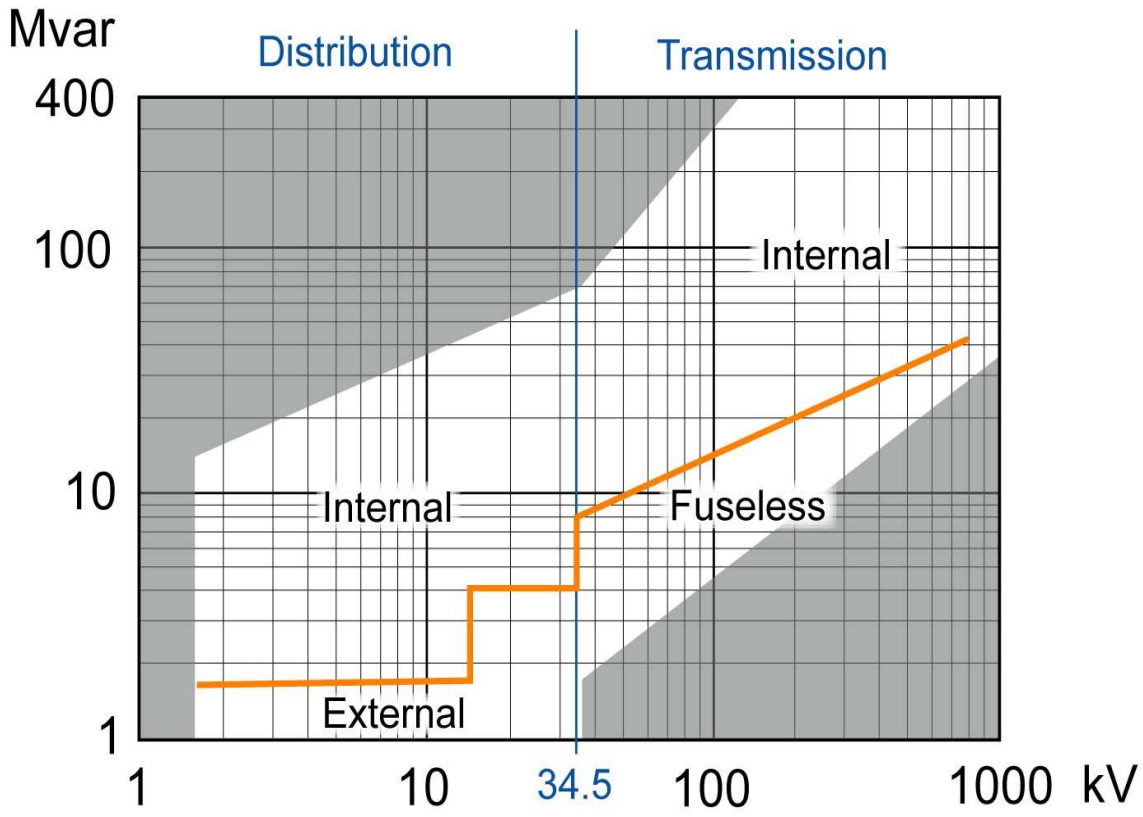
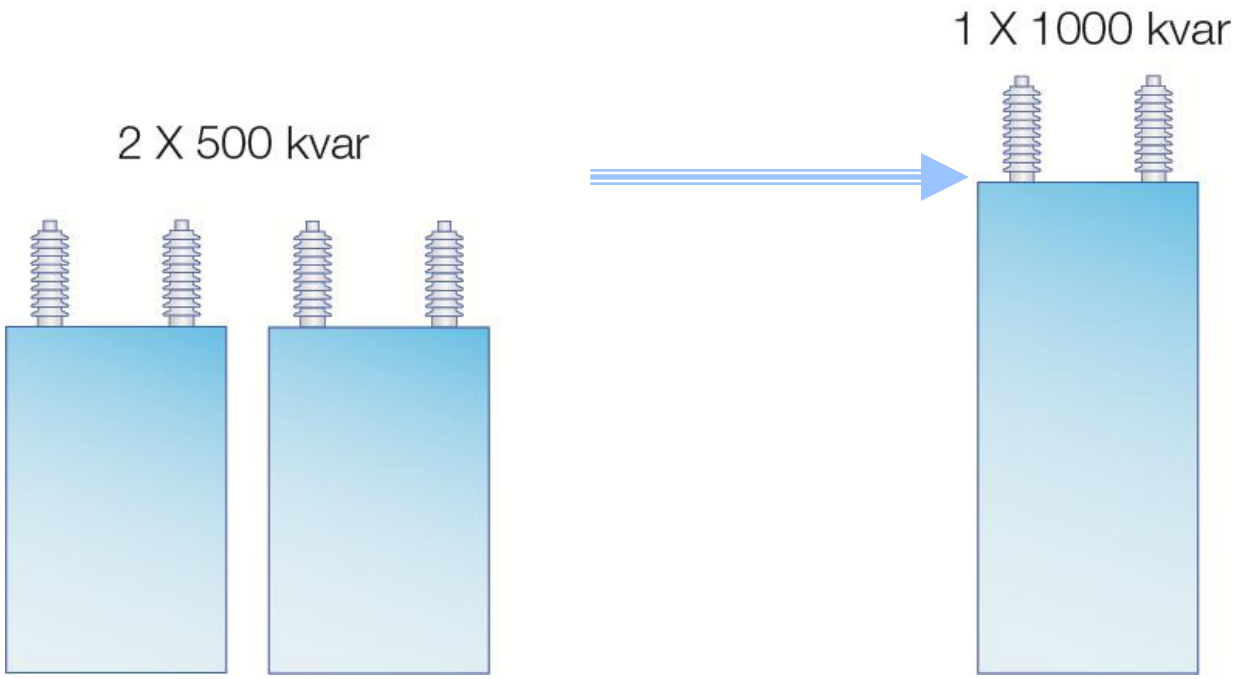


ABB is the only manufacturer supplying all types of fusing technologies

ABB's unique features
Large units - gives lower cost for the customer

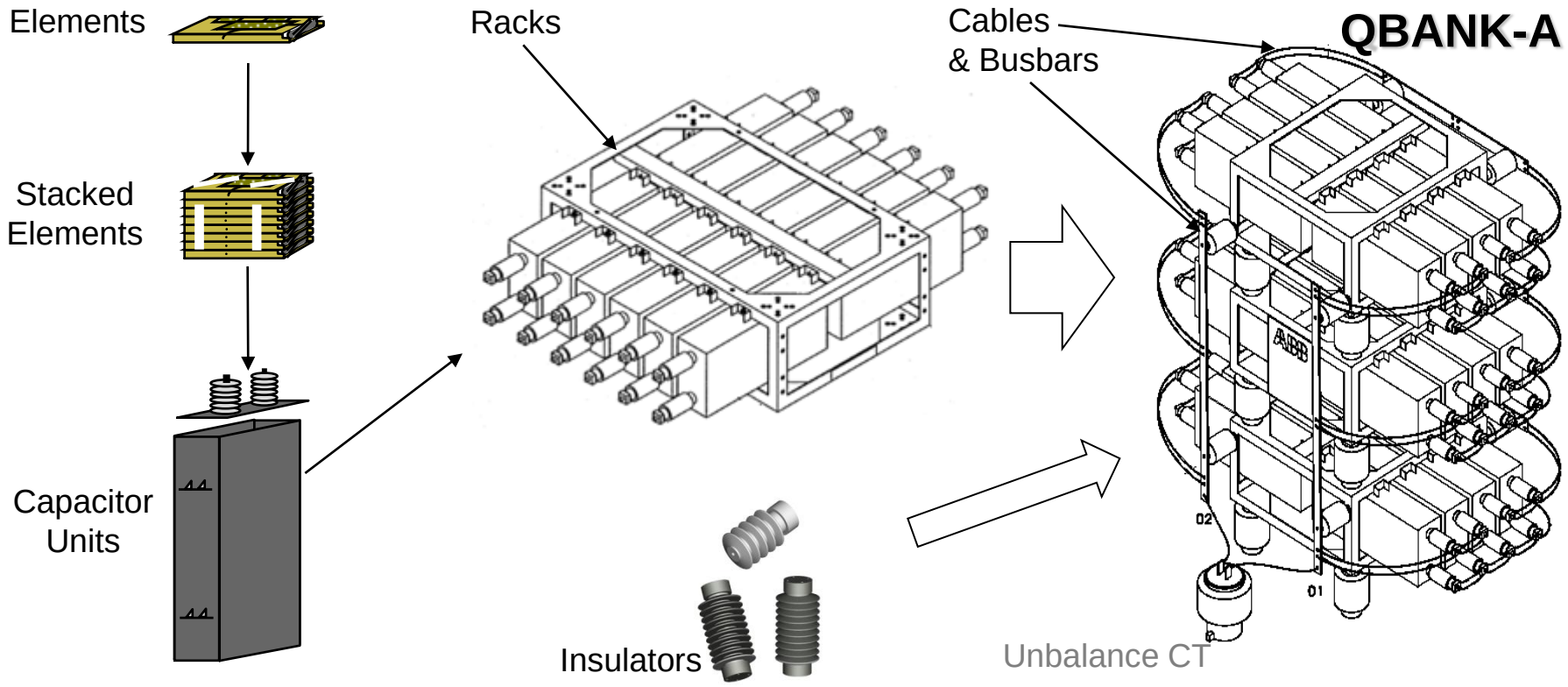
- Same dielectric stress
- Same number of elements
- Same active material

- Less passive material (bushings, insulation etc.)
- Less ground area implies
- Less foundation
- Less fence



Power Factor Compensation & Filter Solutions
Capacitor Banks: Core components

Bank design means transforming the requested reactive power into a physical structure with all environmental aspects and customer requirements taken into account.



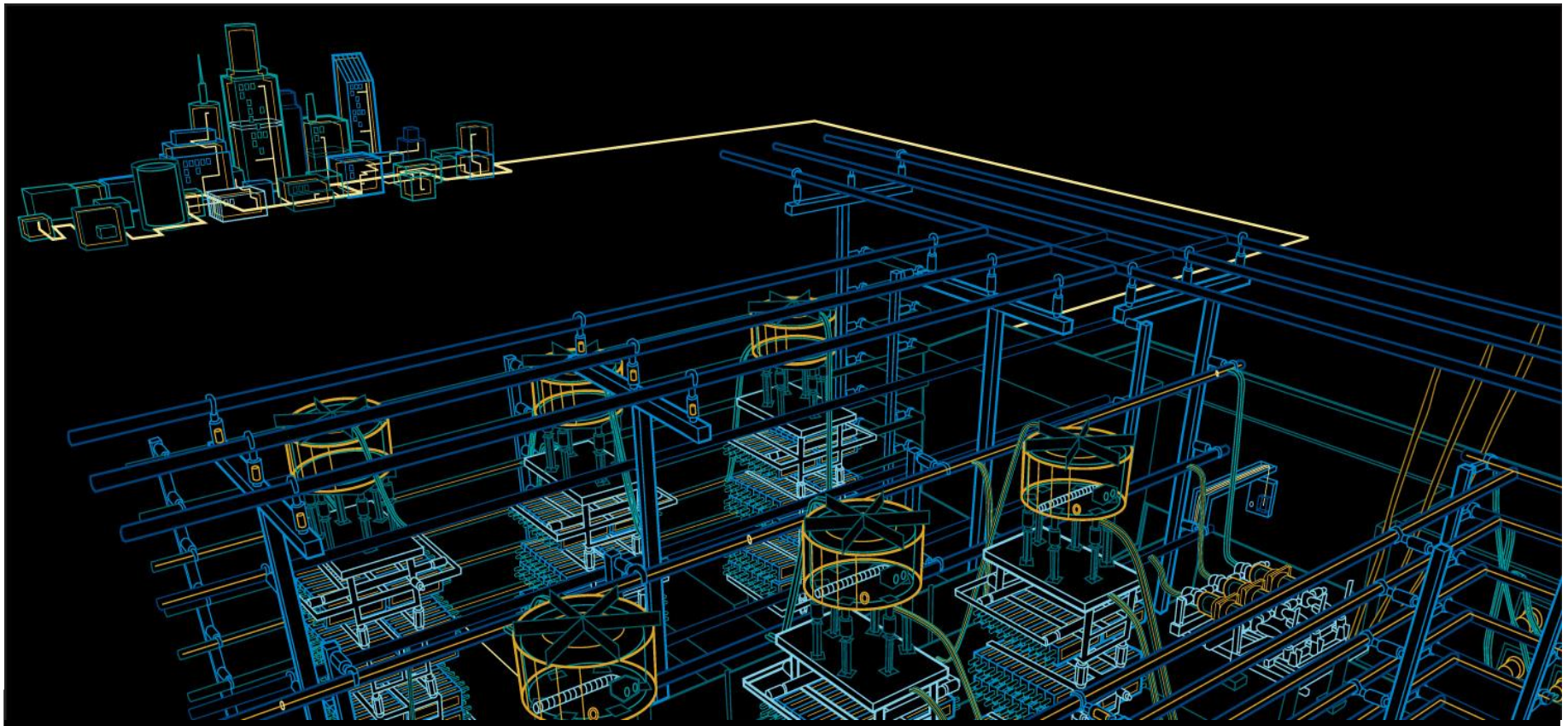
Power Factor Compensation & Filter Solutions
Harmonic Filters: Core components

Capacitors
C [µF]

Reactors
L [mH]

Resistance
R [Ω]

For filter performance these values are the important



Power Factor Compensation
ABB Capacitors
History and background

ABB Capacitors
ABB Production Facilities & Technical Centers

- Number of HV/MV factories: 4
- Number of LV factories: 2
- Local assembly units: 5
- Sales Office in 100 countries

ABB in Ludvika
A world center of high voltage

Surge Arresters

Instrument Transformers

Capacitor Banks

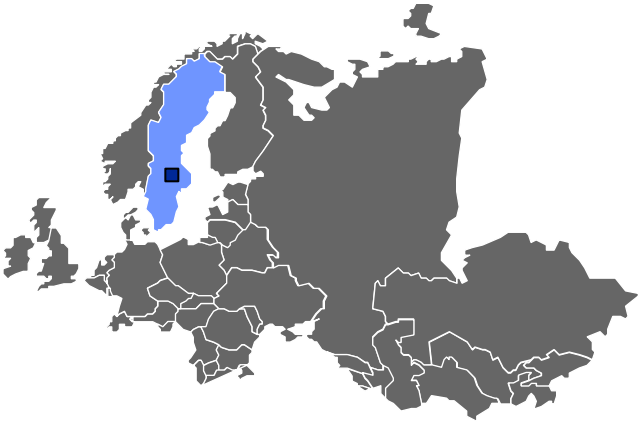
Live Tank Circuit Breakers

Disconnecting Circuit Breakers

One-Stop source for air-insulated HV equipment

ABB in Ludvika
“The High Voltage Valley”

Capacitors in ABB
Technical Lead Center in Ludvika



- Technical lead center for ABB medium and high voltage capacitors
- One of the worlds largest factories for capacitors.
- Most modern factory in the world
- Export: >95%
- Employees: app. 150
- Volume: 30 000 Mvar/year

Capacitor plant area

Capacitors in ABB
High quality production facility






One of the most modern production lines with:

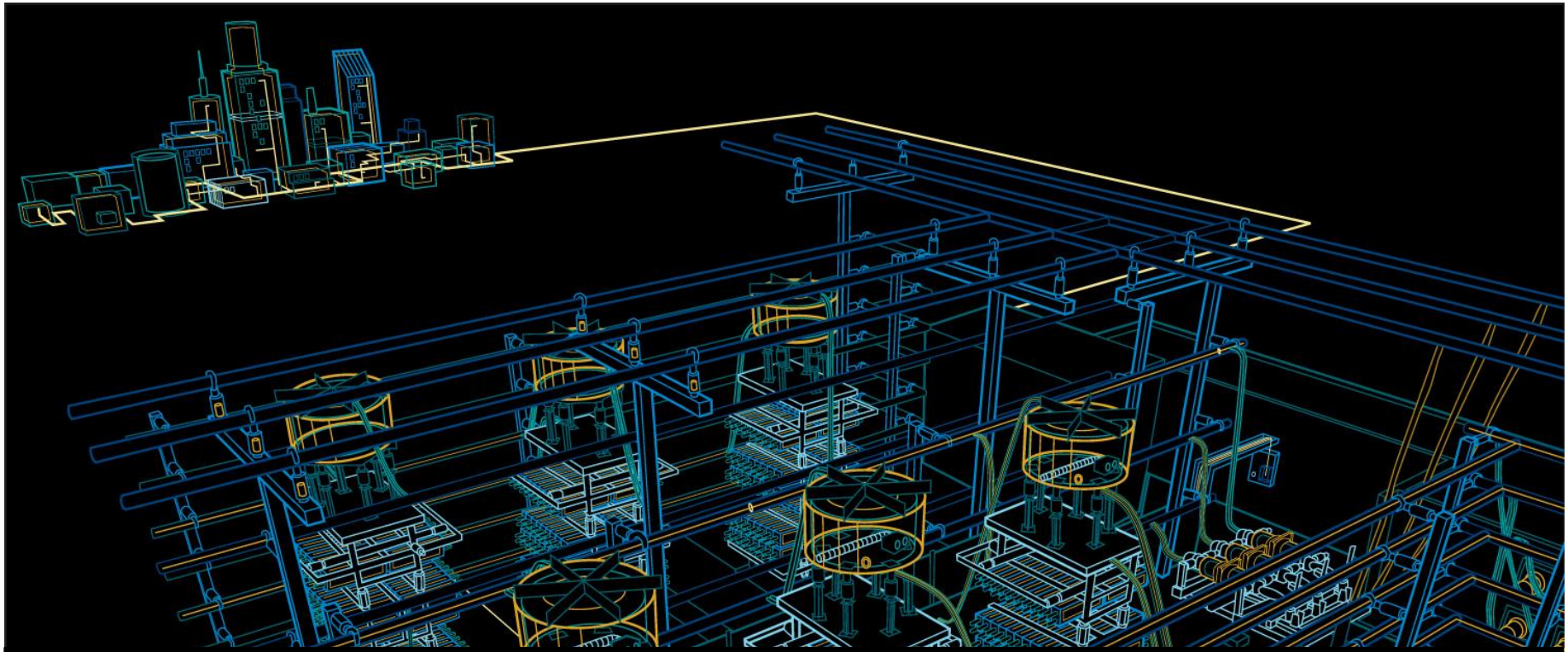
- Continuous optimization and improvement programs
- Certified personnel

Traceability through Electronic control cards

- Order no., part no., batch no., operator's name etc. stored at each workstation through barcode system

Extremely low failure rate for capacitor units

Quality ensured by most modern optimized production process

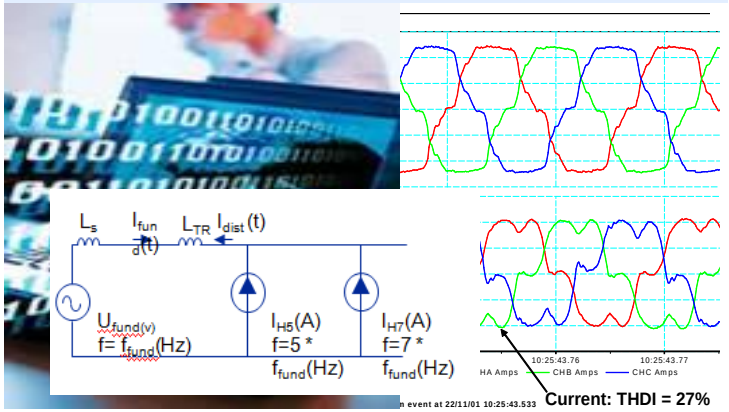


Power Factor Compensation
ABB MV & HV Product Portfolio

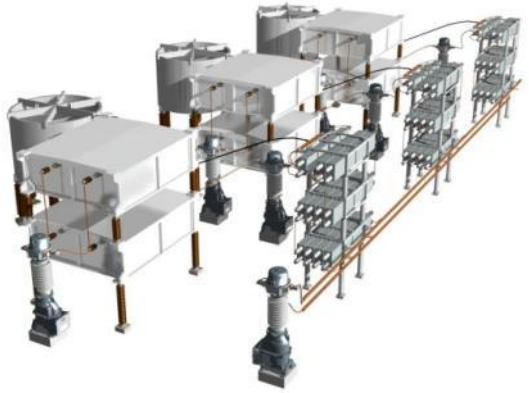
ABB Capacitors
Product Scope

Measuring

Harmonic Analyses / Calculations



Solution



Product delivery

Measuring

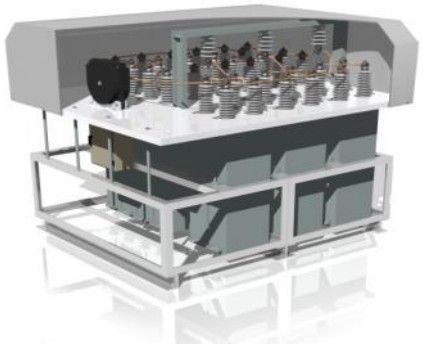
Education

We can meet all customer needs

ABB MV & HV Capacitors Portfolio
Capacitor units: HiQ capacitors for all applications

Capacitor unit types	
Internally fused units	
▪ Unit voltage range:	1-15 kV
▪ Reactive power range:	300-1200 kvar (50 Hz)
Externally fused units	
▪ Unit voltage range:	2.4 – 25 kV
▪ Reactive power range:	100 – 500 kvar (50 Hz)
ABB fuseless units	
▪ Unit voltage range:	12 – 25 kV
▪ Reactive power range:	300 – 1200 kvar (50 Hz)

ABB MV & HV Capacitors Portfolio
Medium voltage enclosed capacitor banks

ABBACUS	EMPAC	SIKAP
		
1-36 kV	**1-36 kV**	**1-24 kV**

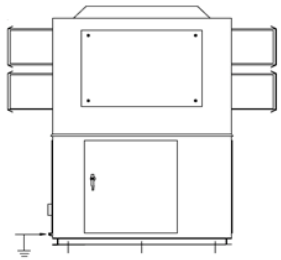
+ Control Equipment & Switchgear −

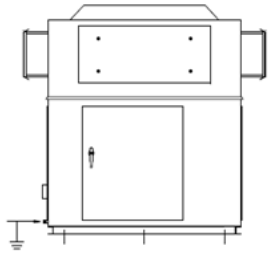
Complete with switchgear or only capacitor bank

ABB MV & HV Capacitors Portfolio
MV enclosed capacitor bank type ABBACUS

Type:	**ABBACUS** Enclosed mult-step switched cap. bank
<u>One enclosure = Several steps</u>	
Voltage Range:	Max. 36 kV
Power Range:	Up to 20 Mvar
Switching:	Yes
Protection degree:	IP65
Capacitor units:	Capacitors units equipped with internal fuse and discharging resistor.
Connection	Single or Double Star
Installation:	Indoor/Outdoor
Temperature range:	-50 to +55 ℃ (up to 24 kV) -10 to +55 ℃ (36 kV)
Delivered with all internal electrical wiring between capacitors; CT and reactors (if included) pre connected / factory assembled	

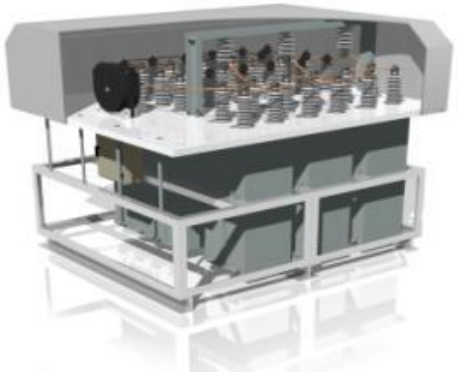
ABB MV & HV Capacitors Portfolio
MV enclosed capacitor bank type EMPAC

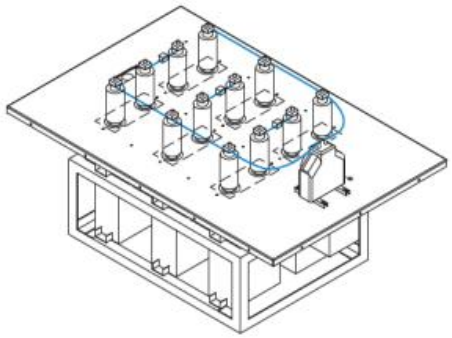




Type:	**EMPAC** Enclosed switched MV Capacitor Bank
<u>One enclosure = One step</u>	
Voltage range:	Max. 36 kV
Power & Voltage range in <u>one single step;</u>	▪ Up-to 24 kV – 1 level: 7.2 Mvar ▪ Up-to 24 kV – 2 levels: 10.8 Mvar ▪ 24 to 36 kV – 2 levels: 14.4 Mvar
Switching:	Yes (Optional)
Protection degree	IP 44
Capacitor units:	Capacitors units equipped with internal fuse and discharging resistor.
Connection:	Double star
Installation	Indoor or Outdoor
Temperature range:	-25 to +40℃
Delivered with all internal electrical wiring between capacitors; CT and reactors (if included) are pre-connected/factory assembled	

ABB MV & HV Capacitors Portfolio
MV enclosed capacitor bank type SIKAP





Type:	**SIKAP** Enclosed MV non-switched capacitor bank
One enclosure = One step	
Voltage Range:	4.5 - 24 kV
Power Range:	Up to 18 Mvar
Switching:	No
Protection degree:	IP44
Capacitor units:	Capacitors units equipped with internal fuse and discharging resistor.
Connection	Single or Double Star
Installation:	Indoor/Outdoor
Temperature range:	-40 to +40℃
Origin:	Sweden
Delivered with all internal electrical wiring between capacitors, CT and reactors (if included) pre-connected/factory assembled	

ABB MV & HV Capacitors Portfolio
MV & HV Product Range: Main ratings





	ABBACUS	EMPAC	SIKAP	Q-POLE	Q-BANK
	MV Metal enclosed capacitor banks Control equipment and switchgear			Pole-mounted MV bank	MV & HV open-rack capacitor banks
Application: var compensation Harmonic filtering Installation	 Yes Yes (1) Indoor & outdoor	 Yes Yes (2) Indoor & outdoor	 Yes Yes (2) Indoor & outdoor	 Yes No Outdoor	 Yes Yes Indoor & outdoor
Frequency	50 and 60 Hz	50 and 60 Hz	50 and 60 Hz	50 and 60 Hz	50 and 60 Hz
Voltage	Up to 36 kV	Up to 36 kV	Up to 24 kV	Up to 36 kV	Up to 800 kV
Max. total reactive power @50 Hz	20 Mvar	14.4 Mvar	18 Mvar	3.6 Mvar	Undefined (limited by design)
Multi-step **Max. power per step**	Yes (Up to 8) Up to 5 Mvar	No -	No -	No -	No -
IP	65	44	44	00	00
Temperature range	-50 to +55 ℃	-25 to +40 ℃	-40 to +40 ℃	-50 to +55 ℃	-50 to +55 ℃
Applicable standards	IEC 60871-1, IEC 60871-4, IEEE 18, Others on request				

1) Mostly for detunned filtering, in order to prevent resonance issues. Small tunned filters can also be used, mostly with filter buliding blocks (reactors and resistors) installed separated and not in the enclosure.
2) Can be used for tunned filters with filter buliding blocks (reactors and resistors) installed separated and not in the enclosure.

ABB MV & HV Capacitors Portfolio
MV & HV Product Range: Main features & accessories





		ABBACUS	EMPAC	SIKAP	Q-POLE	Q-BANK
		MV Metal enclosed capacitor banks Control equipment and switchgear			Pole-mounted MV bank	MV & HV open-rack capacitor banks
Switched multi-step bank		●				
Relays	**var**	●	●		●	
	Protection	●	●		●	
	Unbalance	●	●	● (1)	● (1)	● (1)
Switching	**Contactors & switches**	● (1 per step)	● (1 per bank)		● (1 per bank)	● For HV only
	Circuit breaker & accessories	● (1 per step)	● (1 per bank)			
MV fuse-link protection		●			●	
Earthing switch		●	●			
Reactors	**Inrush**	●	●	●	●	●
	Detuned	●				●
	Filter	● (1)	● (1)	● (1)		●
Instrument Transformers	**Unbalanace CT**	●	●	●	●	●
	Protection CTs	●	●			
	Protection VTs	●				
	Rapid-discharge VT's	●	●	●		●

(1) Supplied loose and installed separately

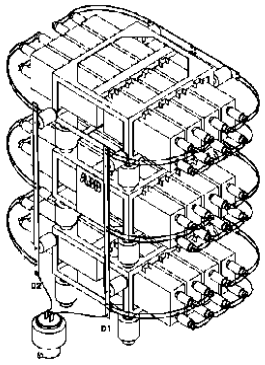
ABB MV & HV Capacitors Portfolio
Pole-mounted MV capacitor bank

Type:	**Q-POLE** Pole mounted capacitor bank
Voltage Range:	Up to 36 kV
Power Range:	Up to 3.6 Mvar
Switching:	Yes
Protection degree:	IP00
Capacitor units:	Capacitors units equipped with discharging resistor.
Connection:	Designed from voltage and system grounding
Installation:	Outdoor
Temperature range:	-50 to +55℃
Delivered with all electrical wiring between capacitors; Controller, CS, PT and reactors (if included) are pre-connected/factory assembled	

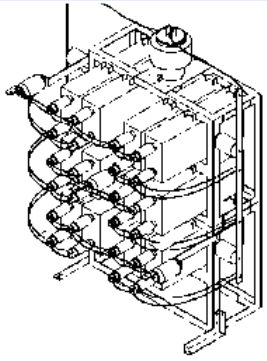
ABB MV & HV Capacitors Portfolio
MV & HV open-rack capacitor bank type QBANK

Type:	**QBANK** Open-rack capacitor bank
Voltage Range:	1 - 800 kV
Power Range:	0.5 - 300 Mvar
Structures	Hot-dip galvanized steel, copper bars and wires, porcelain support insulators
Mechanics	Designed for wind, snow, seismic requirements, etc.
Connection:	Designed from voltage and system grounding
Temperature range:	-50 to +55℃
Installation:	Indoor or outdoor, side-by-side or stacked
Delivered mounted and connected as far as possible in the factory (excluding support insulators)	

QBANK-A



QBANK-B



QBANK-C

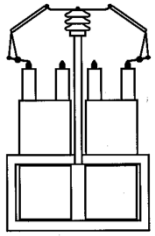
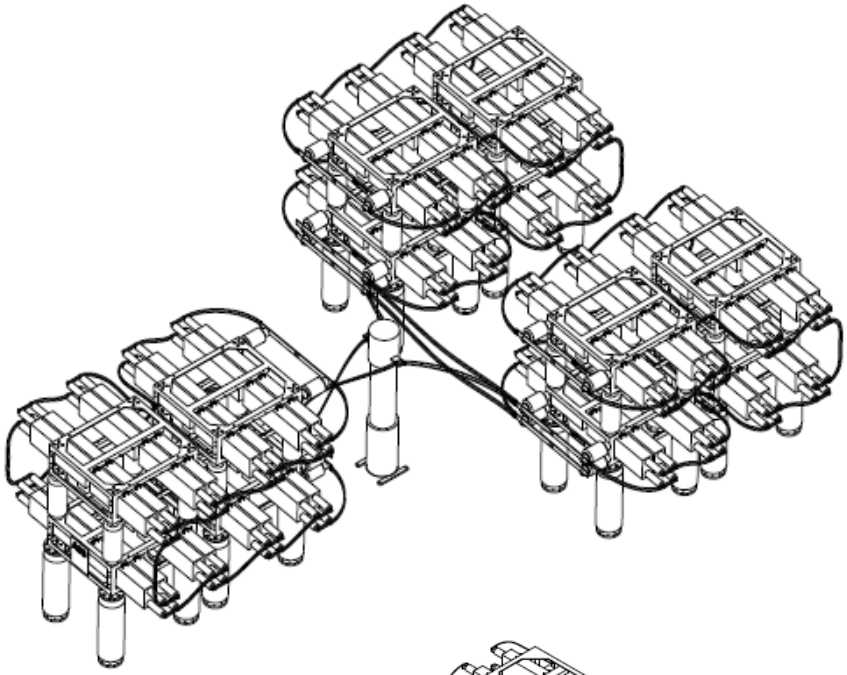
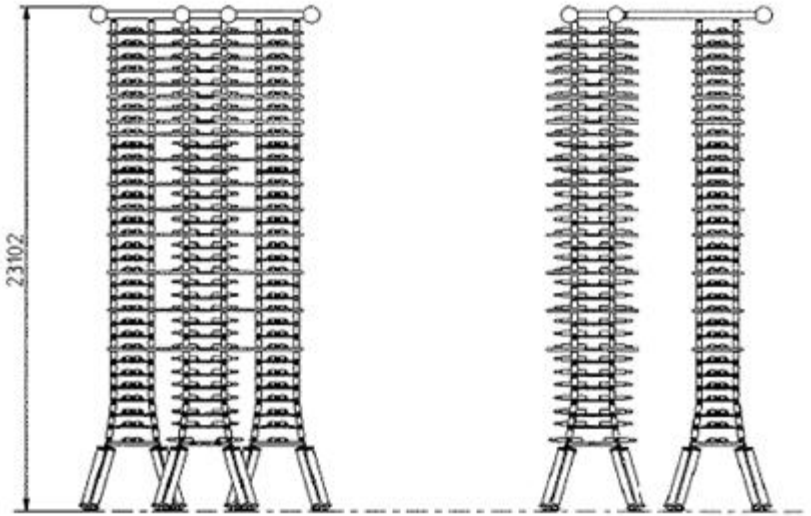
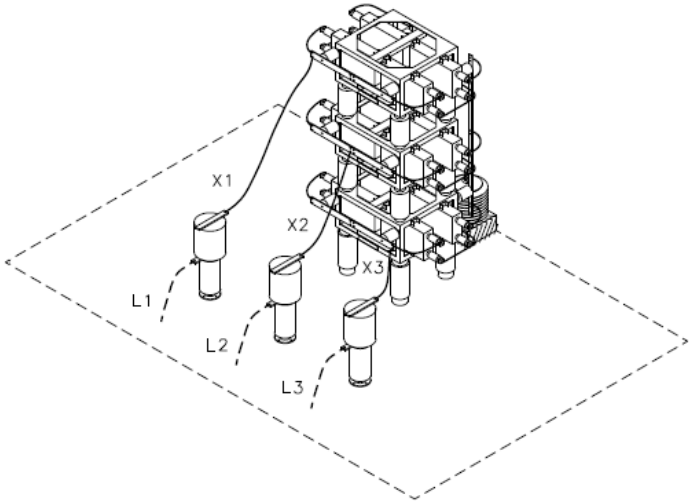


ABB MV & HV Capacitors Portfolio

MV & HV open-rack capacitor bank type QBANK







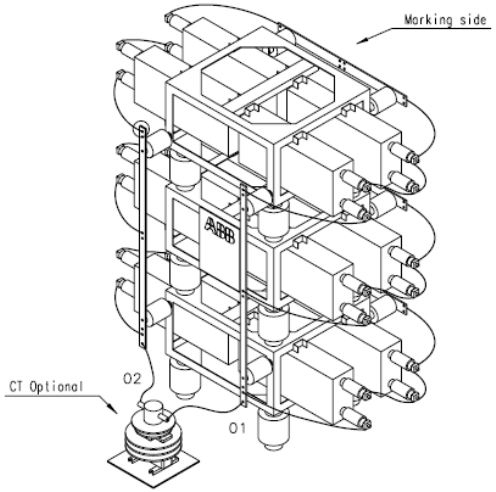
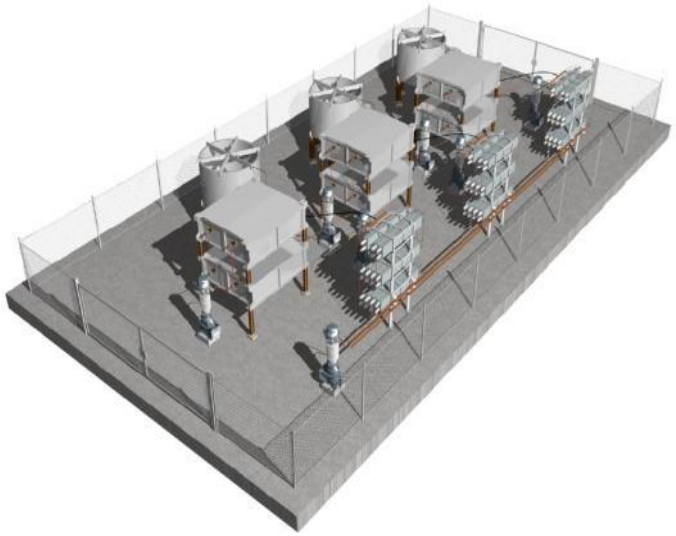


ABB MV & HV Capacitors Portfolio
Harmonic filters type CHARM



Type: CHARM

Tuned or detuned design:

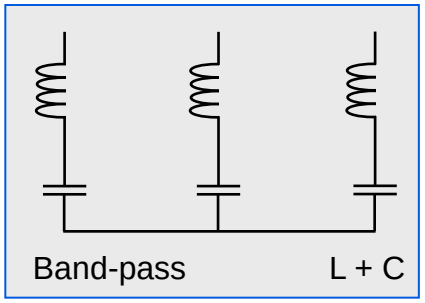
- **Tuned filters:** Suitable when source of harmonics, and harmonic content is well defined
- **De-tuned filters:** Suitable when harmonics originate from many sources, and many harmonic frequencies are present

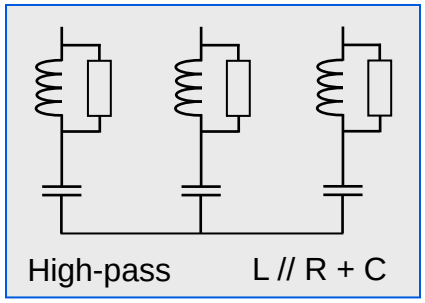
Band-pass, High-pass or C-type filters

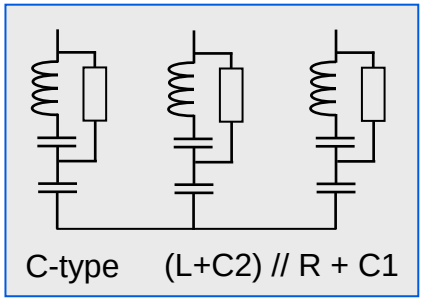
Voltage Range: 1 - 800 kV

Power Range: Defined by needs

Temperature range: -50 to + 55 ℃

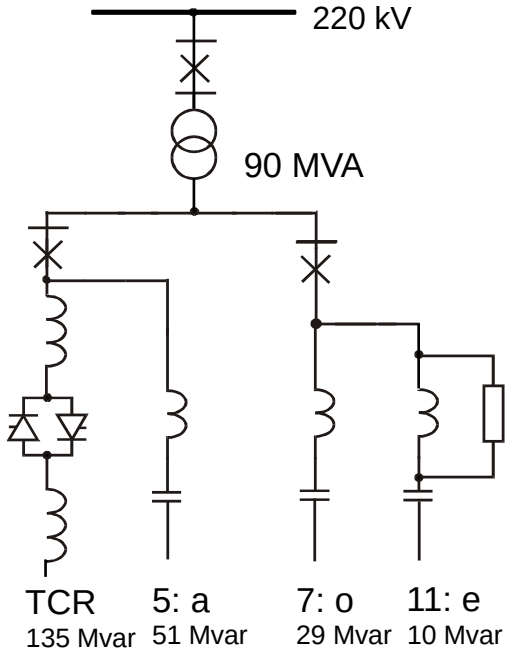






(filter with extra low fundamental losses)

ABB MV & HV Capacitors Portfolio
Dynamic compensation: SVC



SVC

With dynamic compensation following additional features will be achieved:

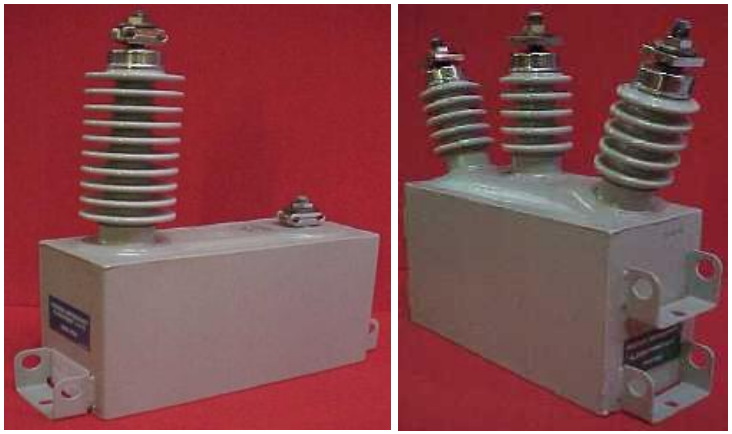
- Fast voltage fluctuation (Flicker)
- Phase asymmetric loads
- Continuous power factor control

Typical application is fast changing loads

These applications need SVC

Power Range: Defined by needs

ABB MV & HV Capacitors Portfolio
Surge capacitors and motor surge protection



Surge capacitor
1 phase or 3 phases

Motor Surge Protector (MSP)
Includes surge capacitor and surge arrester

Surge Capacitors & MSP

Protection against power surges, switching transients, faults, and lightning strikes mainly for critical industrial loads:

- Large Motors and generators;
- Large transformers;
- MV switchgear and motor control centers

The primary function of the Type MSP motor surge protector is to guard the winding insulation of the device being protected.

Voltage Range:	2.4 - 24 kV
Availability:	Standard units kept in stock

ABB MV & HV Capacitors Portfolio
Switching: Capacitor switch PS range

PS15 (15 kV) → PS36 (36 kV)
Up to 400 A
ABB vacuum interrupter technology
Magnetic actuator
Mechanical or electrical latching
NO oil, gas or foam
Maintenance free
Hydrophobic ‘cycloaliphatic’ epoxy (HCEP) resin insulator

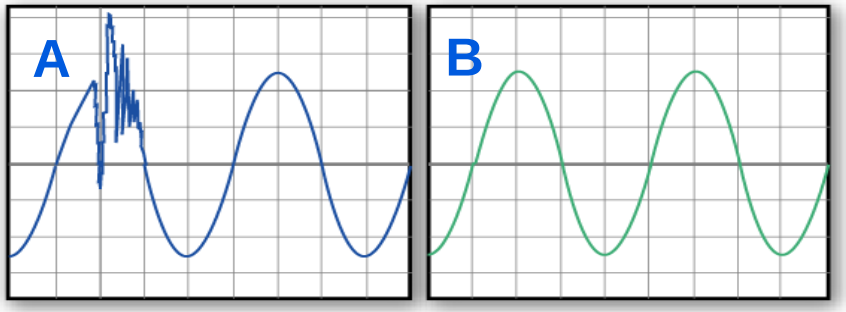
ABB MV & HV Capacitors Portfolio
Capacitor Switch: CQ900 range

CQ900 Range
User friendly interface
Extensive range of control modes
Measurement & monitoring
Data logging
Protection
Communication: DNP3, IEC 61850
Easy programming & commissioning
Durable IP54 power coated stainless steel enclosure

ABB MV & HV Capacitors Portfolio
Synchronized switching: Switchsync™ relays

Switchsync Range
Controlled switching of the capacitor bank breaker gives efficient reduction of the switching transients
Well proven Switchsync™ controllers
ABB's circuit breakers are well suited
Damping reactors are normally superfluous

Voltage transients when energizing one phase of a 72 kV capacitor bank



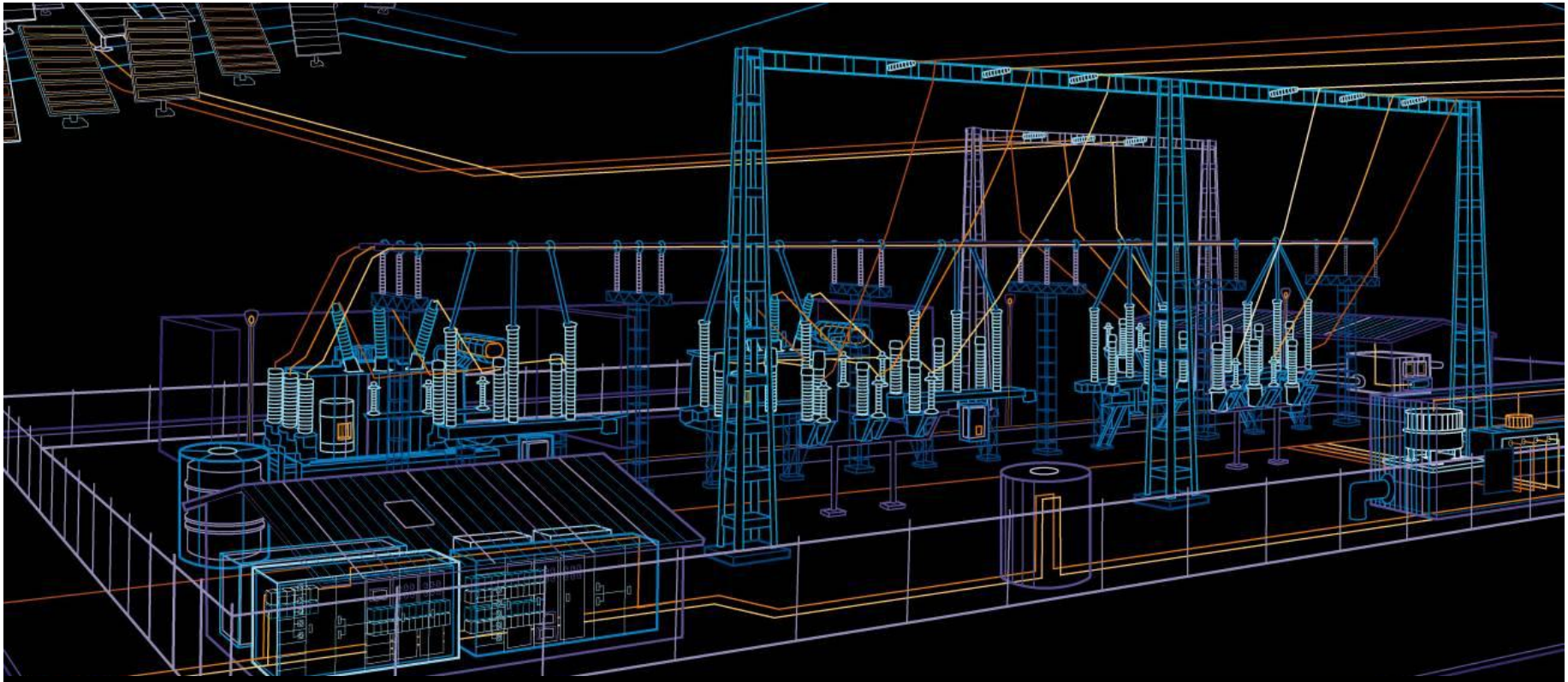
A: Energizing close to the power frequency voltage peak. A high voltage transient is generated

B: With Switchsync™ relay. Energizing close to voltage zero. The transient is considerably reduced

Energizing of capacitor banks and harmonic filters may cause severe inrush currents and voltage oscillations

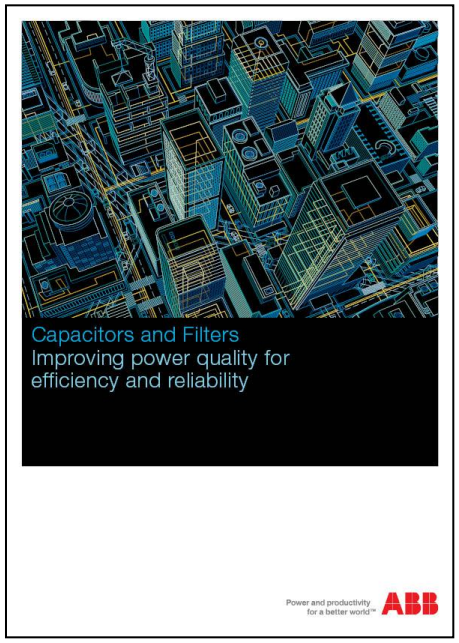
ABB MV & HV Capacitors Portfolio
Metering & Maintenance: CB2000

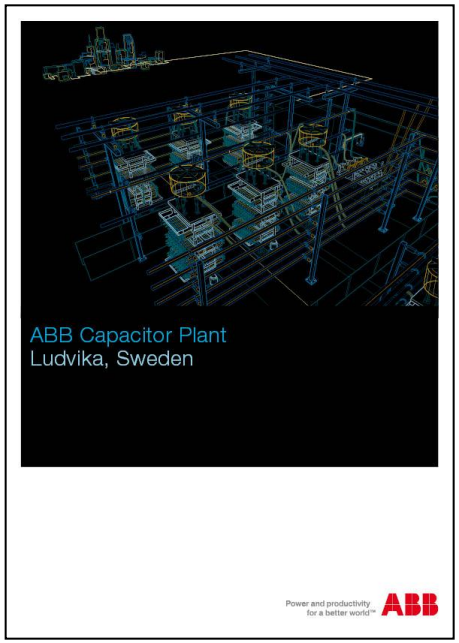
Capacitance Bridge Type CB2000
Developed for capacitor measurements in HV capacitor banks
Easy to use and handle
Data collection & storage
No disconnections in the bank
Shorter service operations
No disconnections required in the capacitor bank during measurement



High Voltage Capacitors
Documentation

Documentation
Catalogues





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