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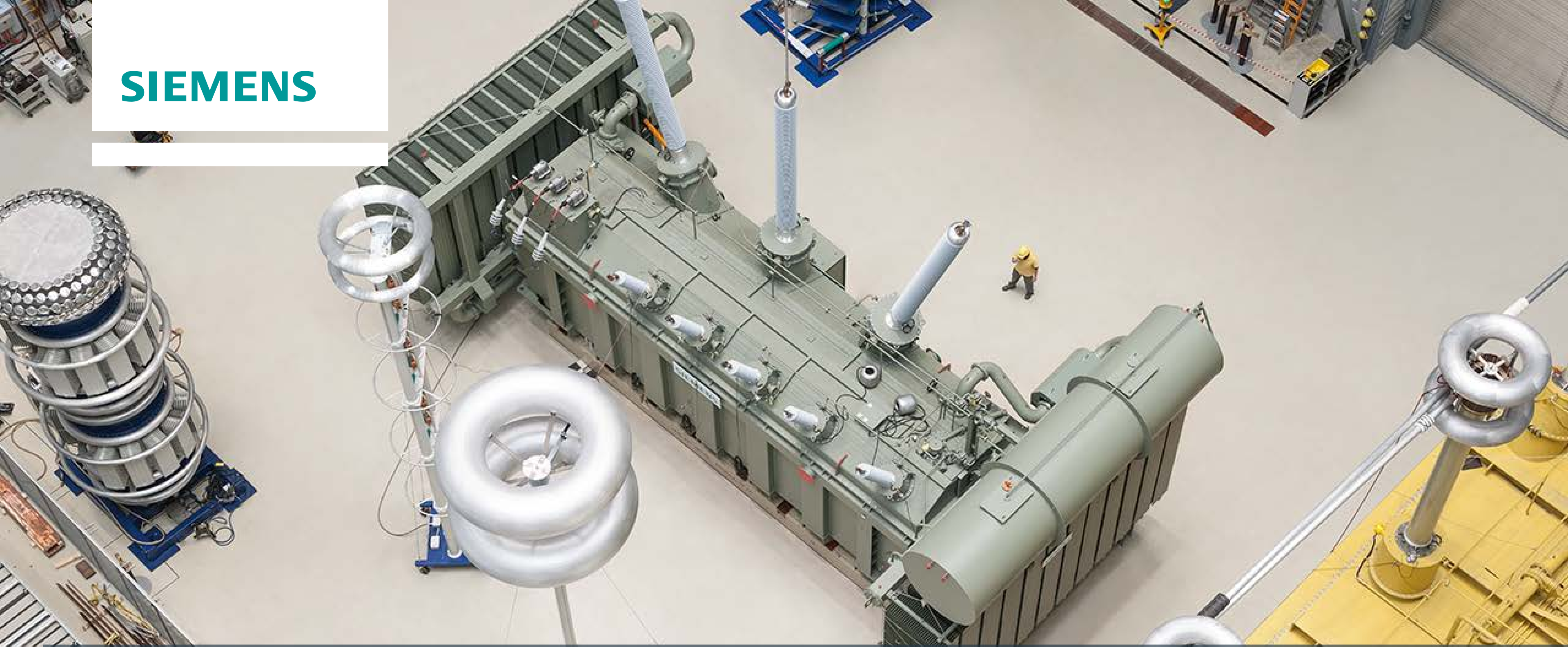

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Feasibility study of the maximum possible regulation range of a 735kV – 110Mvar single phase shunt reactor utilizing an on-load tap-changer

Capacitive reactive power in power grids

The capacitive reactive power generated in electrical power grids increases

- with the voltage level
- with the length of the power lines

Moreover, the application of underground cables or submarine cables for offshore applications results in increased capacitive load currents

Compensation of capacitive reactive power

Shunt reactors are widely used in order to compensate reactive power, control the power frequency voltage and keep line losses low.

A solution to compensate different load cases is to switch in and out several fixed shunt reactors.

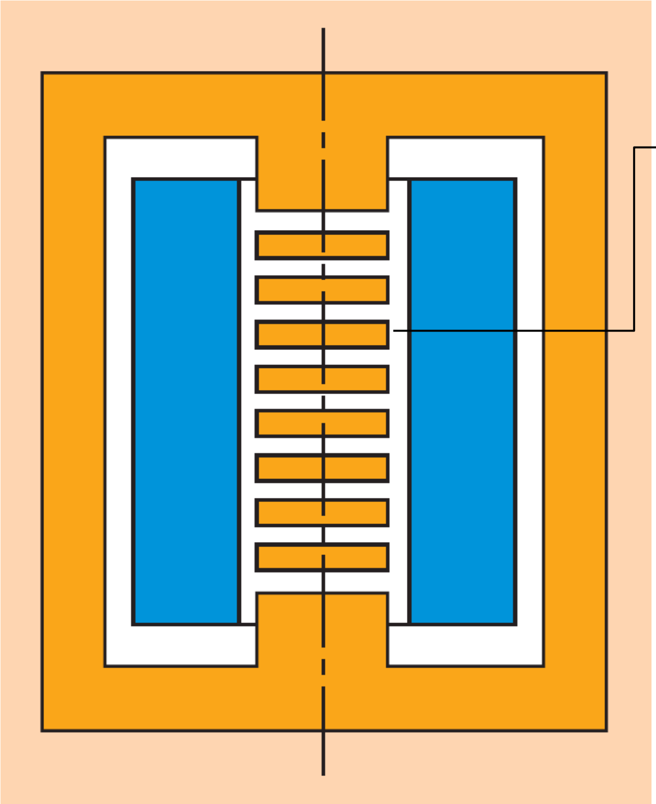
Moreover variable shunt reactors can be used in order to match the compensation to the load case.

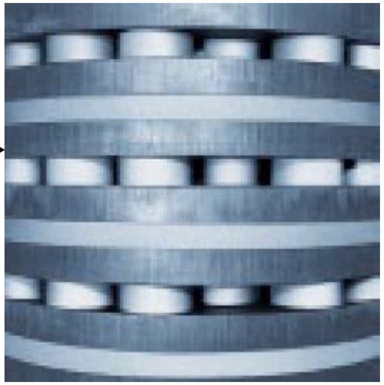
Advantages of variable shunt reactors

Compared to several fixed shunt reactors a VSR has some advantages:

- Smaller discrete steps of reactive power achievable
- Smaller footprint in substations
- Less circuit breakers needed
- Reduced frequency of circuit breaker operation

General design of gapped –core shunt reactors





Cross-sectional-area of the windings

Core (limb, yokes and return limbs)

$$W = \int \frac{B^2}{2 \cdot \mu_0} dV \qquad L = \frac{2 \cdot W}{I^2}$$

W = stored magnetic energy V= volume

B = magnetic flux density

I = peak value of current through reactor

Variable reactive power due to changing number of turns

$$L = \frac{N^2}{R_m}$$

Since L~Q, the reactive power can be adjusted by changing the number of turns

Reactance does not vary exactly with the second power of number of turns due to effect of the winding geometry which is changing the effective reluctance

Limitation of regulation range

The element which is limiting the regulation range of a variable shunt reactor is the on-load tap-changer (OLTC).

For example, some of the limiting parameters are:

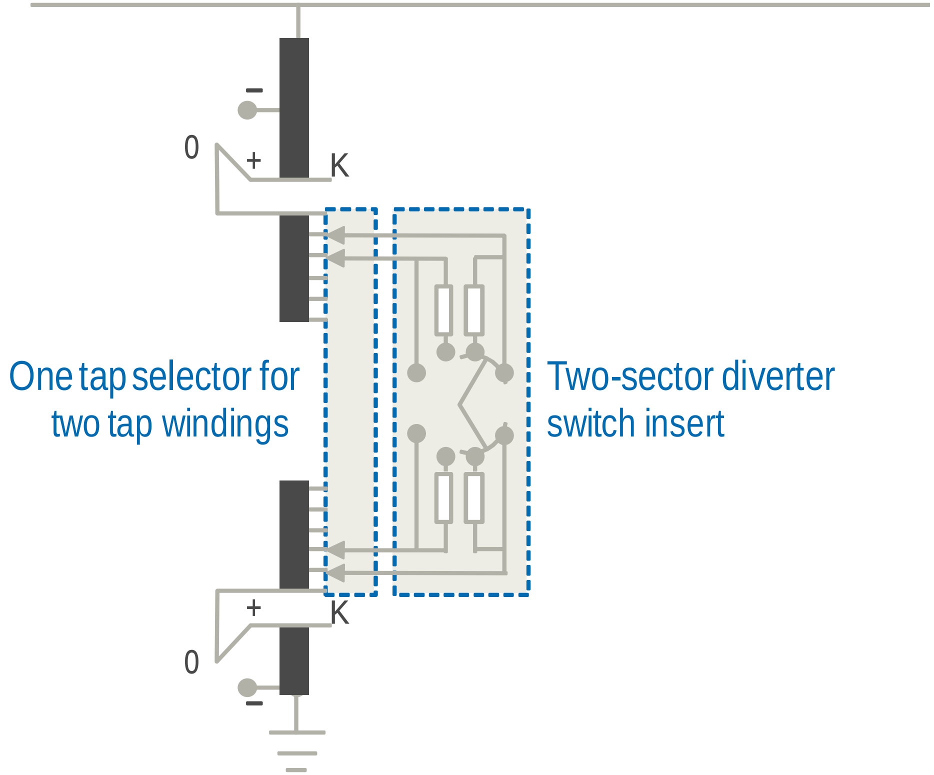
- Maximum permissible voltages across internal insulating clearances
- Maximum switching capacity
- ….

Limitation of regulation range

Using standard on-load tap-changers (coarse-fine or reversing regulation):
The regulation range is limited to approximately 35% - 40% ($U_{max} = 800kV/\sqrt{3}$)

Theoretically up to 60% regulation range is possible with the limitations of the newly developed advanced OLTC

Principle of advanced On-load Tap-changer



Coarse fine regulation is chosen due to less losses. The possible effective step-voltage is doubled due to introduction of a second coarse and fine winding.

Main performance data of fixed and variable shunt reactor

Voltage line to ground	U_r = 735 kV / √3
Max. voltage line to ground	U_m = 800 kV / √3
Rated power	S_r = 110 MVAr
Rated frequency	f_r = 60Hz
Rated current at max. power	I_r = 259.2A
Max. continuous current at U_m	I_{max}= 282.1 A
Connection diagram	i
Rated inductance	L_r= 4.3424H +/- 2.5%
Linearity	150%
Cooling type	ONAN

Main performance data of fixed and variable shunt reactor

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Line terminal insulation levels:

Maximum system voltage	800 kV
Lightning impulse level (BIL)	1950 kV
Chopped wave level	2145 kV
Switching impulse level	1550 kV
Low frequency overvoltage test (phase to ground, one hour level)	750kV

Neutral terminal insulation levels:

Lightning impulse level (BIL)	350kV
Low frequency overvoltage test	140kV

Additional data on VSR design:

Control unit	OLTC
Reactive power at min. turn position (at 735kV)	110 MVAr

Based on this data, two reactor designs are drafted and later on compared:

1. A fixed rating shunt reactor
2. A variable shunt reactor using the advanced OLTC

Fixed parameters for comparison

As a a base for comparison

- losses (at maximum power tap position in case of variable shunt reactor) are kept constant for both designs
- Moreover the same core diameter and gap dimensions is used

Achieved regulation range of the variable shunt reactor

In this particular case the maximum possible regulation range is not anymore restricted by the tap-changer (theoretically 60% possible).

It is limited by the chosen UHV-Design of the variable shunt reactor (50%).

Achieved regulation range of the variable shunt reactor

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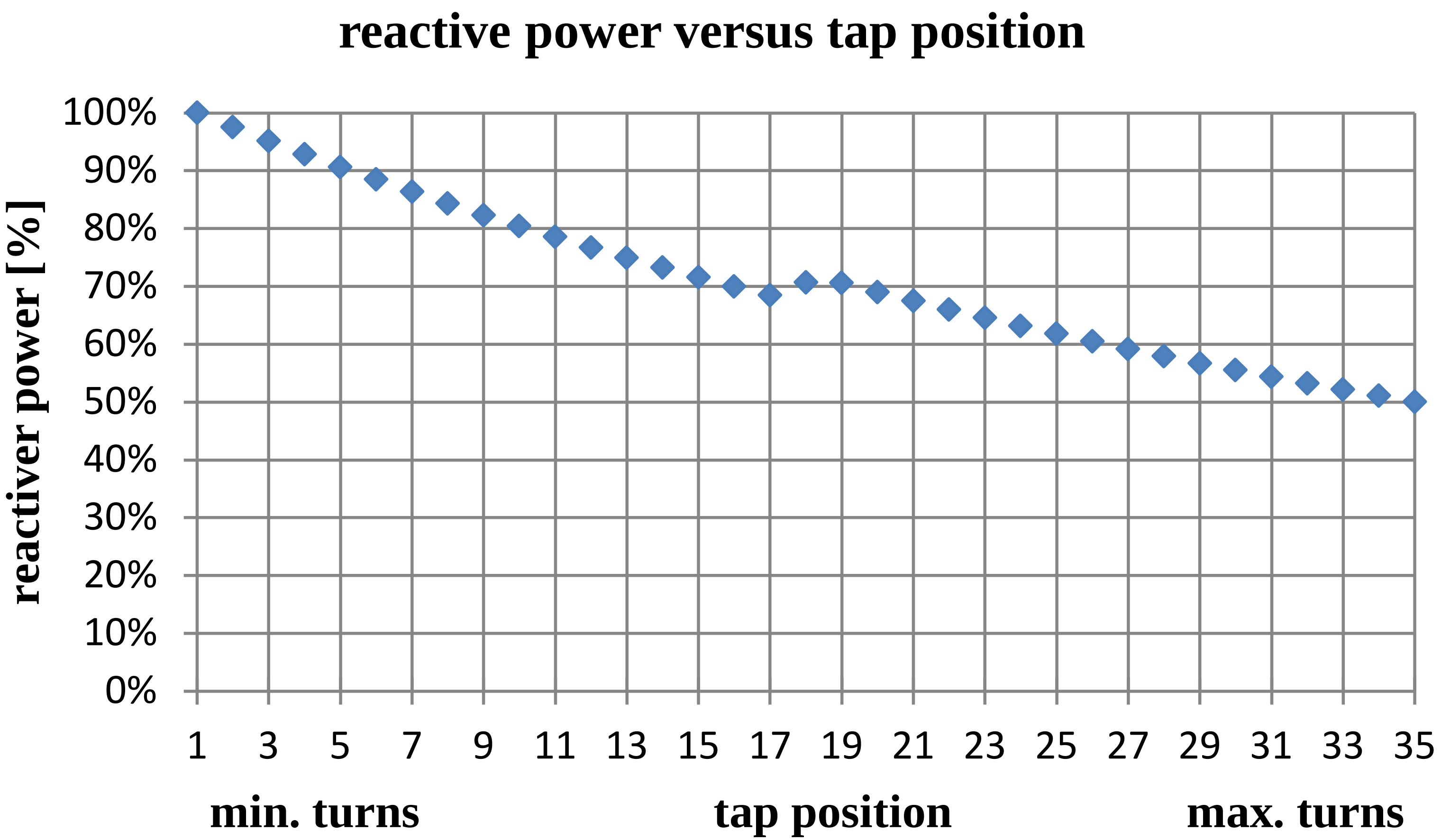
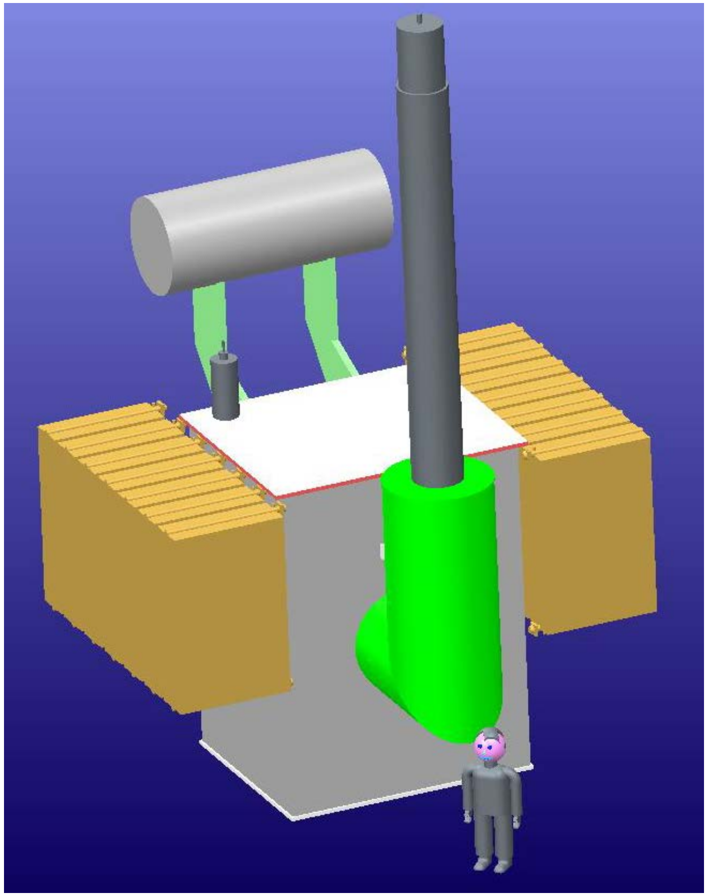


Comparison of fixed / variable shunt reactor design

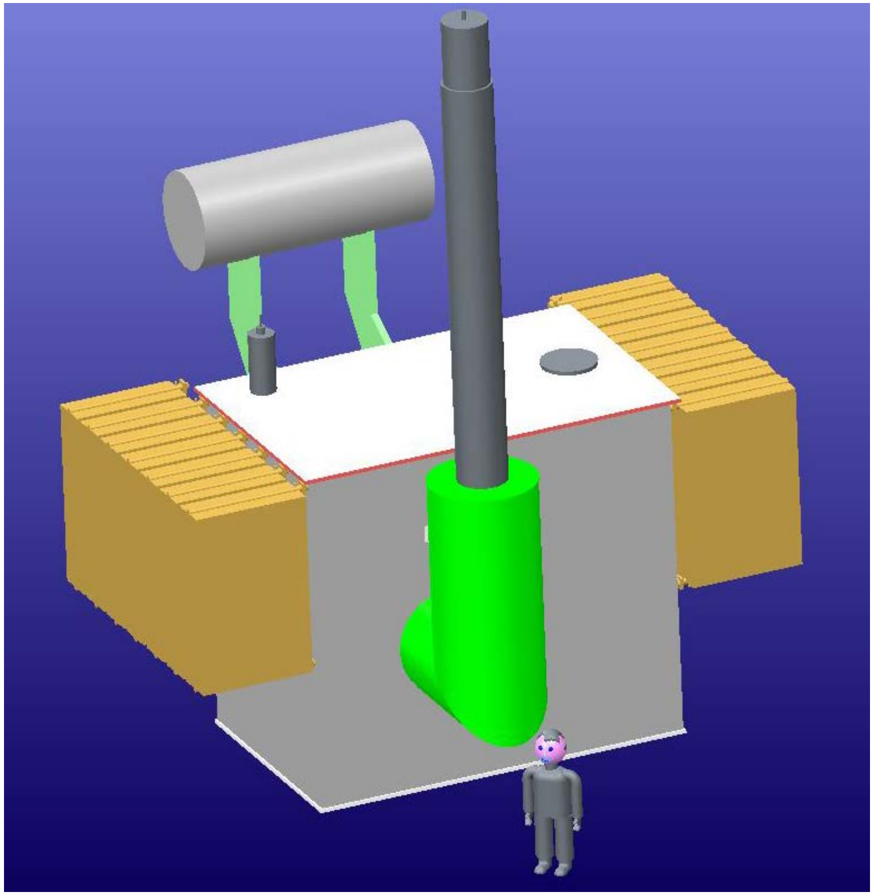
	Fixed shunt reactor	Variable shunt reactor	Ratio (variable / fixed)	Difference (variable – fixed)
Total mass	132 t	190 t	1.44	58 t
Total losses @ 85° C and Ur	188 kW	188 kW	1.00	0 kW
Sound power level	~102 dB (A)	~102 dB (A)	-	-
Tank length [1]	3890 mm	5610 mm	1.44	1720 mm
Tank width [1]	3340 mm	3760 mm	1.13	420 mm
Tank height	4528 mm	4578 mm	1.01	50 mm
Approximate footprint [2]	43.5 m^2	58.3 m^2	1.34	14.8 m^2

[1] including stiffeners, [2] including turrets, compensator, radiators

Visualization of fixed and variable shunt reactor in simplified 3D models



Fixed rating shunt reactor



Variable shunt reactor

Conclusions

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- 50% regulation range (110MVAr-55MVAr at rated voltage of 735kV/√3) achieved with this particular design

Compared to solutions using several fixed rating shunt reactors a VSR has following advantages:

- Smaller discrete steps of reactive power
- Smaller footprint in substations
- Less circuit breakers needed
- Reduced frequency of circuit breaker operation

Thank you for your attention!