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**Static Frequency Converters for  
Factory and Field Testing of Power  
Transformers by Induced Voltages**



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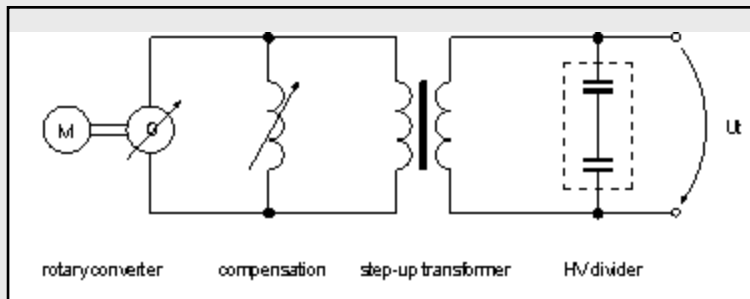
Germany

USA

# 1. Why Frequency Converters instead of Motor/Generator Sets ?

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## M/G based test system



Traditionally applied for stationary application, long experience;

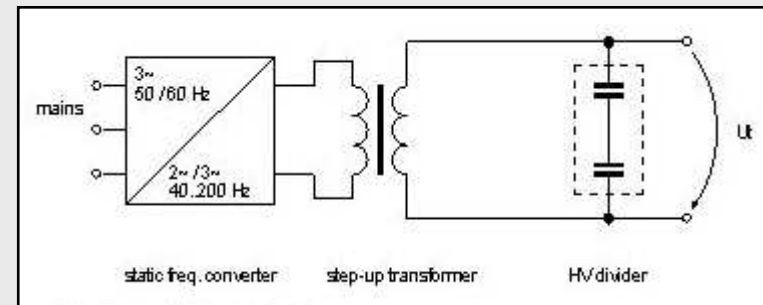
Two-frequency M/G set or two separate sets;

Control also by means of power electronics, dynamics by the machines

Heavy machines for stationary application;

Special machines, difficult to get on the market; remarkable prices which may increase in the future.

## FC based system



Progress in power electronics enabled development, less experience till now;

Frequency can be adjusted (e.g. 40...200Hz, quartz-stable);

Excellent dynamic behavior, application of advanced control features;

Relatively lightweight and compact, optimum for on-site application;

With further development of power electronics even a reduction of price can be expected.

## 2. Basic Problems: Sinusoidal Waveshape and Low PD Noise Level (1)

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Frequency converters for drives are controlled according to a sinusoidal current, which means the waveshape of the voltage is not so important.



In HV testing and especially in loss measurement a sinusoidal voltage is required (IEC 60060-1, IEC 60076-3) –

**necessary development of voltage controlled FC based on power transistors (IGBT).**

The IEC/IEEE Standards require a total harmonic distortion of

$$\text{THD} \leq 5\%,$$

The PD measurement shall be made down to

$$q \approx 20 \text{ pC}$$

which requires a PD basic noise level

$$q_n \approx 10 \text{ pC.}$$

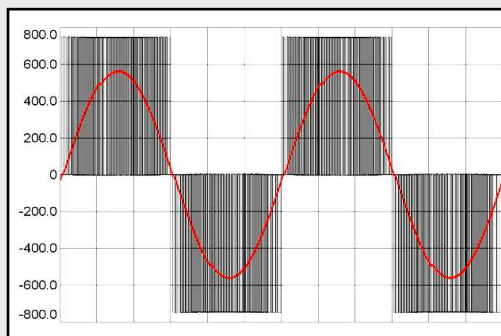
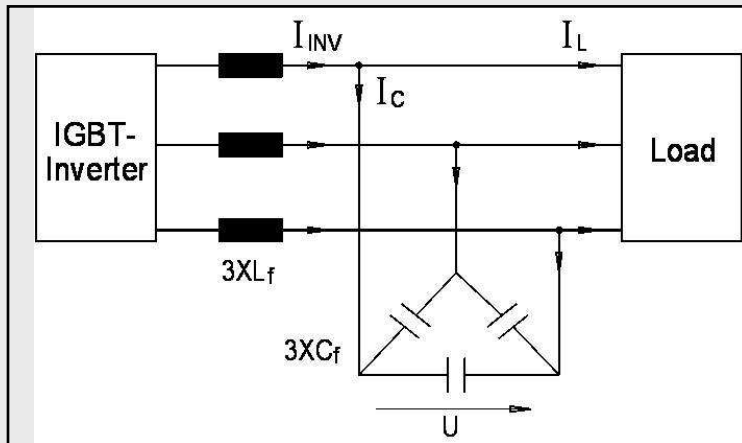


Low THD means a large number of switching impulses of the IGBT's, but low PD basic noise level means a low number of switching pulses –

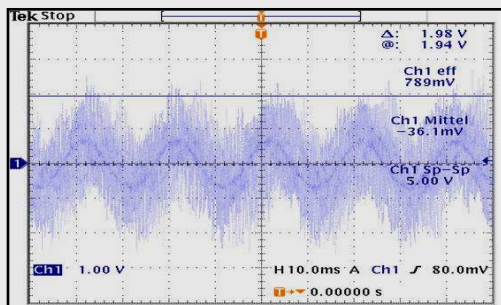
**necessary development of a FC which realizes the balance between THD and PD noise level.**

**Some results of these developments are shown on the following transparencies.**

## 2. Basic Problems: Sinusoidal **Waveshape** and Low PD Noise Level (2)

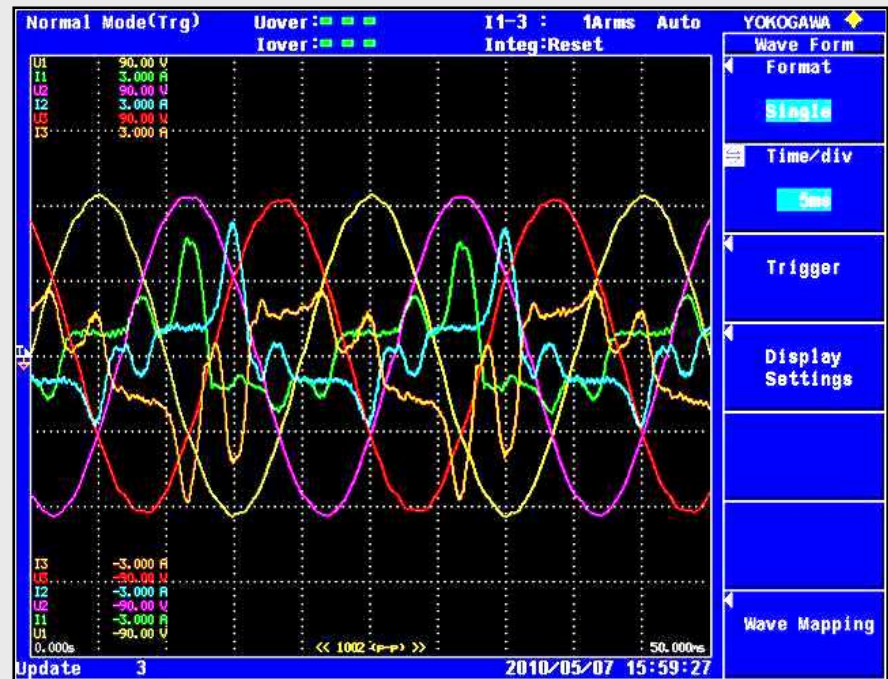


**Symmetric disturbances** by pulsed output voltage (red: fundamental wave)



**Asymmetric disturbances to ground**

A sinusoidal waveshape within the IEC/IEEE requirements  $THD \leq 5\%$  can be guaranteed by internal filters in the FC and an external power sine wave filter acting against both types of disturbances.



No-load test: Voltage of  $THD=1.46\%$  at current with  $THD=69\%$ !

## 2. Basic Problems: Sinusoidal Waveshape and Low PD Noise Level (3)

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In addition to special measures in the FC itself, the application of classical **HV L-C filters** between exciter transformer and transformer under test is very useful.

**Mobile system**



**Stationary system**

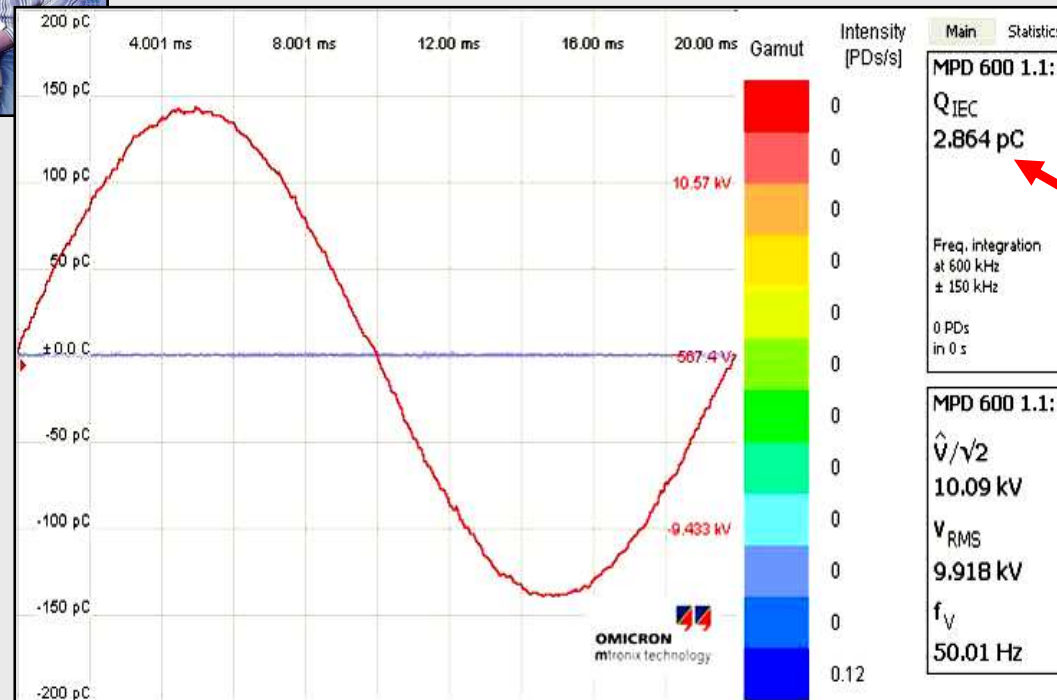


## 2. Basic Problems: Sinusoidal Waveshape and Low PD Noise Level (4)



The experience shows that industrial test labs with optimized HV test circuits can reach sufficiently low PD noise levels including test object :

$$q_n \leq 10\text{pC.}$$



3pC

## 2. Induced Voltage Tests: The Requirements and the Solution (1)

### Requirements:

Three-phase voltage

$f \geq 2 \cdot f_{\text{rated}} = 100/120 \text{ Hz}$

THD  $\leq 5\%$

PD measurement

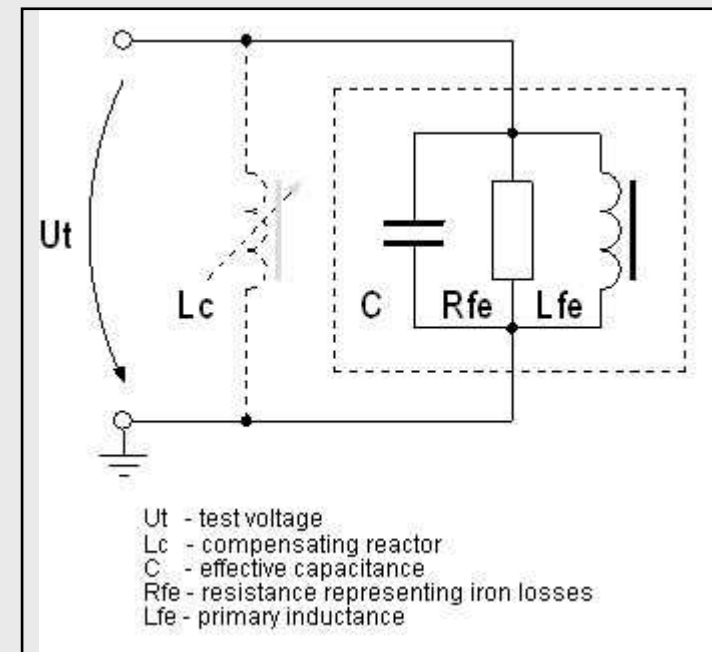
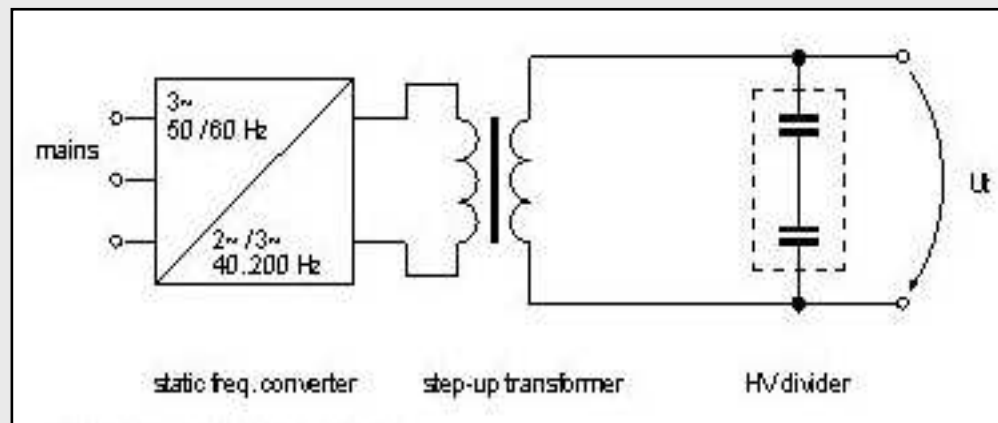
### Solution:

All requirements fulfilled, additionally:

Self-compensation is automatically adjusted;

No risk of self-excitation

Parallel connection of several systems

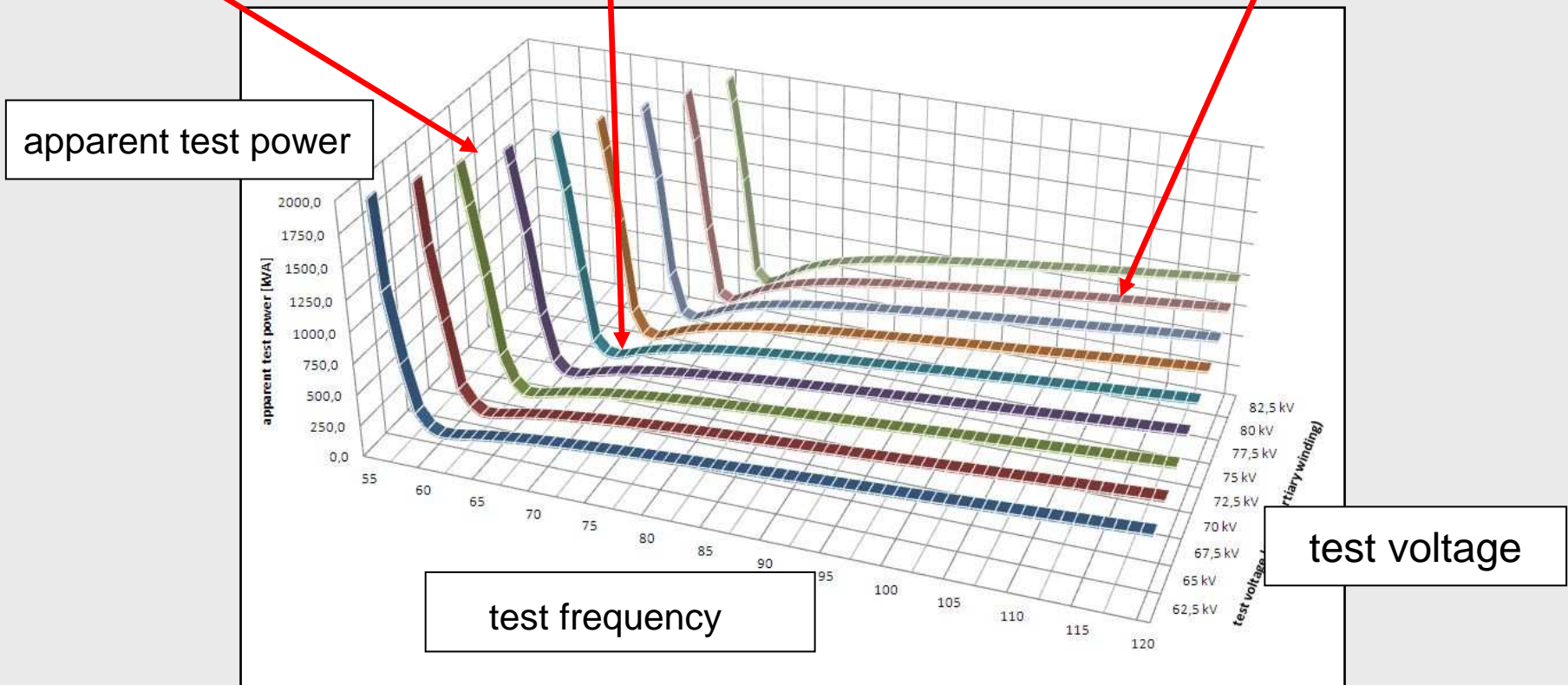


## 2. Induced Voltage Test: Test Power Demand and Frequency (2)

Behavior of transformers under induced voltage test::

at lower frequencies – inductive load; at higher frequencies – capacitive load

in between “natural frequency” of self-compensation



### 3. No-Load Loss Measurement : The Requirements and the Solution

Requirements:

Three-phase voltage

$f = 50/60 \text{ Hz}$

$\text{THD} \leq 5\%$

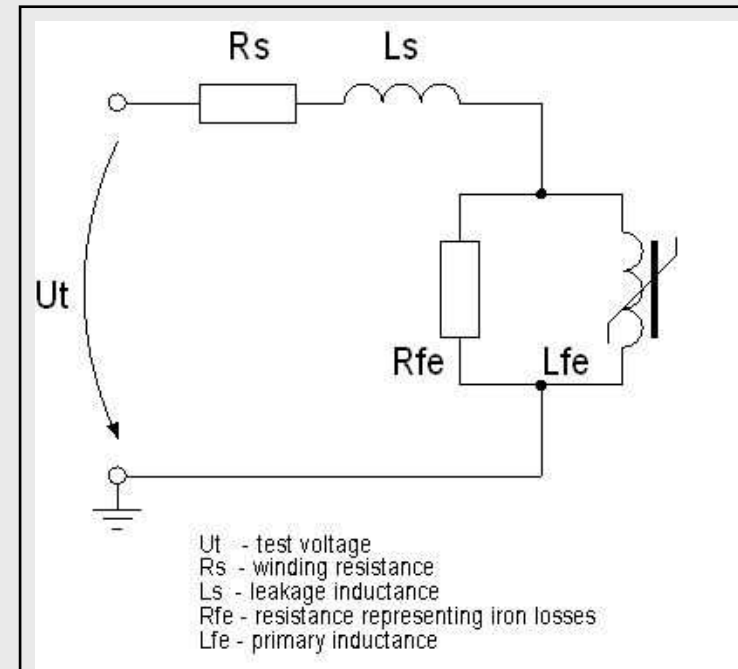
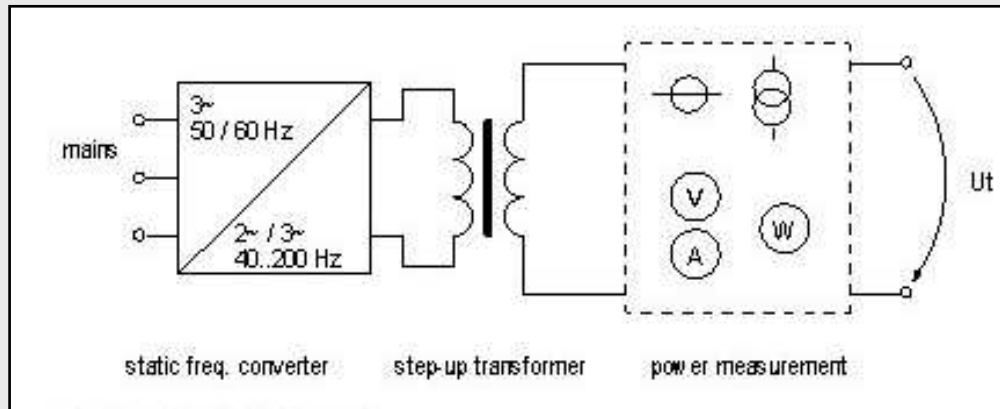
form factor (rms vs. rectified mean)  $\leq 3\%$

Solution:

All requirements fulfilled, additionally:

good dynamics due to rejection of test voltage harmonics

Parallel connection of several systems



## 4. Short Circuit Loss Measurement: The Requirements and the Solution

Requirements:

Three-phase voltage

$f = 50/60 \text{ Hz}$

$\text{THD} \leq 5\%$

form factor (rms vs. rectified mean)  $\leq 3\%$

Compensation of reactive power

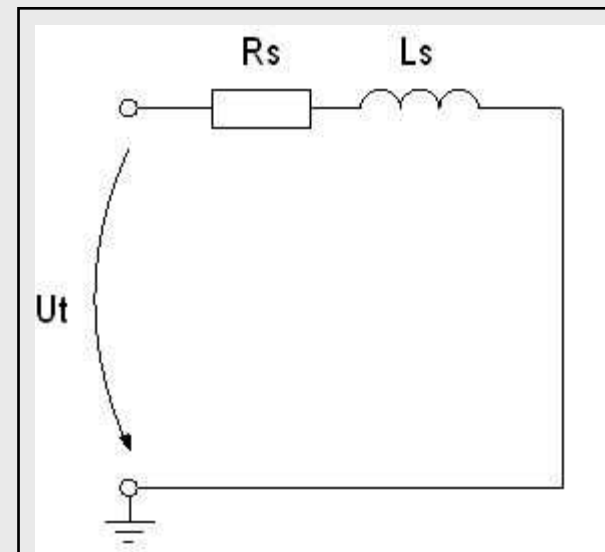
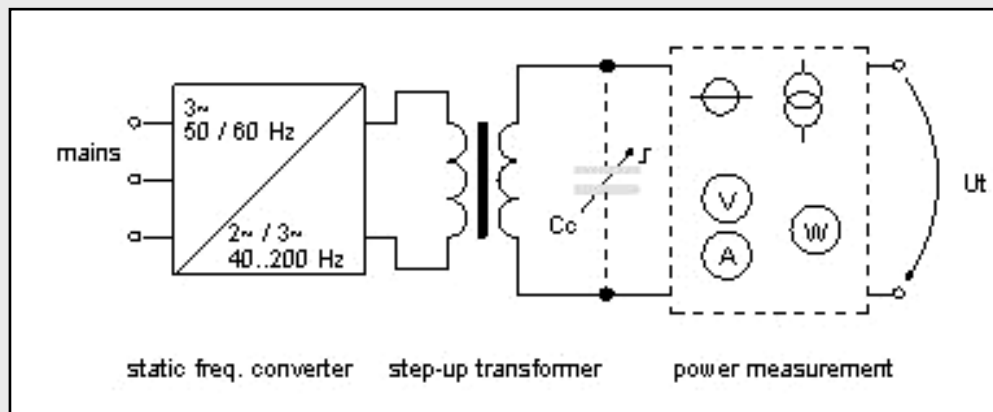
Solution:

All requirements fulfilled, additionally:

good dynamics due to rejection of test voltage harmonics

Parallel connection of several systems

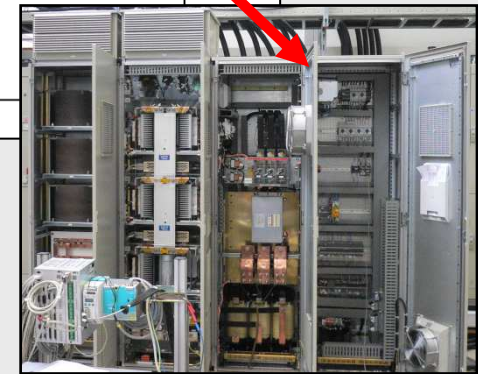
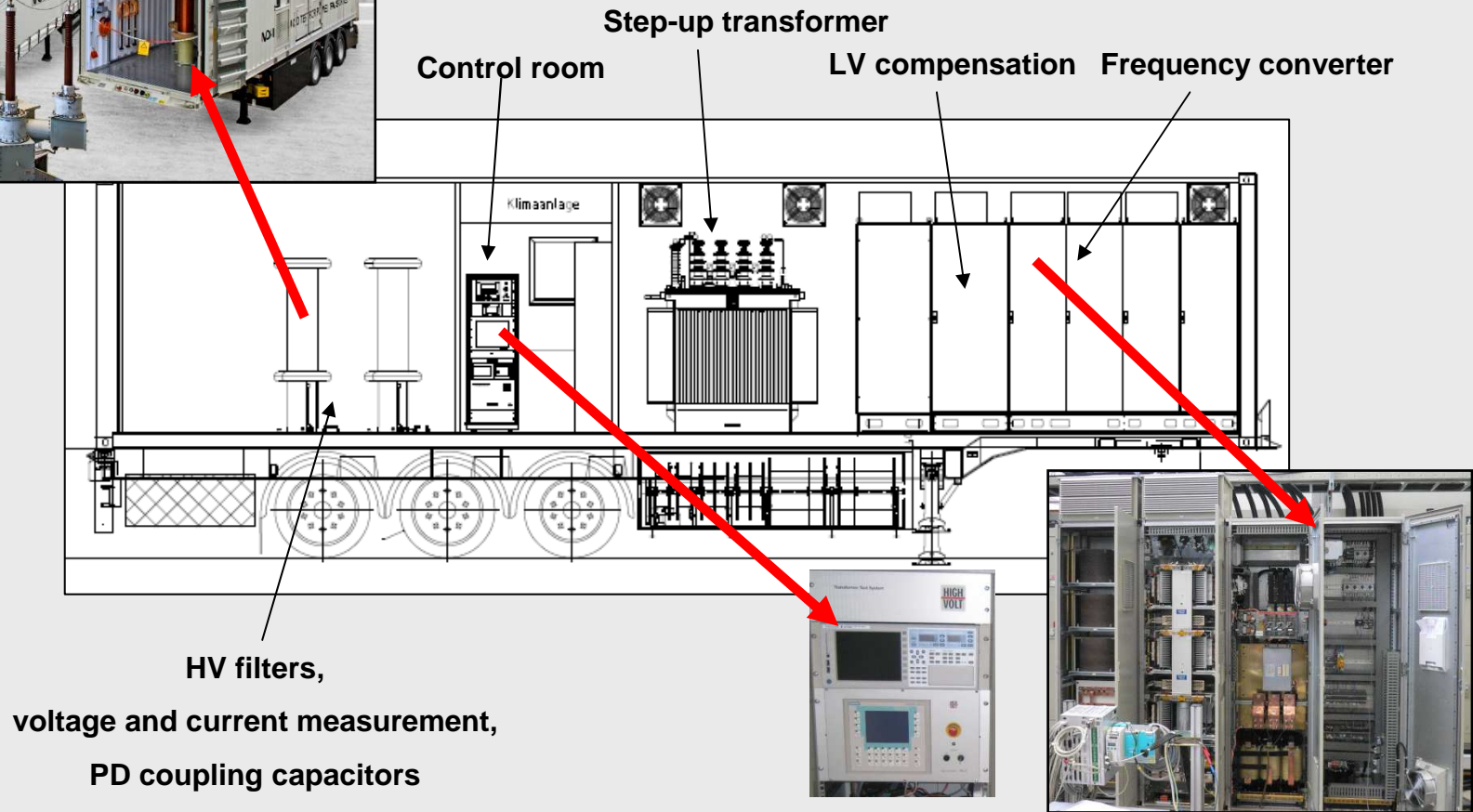
Negative sequence controller for single phase operation



## 5. Example: Mobile Test System for On-Site Testing (1)



Design of a trailer with all equipment necessary for testing with induced voltages



## 5. Example: Mobile Test System for On-Site Testing (2)

In addition to the test requirements, mobile systems are characterized by

- low weight-to-test power ratio,
- compact,
- robust against mechanical shocks during transportation,
- low power demand,
- easy to handle.

FC-based test systems are optimum for these requirements.



## 6. Example: Stationary Test System for Routine and Type Testing (1)

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Frequency converters, filters, primary compensation, water cooling

Dresden Transformer Test Field of Siemens AG

FC characteristics: 1250 kW, 6000 kVA

Capacitor bank: 133 000 kVA

Step-up transformer; steps up to 80 kV

Capacitor bank for compensation, step-up transformer top, busbars

Photos: Courtesy Siemens AG TBD



## 6. Example: Stationary Test System for Routine and Type Testing (2)

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Dresden Transformer Test Field of Siemens AG

Photos: Courtesy of Siemens TBD



Variable frequency resonant test system 350 kV for applied voltage tests,  
Impulse voltage test system 2000 kV, 200kJ,  
Systems for induced voltages as described.

## 7. Conclusions

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1. For power transformer testing, AC voltage test systems based on static frequency converters are successfully operating for both, routine and type testing in factories and field testing after assembling or repair on-site.
2. All requirements of the relevant standards can be fulfilled. Power rating can be enlarged by the application of the modular principle of parallel connections of several systems. This is especially helpful for transformer testing in the field.
3. The remaining present limitation in active power of 4 MW and in apparent power of 12 MVA will be enlarged with the further development of power electronics.
4. The authors have no doubt that transformer testing will be dominated by systems based on power electronics in the future.