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Innovative design of IEDs and functions allows flexible transformer protection applications

Flexible transformer protection applications

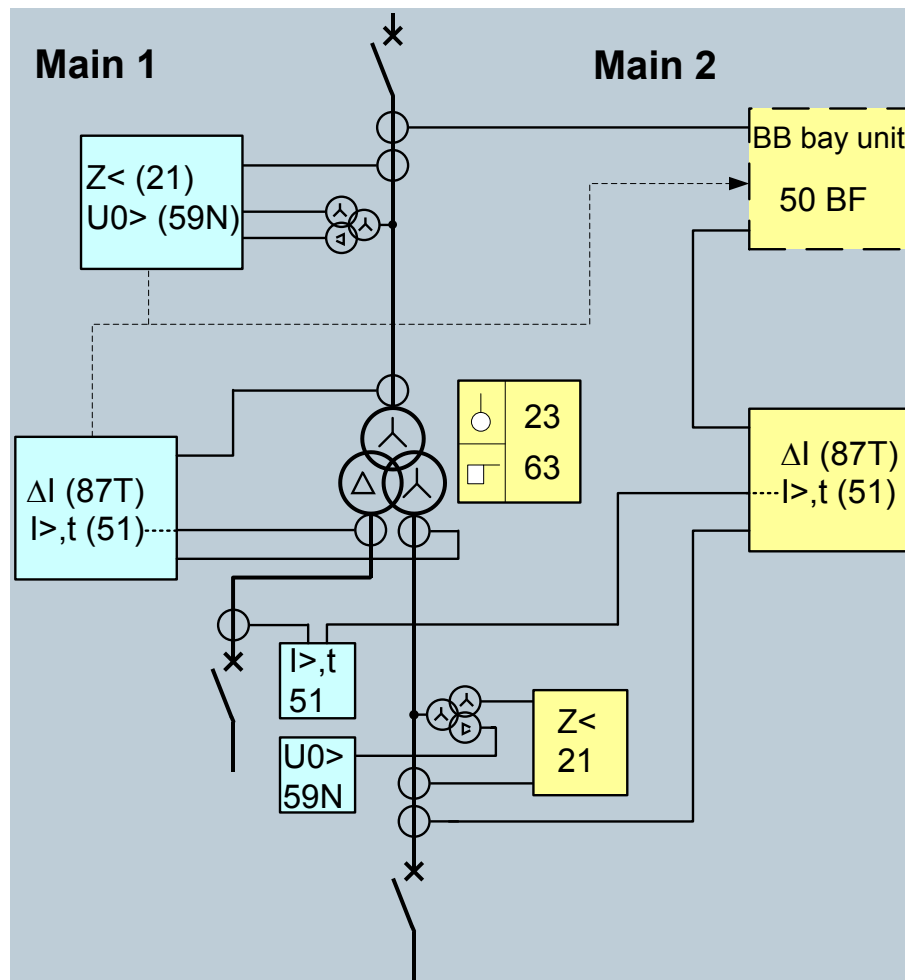
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(single core design)

Basics

Protection concept of a power transformer



Example from Germany

- Two differential protection devices (different suppliers)
- Buchholz protection is used in all applications
- Distance protection is the back-up protection (EHV, HV)
- Overcurrent protection (MV)
- Breaker failure protection (HV) realized in the bay device of decentralized busbar protection

Note:

CIGRE- Report of WG B5.05 is also available "Modern techniques for protecting, controlling and monitoring power transformers", 2009

Improvements of differential protection Inrush detection

Practical experiences:

Few malfunctions due to less amount of 2nd harmonics



Typical threshold:

$$15 \% I_{2.Harm}/I_{1.Harm}$$

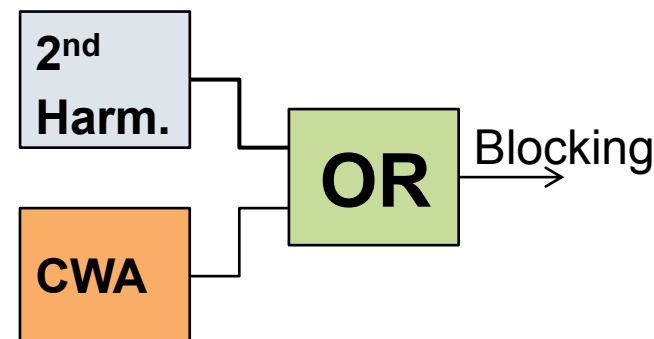
Phase L2 has 12%,
Cross block doesn't help

Solution:

Additional criterion:

Current **W**ave form **A**nalysis (CWA)

Typical for an inrush are **flat areas**



Improvements of differential protection

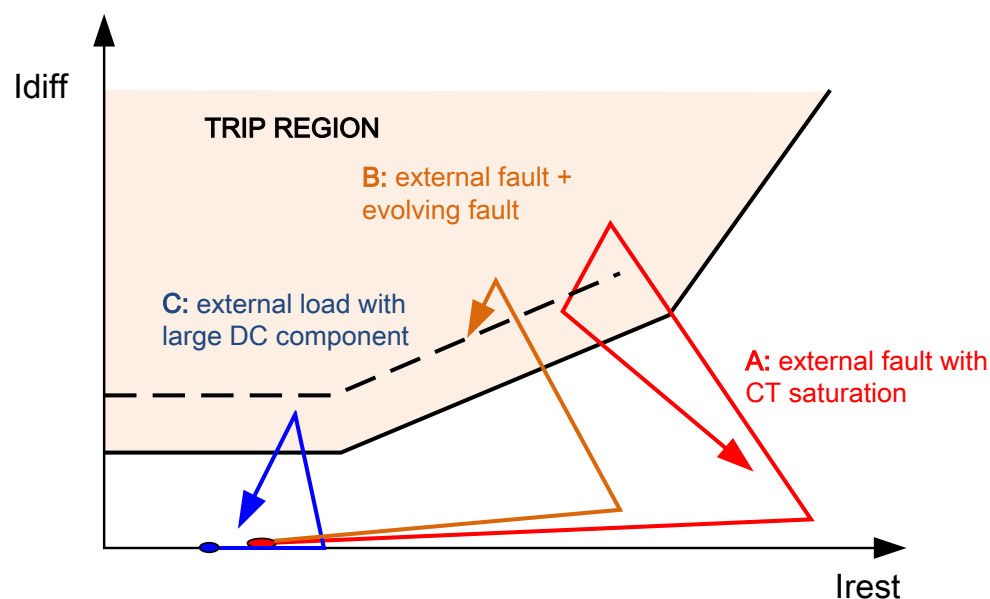
CT saturation and CT requirements

Practical experiences:

Few malfunctions due to CT saturation at external faults

(assumed reason: remanence at closed core CTs (P-type))

Three typical cases:



Solution:

Algorithmic improvement:

- Evaluation of current wave form by using an estimation algorithm (case A, B);
- This leads to a lower transient dimensioning factor (K_{td} from 3 to 2)
- Temporarily increased characteristic at current with dc offset and restraint current jump (case c)

Clear definition of CT requirements:

- Transient performance factor via $K_{td} = 2$
- For new plant: CT with a gap is an option (e.g. PR core; R means low remanence)

Improvements of differential protection

Restraint current measurement

Breaker and half application:

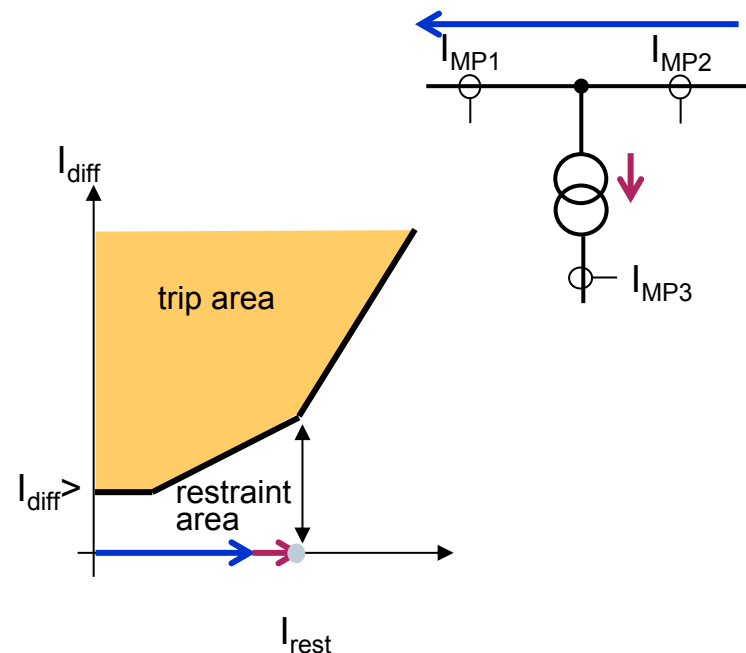
High current in diameter and in the feeder a transformer with a low apparent power

$$\text{I: } I_{\text{Restr}} = \sum_{k=1}^{n+m} |I_k|$$

$$\text{II: } I_{\text{Restr}} = \frac{1}{m+n} \sum_{k=1}^{n+m} |I_k|$$

$$\text{III: } I_{\text{Restr}} = \left| \sum_{k=1}^n I_{S1,k} \right| + \left| \sum_{k=1}^m I_{S2,k} \right|$$

$$\text{IV: } I_{\text{Restr}} = \text{Max}(|I_k|)_{k=1, 2, \dots, n+m}$$



Solution:

Method (IV) is optimal approach for different applications (maximum current of a measuring point(MP) is used

Functional improvement SIPROTEC 5 - Modularity in hard- and software

Modular hardware

Flexible configuration (IOs)



Modularity in communication

different plug-in modules, protocols



Device

SIPROTEC

81	50
40	27
67	21
21	87

Load functions
from a library

Engineering Tool

DIGSI

49T	50N	27	50	86	24
67	87L	51G	79	63	50
40	59	64	51N	49	64R
32R	21	67G	79	63	51V
81	87T	51	87N	37	...

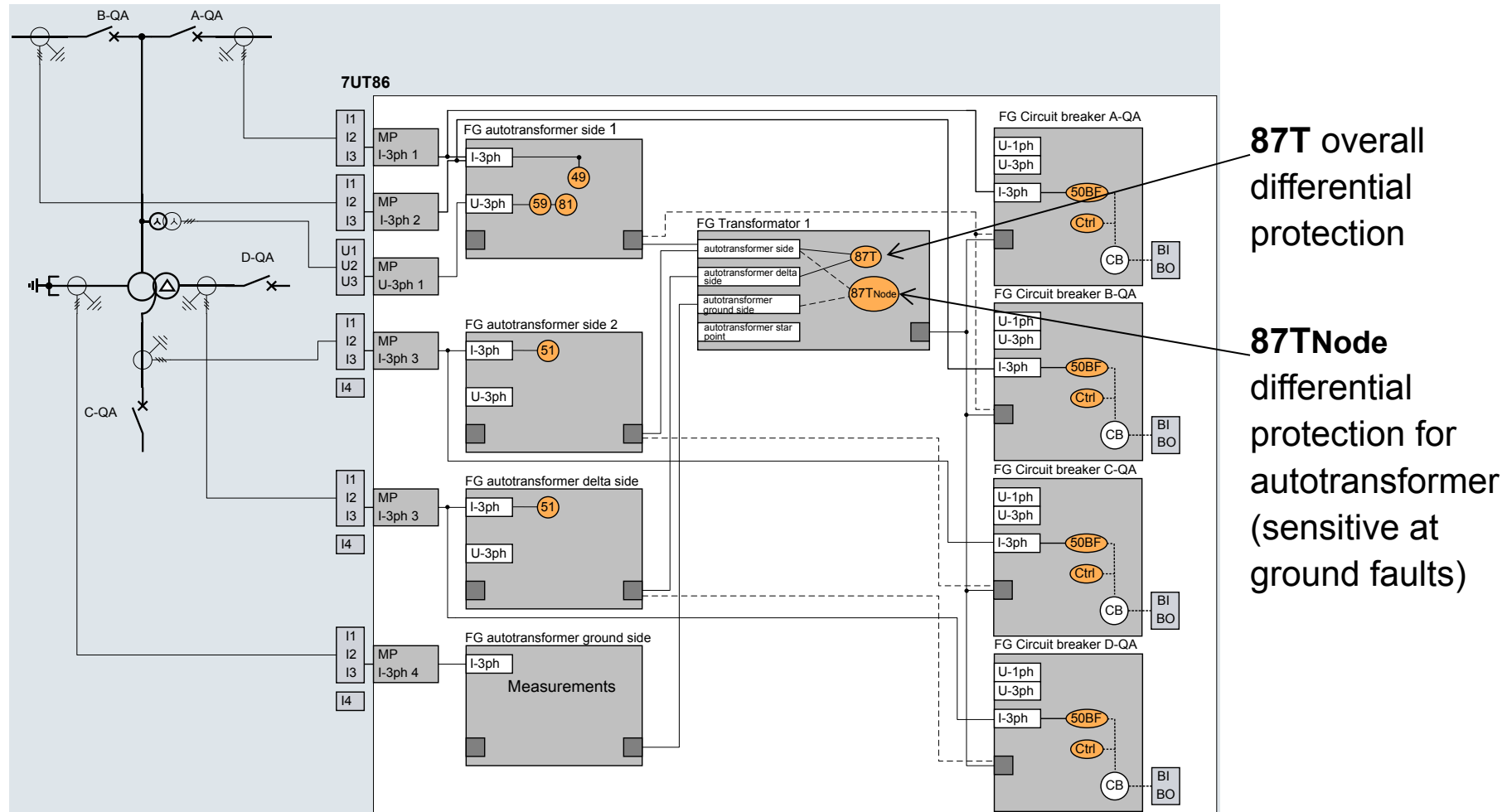
Expand the basic functionality according to your needs.

- Define your device as required at the beginning
- Adapt your device during life time by adding or substituting of functions

Functional improvement

Autotransformer bank application

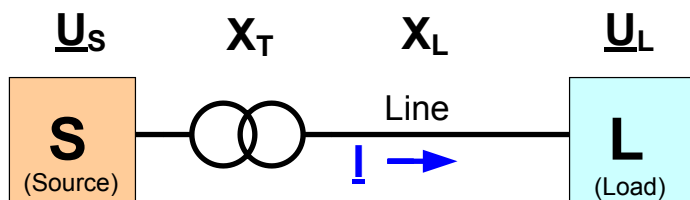
Two differential protection functions operates in parallel → high sensitivity, phase selective trip indication



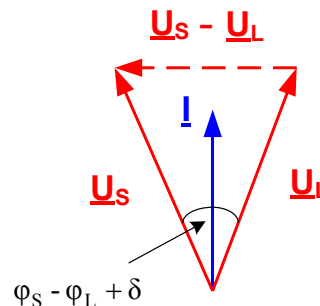
Phase shift transformers and special transformers

Basics

Phase shift transformer:



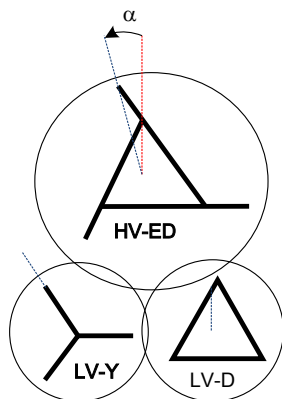
$$P = \frac{U_S U_L}{X_T + X_L} \sin(\varphi_S - \varphi_L + \delta)$$



- Control of active power flow (P) via a variable angle δ
- Realization via phase shift transformer

Conclusion: Variable phase shift must be considered by the protection (it's depends on the tap changer position and not anymore a multiple of 30)

Special transformer:



Special transformers are used in inverter applications (variable frequency drives, FACTs,...)

Typical is a special phase shift (7.5 -15) and multiple winding to reduce harmonics in the power system

Conclusion: This special phase shift must be considered by the differential protection

Phase shift transformers and special transformers

Universal transformation matrix

Power transformer have a phase shift of 30° or a multiple of 30° .
This is considered in the transformation matrix for phase angle shift correction.

A new transformation is designed to cover all different application.

$$\begin{pmatrix} I_{L1}^{**} \\ I_{L2}^{**} \\ I_{L3}^{**} \end{pmatrix} = \begin{pmatrix} f(\alpha) & f(\alpha - 120^\circ) & f(\alpha + 120^\circ) \\ f(\alpha + 120^\circ) & f(\alpha) & f(\alpha - 120^\circ) \\ f(\alpha - 120^\circ) & f(\alpha + 120^\circ) & f(\alpha) \end{pmatrix} \begin{pmatrix} I_{L1}^* \\ I_{L2}^* \\ I_{L3}^* \end{pmatrix}$$

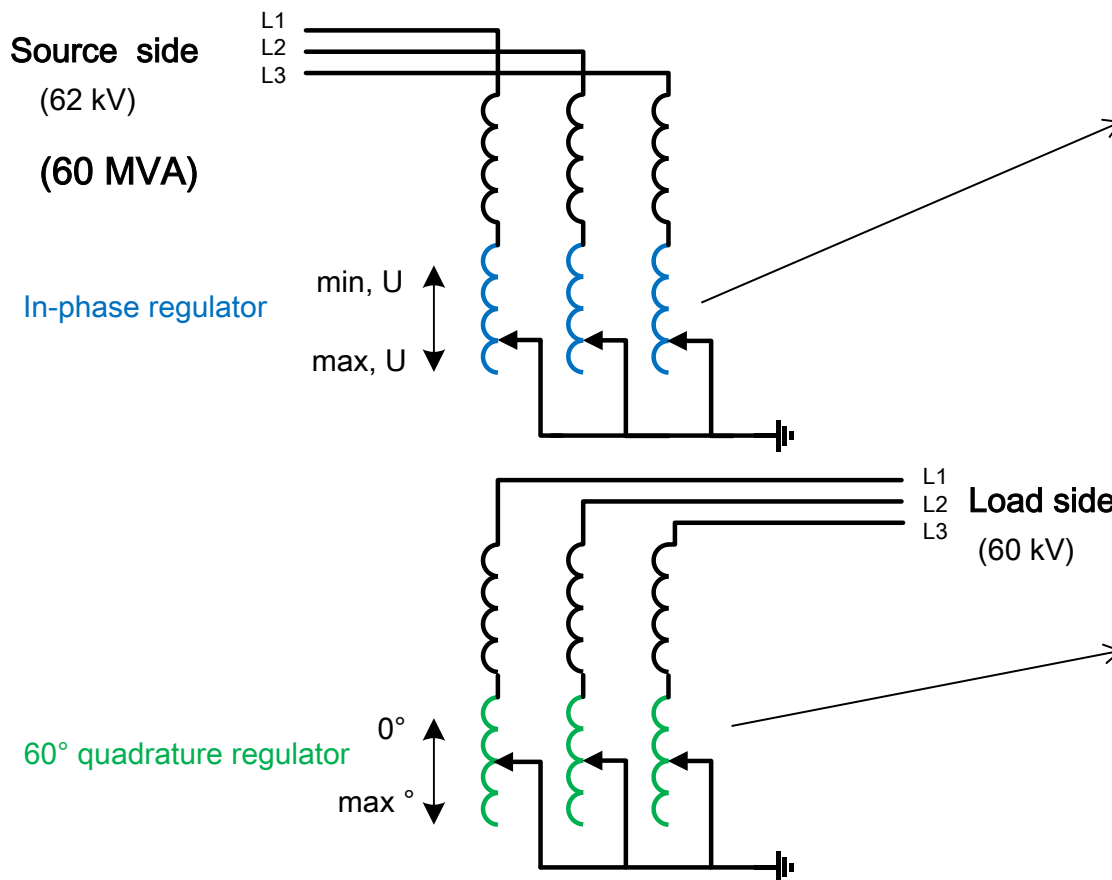
$f(\alpha)$ trigonometric transformation function

$I_{L1,2,3}^*$ Magnitude corrected current (correction of CT- and tap changer mismatching)

$I_{L1,2,3}^{**}$ Phase angle shift corrected current

Application Example: Phase shift transformer

Single core phase shift transformer



Tap changer settings

Tap changer: In-phase L1-S3.Tap changer

Basic position: 24

Volt. diff. adjacent taps: 0.600 kV

Tap changer: Quadrature S32+32.Tap changer

Table of angles: 63

Pos.[]	Angle[°]
1	-119.343
2	-120.918
3	-122.543
4	-124.217
5	-125.940

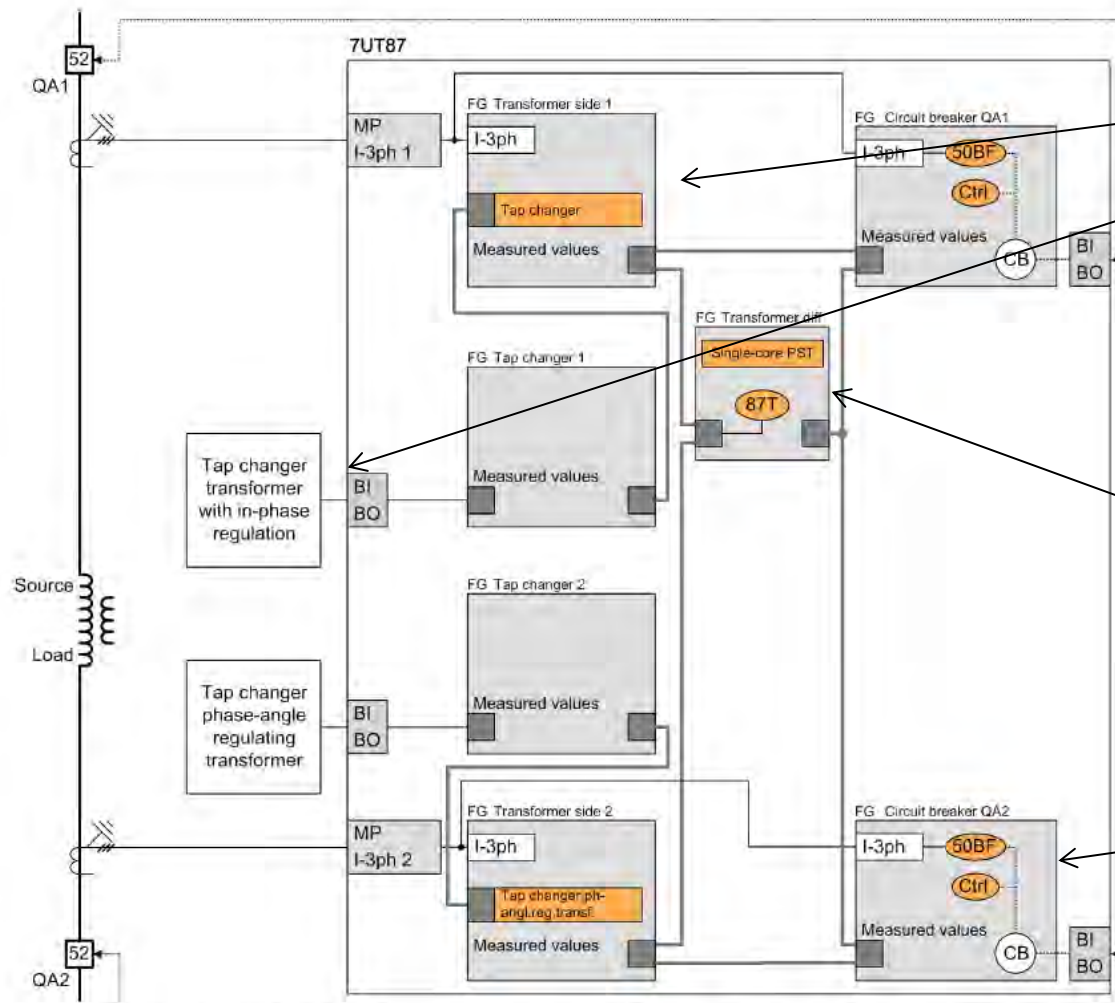
Table of voltages: 63

Pos.[]	Vltg.[kV]
1	60.404
2	59.458
3	58.558
4	57.706
5	56.906

For each tap changer position the transformation matrix is calculated online in device

Application Example: Phase shift transformer

Functional structure



Tap changer position are measured via binary inputs and processed in each transformer side

Differential protection functions (87 T) runs in the FG Transformer diff.

Trip is processed in the FG Circuit breaker, interaction with the CB is realized

Application Example: Phase shift transformer Demonstration of operation



Summary

- **Practical experiences showed there is room for improvements**
 - Extension of inrush stabilization with an additional criterion (CWA + 2nd harmonic)
 - **Fast and safer detection of CT saturation** due current wave analysis via estimation algorithm lead to lower transient performance requirements (K_{td} from 3 to 2)
 - **Modification of the restraint current calculation** to avoid over stabilization
- Recommendation for **CT selection for new installation** → e.g. PR type (max. 10% remanence)
- **Phase shift and special transformers needs a new transformation matrix for phase angle shift correction**
 - New transformation matrix is presented
 - Practical solution of a single core phase transformer was shown

Thank you for your attention!



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