Differential Protection for Special Power Transformers with RET 670

Application Example

1 Introduction

Special power transformers are power transformers which have phase angle shift different from 30° or a multiple of 30° [4]. Typical example is 24-pulse converter transformer with additional phase angle shift Θ of ±7.5°. Such special transformers typically have three windings, but sometimes even up to five windings [1]. They are used to supply different type of power electronics and FACTS devices. Such devices inject a lot of harmonics into the utility power system. By use of converter transformers with special phase angle shift the current harmonic injected in the utility supply system can be substantially reduced [2]. However the differential protection algorithm in RET 670 is fully capable to handle harmonics present in such installations. Thus, due to power quality reasons use of special converter transformers has been increased during last years. Such transformers, with rated power of more then 100MVA have been installed.

The converter transformer additional phase angle shift Θ is typically obtained by special connections of its HV winding [3]. The HV winding is typically connected either as extended-delta, as shown in Figure 1 or as zigzag, as shown in Figure 2. Obviously the special “HV winding extensions” are used in both designs in order to provide required additional phase angle shift Θ. Other converter transformer windings (i.e. LV windings) are connected in the standard way (e.g. either star or delta). It shall be noted that the design in Figure 1 is variation of a Dy11d0 standard power transformer, and the design in Figure 2 is variation of a Yy0d1 standard power transformer [5].

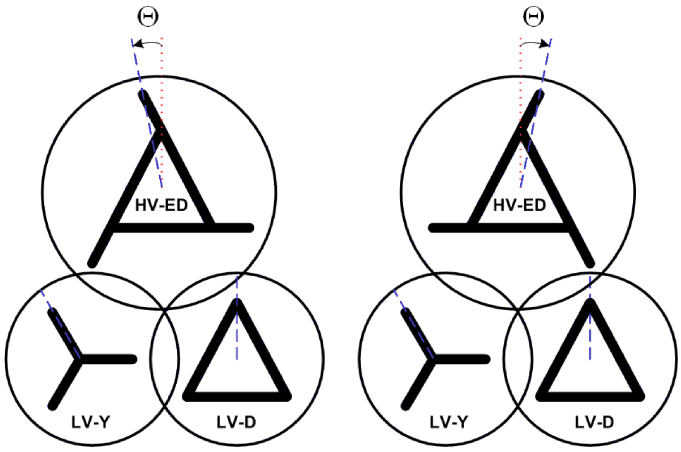

Figure 1: Typical winding connections for extended delta transformer design

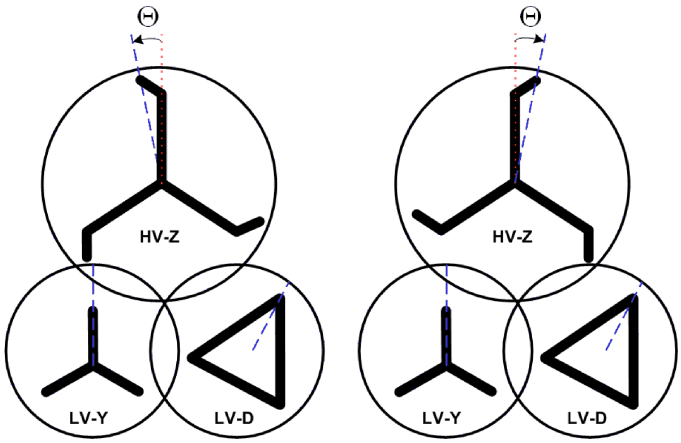

Figure 2: Typical winding connections for zigzag transformer design

2 Description of the problem

Standard three-phase power transformers [5] can be protected without any external interposing CTs with differential protection in RET 670. By parameter settings in RET 670 it is possible to:

- Compensate for standard power transformer phase angle shift (i.e. multiple of 30˚)
- Compensate for CT secondary current magnitude differences on the different sides of the protected power transformer
- Use all star connected primary CTs and still remove zero sequence currents from any transformer side by a parameter setting

However, if RET 670 is directly applied for differential protection of one converter power transformer, it will not be possible to compensate for additional, non-standard phase angle shift Θ caused by special winding connections. As result a permanent false differential current would appear. The false differential current magnitude can be estimated by using the following formula:

$$I_{d\_false} = 2 \cdot \sin\left|\frac{\Theta}{2}\right| \approx \sin|\Theta|$$

For the worst case when Θ=15° the false differential current of up to 26% of the through-load current will appear. As a consequence the minimum pickup of the differential protection must be increased to at least double of this value and differential relay will not be sensitive for the low level internal faults within the protected power transformer.

3 Solution with RET 670 and external auxiliary CTs

If one would be able to provide rotation of the three phase currents externally, in the appropriate direction, by the additional, non-standard angle Θ the net transformer connection as seen by the differential protection in RET 670, reverts back to the standard power transformer phase angle shift as if the converter transformer did not have the special “HV winding extensions”. Then, the RET 670 software features can be used in a usual way to provide differential protection for this special transformer, as if it were a standard power transformer (e.g. with vector group Dy11d0).

For busbar protection summation type design has been used by ABB for decades (i.e. 1ph-RADSS, REB 101, RED 521 & REB 670). The auxiliary summation CT used for this type of design has three primary windings and one secondary winding. It was found out that by using a set of three identical auxiliary summation CTs one can provide external rotation by angle Θ without changing the main CT secondary current magnitude (e.g. with overall ratio 1/1A or 5/5A). The necessary connections, for external rotation of three-phase currents by angle Θ in the anticlockwise direction are shown in Figure 3.

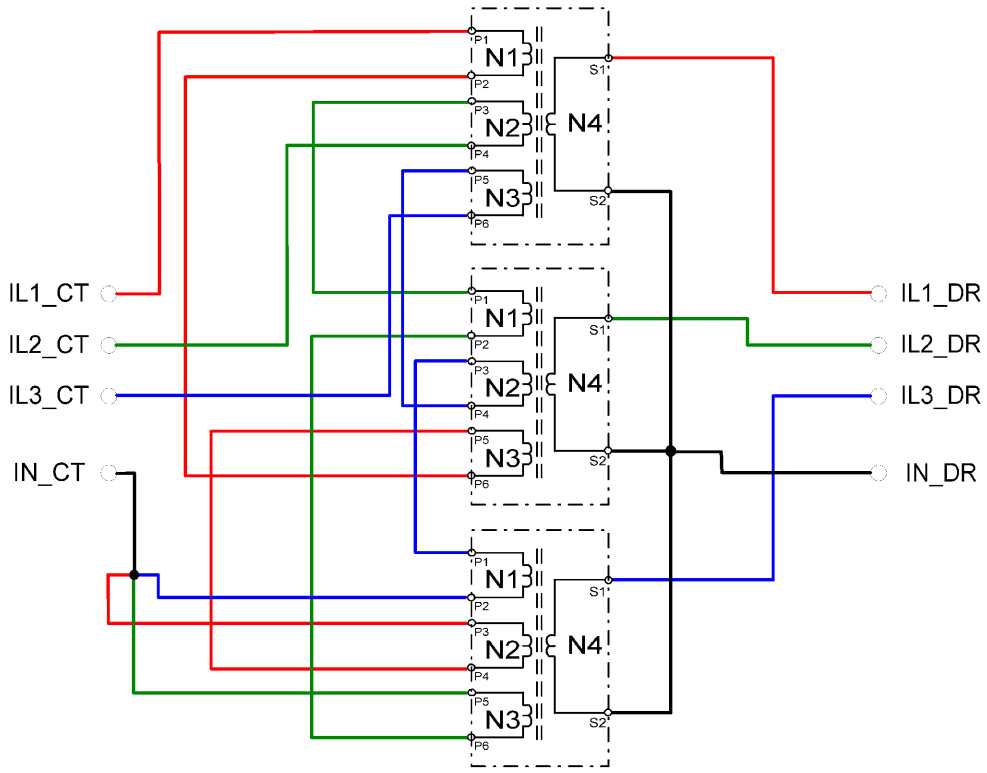

Figure 3: Auxiliary CT set connections for anticlockwise (i.e. positive) rotation by angle Θ

By properly choosing the turn number of the auxiliary summation CT windings (i.e. N1, N2, N3 and N4) the connection shown in Figure 3 will provide rotation by angle Θ in anticlockwise (i.e. positive) direction without changing the main CT secondary current magnitude (e.g. with overall ratio 1/1A or 5/5A). Sometimes, within the same application the rotation in clockwise direction by angle Θ is needed as well. To achieve this, exactly the same auxiliary summation CT set can be used, but it shall be connected as shown in Figure 4. Thus, the connection

shown in Figure 4 will provide necessary rotation of the three-phase currents by angle Θ in clockwise (i.e. negative) direction.

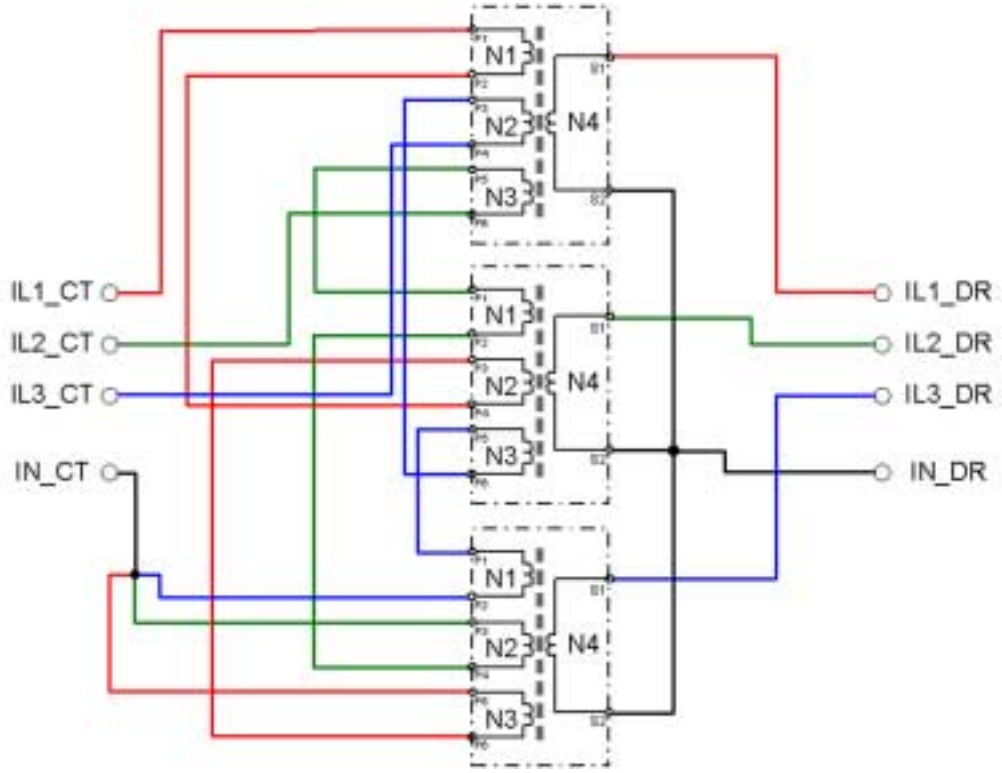

Figure 4: Auxiliary CT set connections for clockwise (i.e. negative) rotation by angle Θ

Table I gives example of possible design solutions regarding the turn numbers within auxiliary summation CT for the most typical, additional phase angle shifts used in practice.

Design Phase Angle Shift Θ	Auxiliary Summation CT Turn Numbers				Auxiliary Summation CT Performance	
	N1	N2	N3	N4	Achieved Overall Ratio	Achieved Rotation Angle
±7.5°	26	16	10	39	1/1.009	±7.59°
±15°	26	19	7	40	1/1.009	±14.92°

Table I: Auxiliary summation CT design details

Small CT secondary current magnitude errors of less than 1% and small phase angle error of approximately 0.1° caused by imperfection of auxiliary summation CT design will not practically cause any significant false differential current in actual installations.

It shall be noted that auxiliary summation CTs are typically design in such way to remove the zero sequence current component from the protected power transformer side where they are connected. Thus, the zero sequence currents will not be available within RET 670 differential function from that power transformer side. However the LV sides of such converter transformers are typically isolated or high impedance grounded. Hence the zero sequence currents on any LV side in case of a LV earth fault are quite limited. Therefore, the absence of these LV sides zero sequence currents will not significantly desensitize the differential relay. Thus the auxiliary CT shall be typically connected on the LV sides of such special transformers.

In order to optimize the auxiliary CT design it is assumed that they will be installed in the same relay cubicle with RET 670 relay. Each set of three auxiliary CTs is delivered on one 2U high, 19” wide plate, ready for mounting within the protection panel. Thus one such plate is required for every power transformer side where external current rotation is required.

More detailed background information about differential protection with auxiliary summation CTs for special power transformers can be found in reference [6].

4 Practical examples

Two application examples will be presented.

4.1 Differential protection solution for a transformer with 15° phase shift

The overall differential protection solution and all relevant data for this transformer application including power transformer vector diagram are shown in Figure 5. By looking into power transformer vector diagram it can be seen that LV no-load voltages shall be rotated by 15° in anticlockwise direction in order to be in phase with HV no-load voltages. Thus, the same rotation shall be provided for LV currents for differential protection. To do that one set of auxiliary summation CT, which provide current rotation by 15° in anticlockwise direction is required. This auxiliary CT set is used in order to put the transformer overall phase shift, as seen by the differential relay, back to the standard Yy0 vector group. The main CT secondary current magnitudes are not altered at all on the LV side. Then RET 670 software features can be used in a usual way to compensate for this special transformer, as if it were a standard two-winding transformer with vector group Yy0. All other relevant application data like main CT ratios and power transformer rated power, rated currents and rated voltages shall be used as they are in the actual installation to derive the RET 670 relay settings.

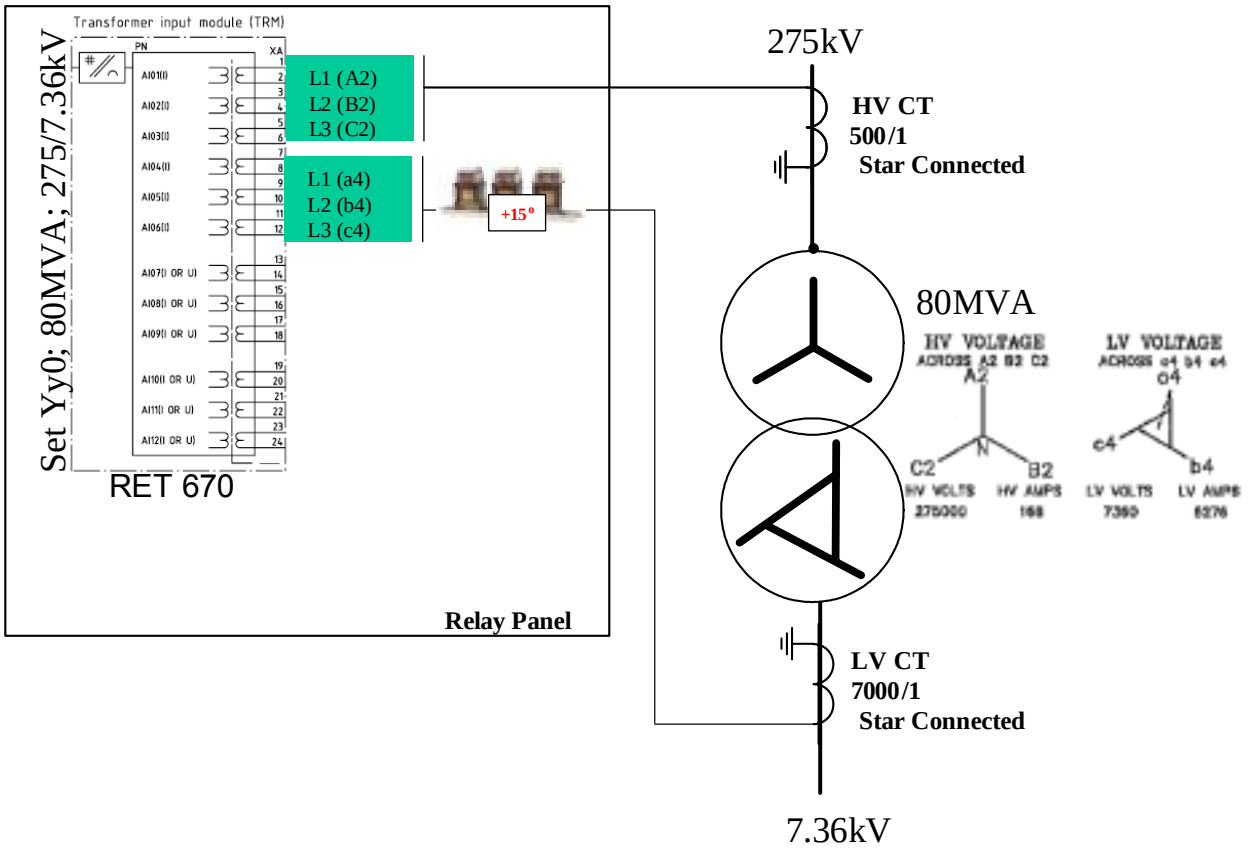

Figure 5: Differential protection solution with RET 670 for transformer with 15° phase shift

4.2 Differential protection solution for a 24-pulse converter transformer

This converter transformer is quite special because within the same transformer tank two three-phase transformers, of similar design as shown in Figure 2, are put together. The first internal transformer has vector group Zy11¾d10¾. The second internal transformer has vector group Zy0¼d11¼. Such arrangement gives an equivalent five-winding power transformer with 15° phase angle shift between LV windings of the same connection type. The power transformer construction details and corresponding phasor diagram for positive sequence no-load voltages are shown in Figure 6.

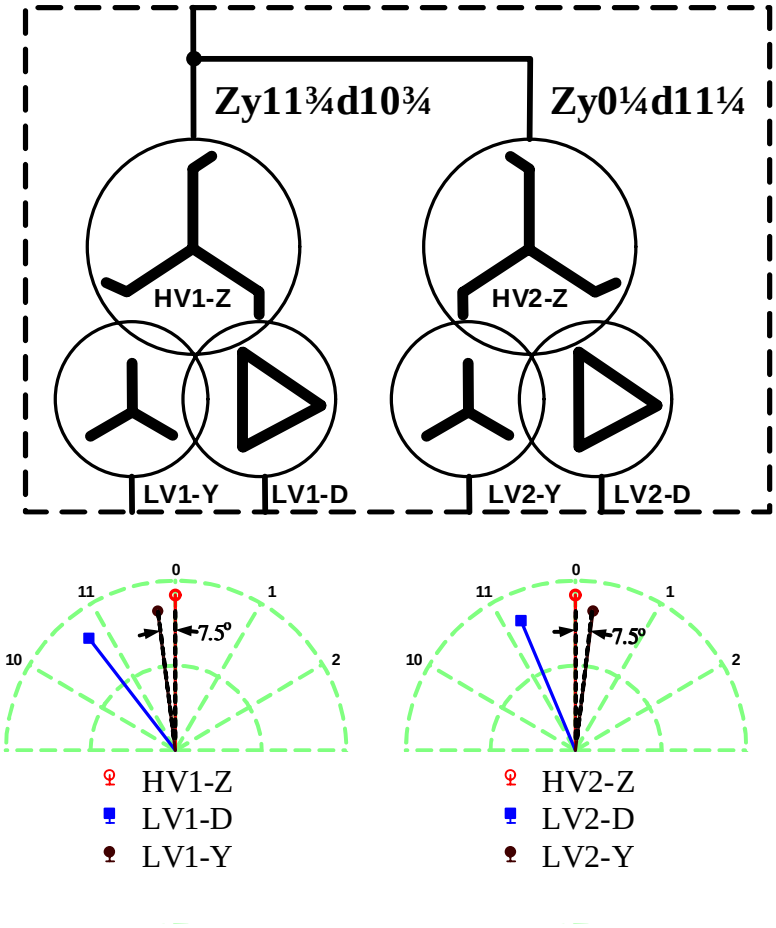

Figure 6: 24-pulse converter transformer and its positive sequence phasor diagram

From the transformer phasor diagram it can be seen that:

- LV1-Y & LV1-D sides shall be rotated by 7.5° in clockwise direction
- LV2-Y & LV2-D sides shall be rotated by 7.5° in anticlockwise direction

Thus, for such transformer four set of auxiliary summation CTs, which provide current rotation by 7.5° are required. Two sets, connected for current rotation in clockwise direction shall be applied on the two LV sides of the first internal transformer. Two sets, connected for current rotation in anticlockwise direction shall be applied on the two LV sides of the second internal

transformer. These auxiliary CTs are used in order to put the 24-pulse converter transformer overall phase shift, as seen by the differential relay, back to the standard Yy0d11y0d11 vector group. The main CT secondary current magnitudes are not altered on any of the four LV sides. Hence, the RET 670 relay software features can be now used in a usual way to compensate for this special converter transformer, as if it were a standard five-winding transformer with vector group Yy0d11y0d11. All other relevant application data like main CT ratios and 24-pulse converter transformer windings rated powers, rated currents and rated voltages shall be used as they are stated on respective equipment nameplates to derive the RET 670 relay settings. The overall differential protection solution is shown in Figure 7. It shall be noted that all twelve peaces of auxiliary summation CTs used for this application are exactly the same.

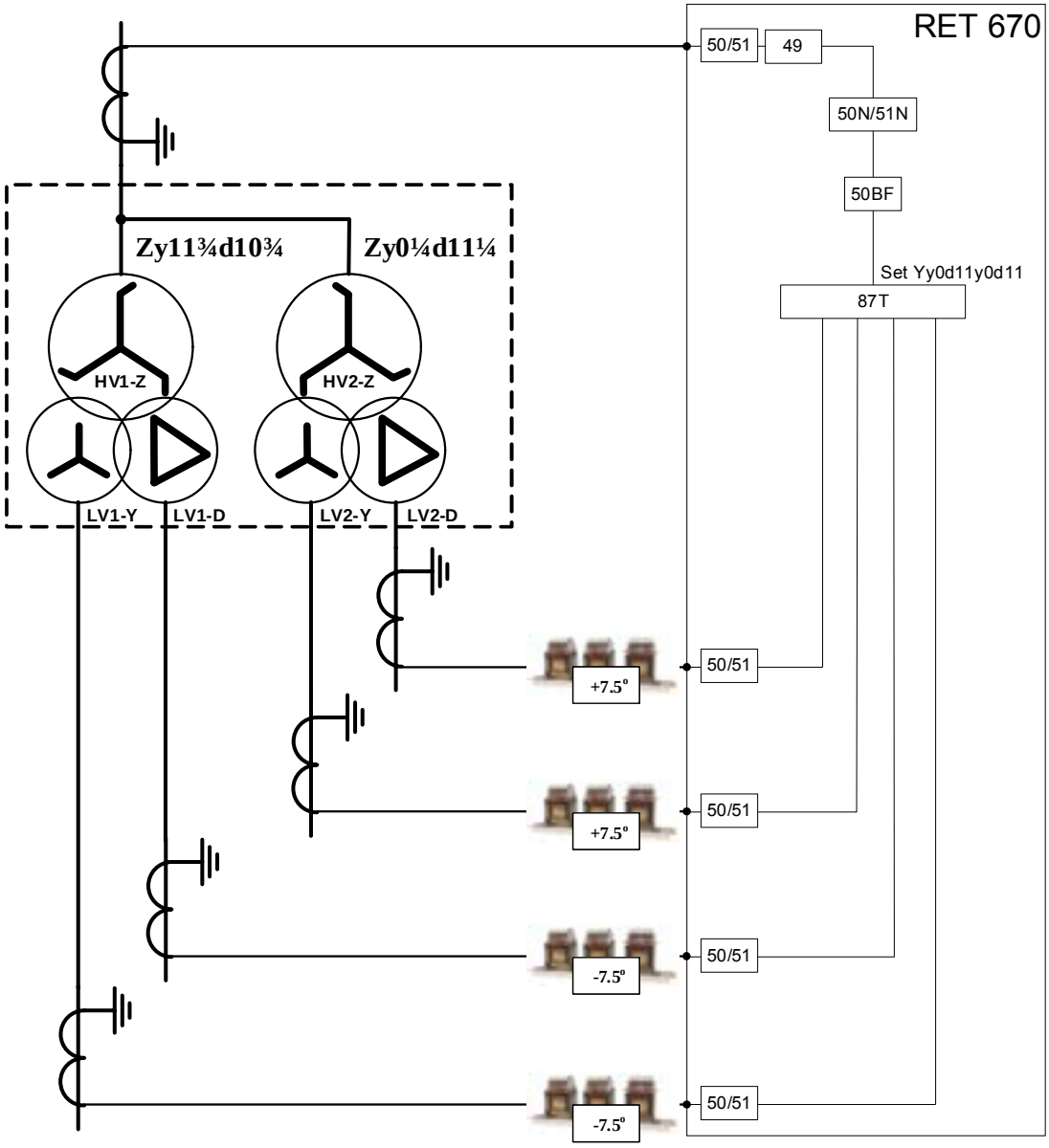

Figure 7: Overall protection solution with RET 670 for 24-pulse converter transformer

5 Summary and conclusions

RET 670 is numerical power transformer differential relay. It can be used to provide differential protection for the special industrial transformers with non-standard, but fixed phase angle shift. The only pre-request is that the external auxiliary CTs are used to compensate for additional phase angle shift Θ, typically caused by special arrangements of the industrial transformer HV winding. Once this compensation is done externally the RET 670 shall be set and applied as if the industrial transformer was designed with the standard vector group connection.

With presented solution RET 670 is ideally balanced during all through load conditions and for all types of external faults. Hence, no false differential current will be measured by the differential relay. This will enable the end user to set the minimum differential protection pickup to a quite sensitive level (e.g. 15-20%). This will insure sensitive protection for low-level transformer internal faults such as interturn faults.

With the presented method the design of external auxiliary CTs can be standardized. The external auxiliary CTs are not dependent on the converter transformer name plate data like rated powers, rated voltages and rated currents, but instead only the following parameters prescribe their design:

1. Main CT rated current (i.e. 1A or 5A)

2. Additional phase angle shift Θ introduced by the converter transformer design

3. RET 670 CT requirements as stated in the relay manual

The presented method is not dependent on the special power transformer construction details. Hence, by using the described principle, it is possible to provide differential protection for any three-phase power transformer with non-standard, but fixed phase angle shift, which can not be directly covered by the setting facilities of the numerical transformer differential protection within RET 670.

When RET 670 is used for differential protection of such special converter transformer it is as well possible to utilize other built-in features like:

- On-line OLTC position reading and automatic turn ratio compensation for the differential protection (assumption is that OLTC is used only for voltage regulation and that its movement do not influence the phase angle shift of the protected transformer)

- Negative sequence external/internal fault discriminator

- Automatic tap changer control and primary switchgear apparatus control

- Restricted earth fault protection function

- Backup protection functions like overcurrent, earth fault, breaker failure etc.

However it shall be observed that some of additional features might require a separate three-phase CT input, without external current rotation by angle Θ, from power transformer sides where auxiliary CTs has been used.

6 References

[1] ABB Leaflet 1LAB 000 019, "Industrial Transformers", ABB Transformers AG, Bad Honnef, Germany

[2] ABB Guide, "AC Drives Technical Guide Book", ABB Oy, Drives, available at http://www.abb.com/motors&drives

[3] O.W. Andersen, “Large Transformers for Power Electronic Loads” IEEE Transaction on Power Delivery, Volume 12, Issue 4, Oct. 1997.

[4] Converter Transformers – Application Guide, International Standard IEC 61378-3, First edition 2006-04.

[5] Power transformer, International Standard IEC 60076, First edition 1997-10.

[6] Z. Gajić, “Differential Protection for Special Industrial Transformers”, Paper Submitted to IEEE Transaction on Power Delivery

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