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Practical Experience with Differential Protection for Converter Transformers

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Summary

The paper will present differential protection schemes for special Converter Transformers. These transformers are typically used to feed MV drives, power electronic or FACTS devices.

Converter transformers are industrial transformers which may have phase angle shift different from 30º or a multiple of 30º. Typical example is 24-pulse converter transformer with additional phase angle shift Θ of ±7.5º. Such special transformers typically have two LV windings, but sometimes even multiple LV windings.

Paper will provide information how differential protection schemes have been designed and present current waveforms from DRs captured in converter transformer installations.

Keywords

Converter Transformers, Differential Protection.

1. Introduction

The converter transformers are used to feed power electronic devices such as MV drives, SVCs, large rectifiers, static frequency converters, etc. Most of applications shown in this paper come from the field of MV variable speed drives. Typical MV drive structure is shown in Figure 1.

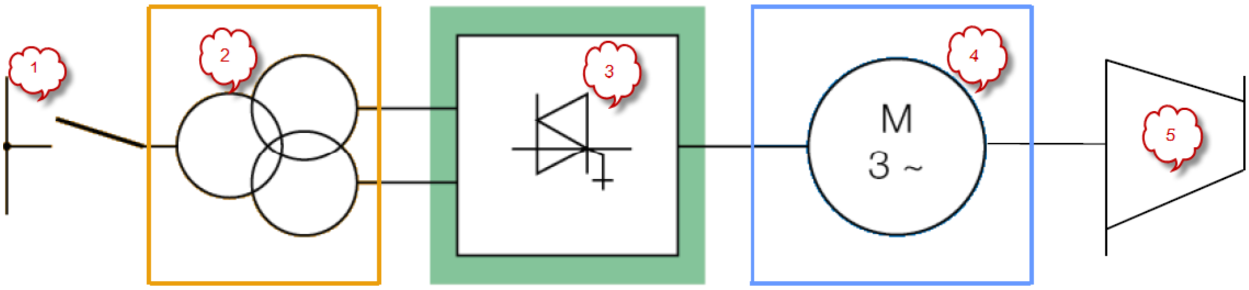

Figure 1 : Typical MV drive setup

Numbers given in Figure 1 point out the following typical parts of every MV drive:
1) Supply network to the MV drive (e.g. 6kV, 11kV, 13,8kV, etc.)
2) Converter transformer

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3) Power electronics part (i.e. MV drive)
4) Motor (synchronous or asynchronous depending on the application)
5) Load driven by the motor

Typical applications for MV drives are: blowers & fans, conveyors, compressors, crushers & rolling mills, extruders & mixers, marine propulsion, mine hoists, pumps in refiners, gas & hydro turbine static starters, soft starters for large machines, wind tunnels, etc.

The main role of the converter transformers in this application is to:

- Adapt the network supply voltage to the power electronics input voltage
- Isolate the power electronics from the supply network
- Restrict short-circuit currents to the power electronics
- Relieve the motor and/or network from common mode voltages
- Reduce radio interference (EMC) from drive to the network (special screen between windings)
- Protect the drive from voltage transients from the feeding network
- Reduce harmonics penetration into the feeding network (transformer impedance and special multi-pulse connections)

Available connection types used for converter transformer design are given in Table 1. For more information about these transformers see references [1,2,3,4].

Table 1 : Properties of Converter Transformers regarding pulse number

Pulse No	No of transformer LV windings	Phase shift between LV windings	Example for converter transformer vector group
6	1	-	Yy0
12	2	30° (60min)	Dy11d0
18	3	20° (40min)	Dd11:20d0d0:40
24*	4	15° (30min)	Dd0:25d11:25 Dd11:75d0:75
30*	5	12° (24min)	-
36*	6	10° (20min)	Yd10:20d11d11:40 Dd11:20d0d0:40
42*	7	8,57° (17min)	-
48*	8	7,5° (15min)	-

* Often built as two or more transformers connected in parallel on HV side (see Figure 6)

Note that converter transformers have been manufactured for applications in excess of 155MVA and are connected to the supply networks of up to and including 400kV.

2. Differential Protection for Converter Transformers

The main application problems for differential relay (i.e. 87T) application on a converter transformer are:

1. How to compensate for the non-standard phase angle shift
2. Cover required number of CT inputs into the differential relay

The main theory how to apply a numerical differential protection designed for standard, three-phase, power transformer onto a converter transformer is given in references [5,6,7]. In this paper only practical installations of a standard transformer differential protection IED, see reference [8], for converter transformer applications will be shown.

3. Differential protection solution for a 18-pulse converter transformer

Differential protection installation on the 18-pulse drive for the oil industry is given in Figure 2. Interposing CTs are used to put the converter transformer vector group to Dd0d0d0 for the differential relay.

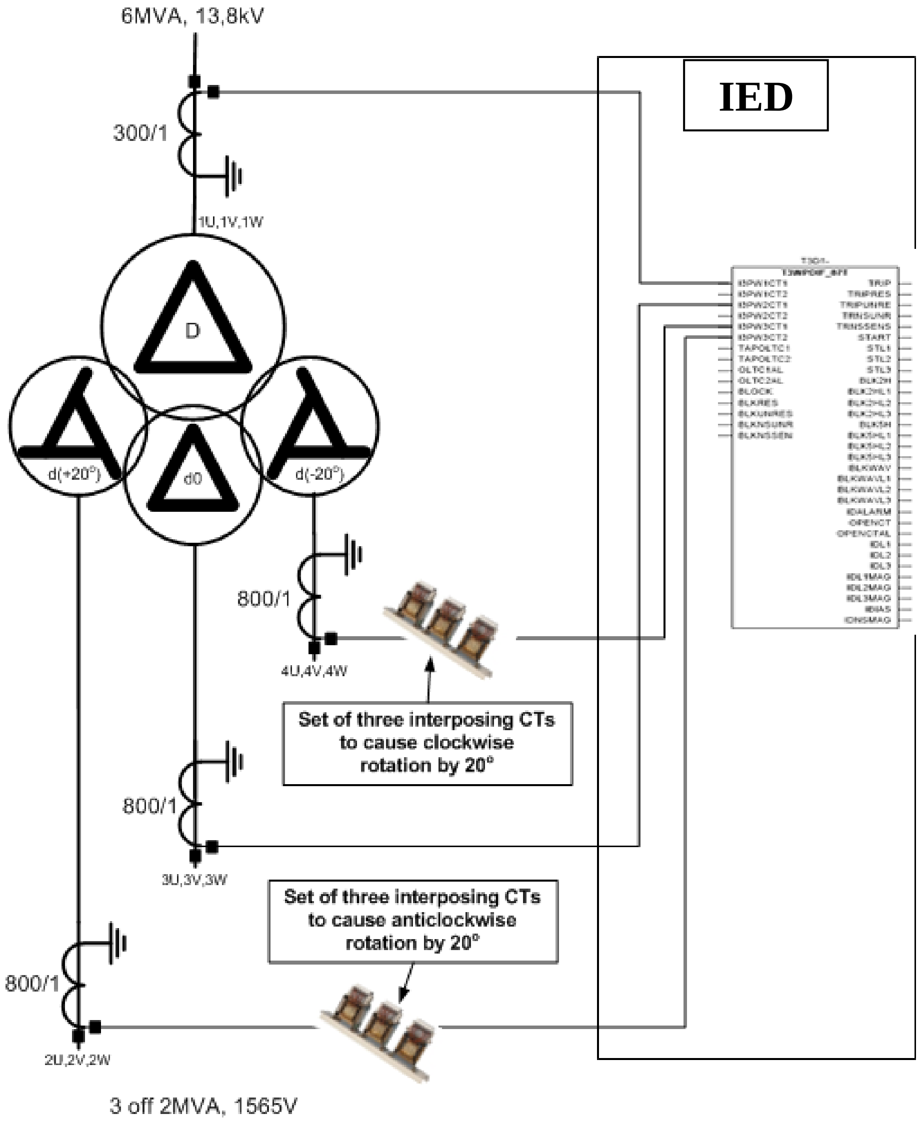

Figure 2 : 18-pulse Converter Transformer with associated 87T relay

Due to limited space only one recording captured during the differential protection commissioning is presented in Figure 3. It is captured during primary stability test when converter transformer was supplied on the HV side from a three-phase, 400V source while the three-phase short-circuits were made outside of the protected zone on all three LV windings. The following traces captured by the differential relay are shown in this figure:

a) HV delta winding CT secondary currents (i.e. in secondary amperes)
b) LV d(+20°) winding CT secondary currents after the interposing CT
c) LV d0 winding CT secondary currents
d) LV d(-20°) winding CT secondary currents after the interposing CT
e) Differential and bias currents within the differential relay (note that they are given in converter transformer primary amperes on the HV side as calculated by this particular 87T relay [8])

This record clearly indicates that all three differential currents are practically equal to zero, while the bias current is high. Thus the 87T differential relay was fully stable during this test. At the same time it can be noted that phase L1 currents from all four windings are in phase. This is possible due to existence of the interposing CTs within the differential protection scheme, which insure that two LV windings with non-standard ±20° phase shift are brought in phase with the other two converter transformer windings. This ensures the stability of the standard transformer differential relay which is actually set to protect the power transformer having standard Dd0 vector group.

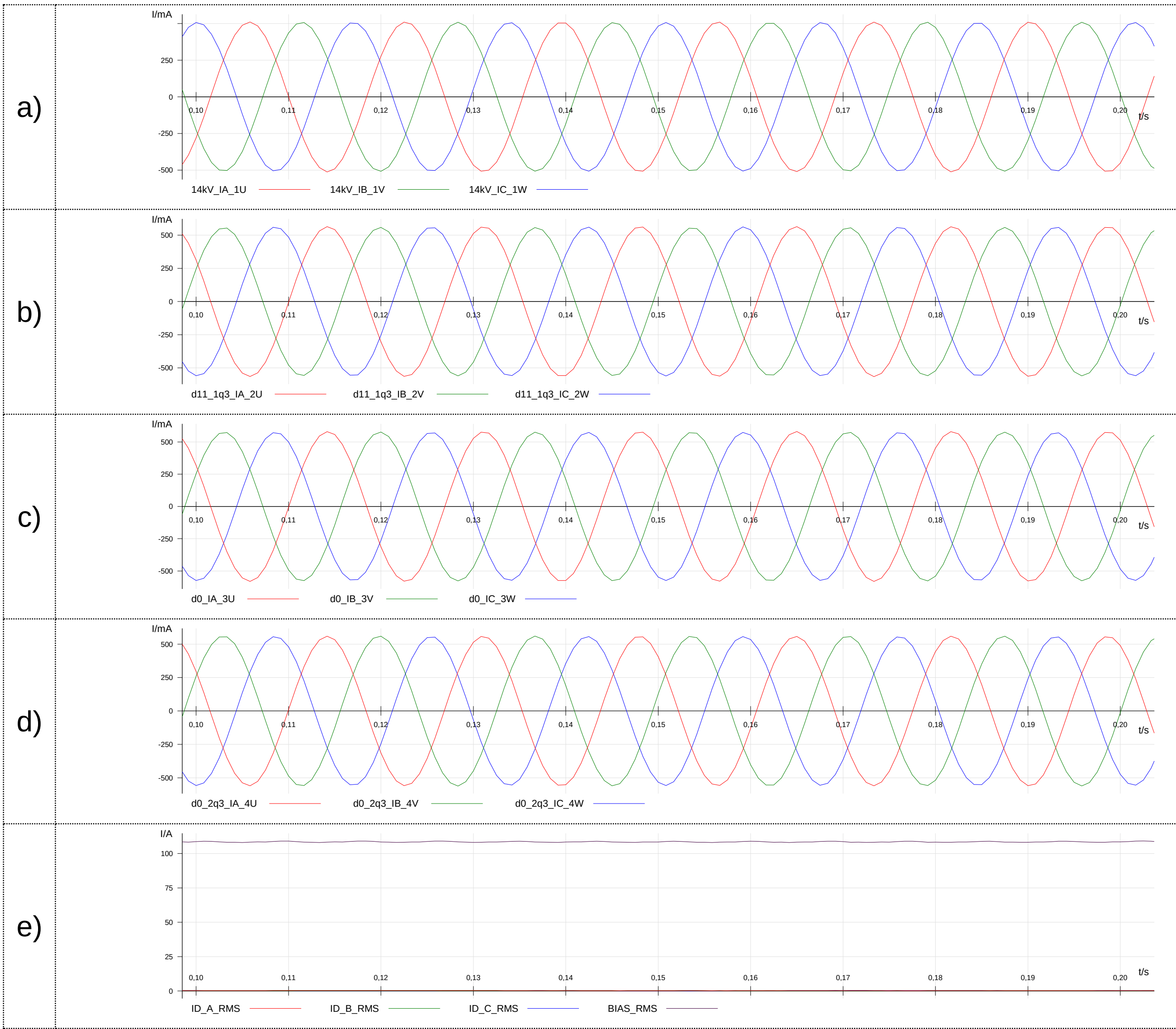

Figure 3: Secondary current waveforms captured by the 87T relay during primary stability test

4. Differential protection solution for a 24-pulse converter transformer

Differential protection installation on the 24-pulse drive for the oil industry is given in Figure 4. Note that in this installation two separate transformers (i.e. T1 and T2) are used to build the converter transformer. Interposing CTs are again used to put the converter transformer overall vector group to Dd0d0 for the differential relay.

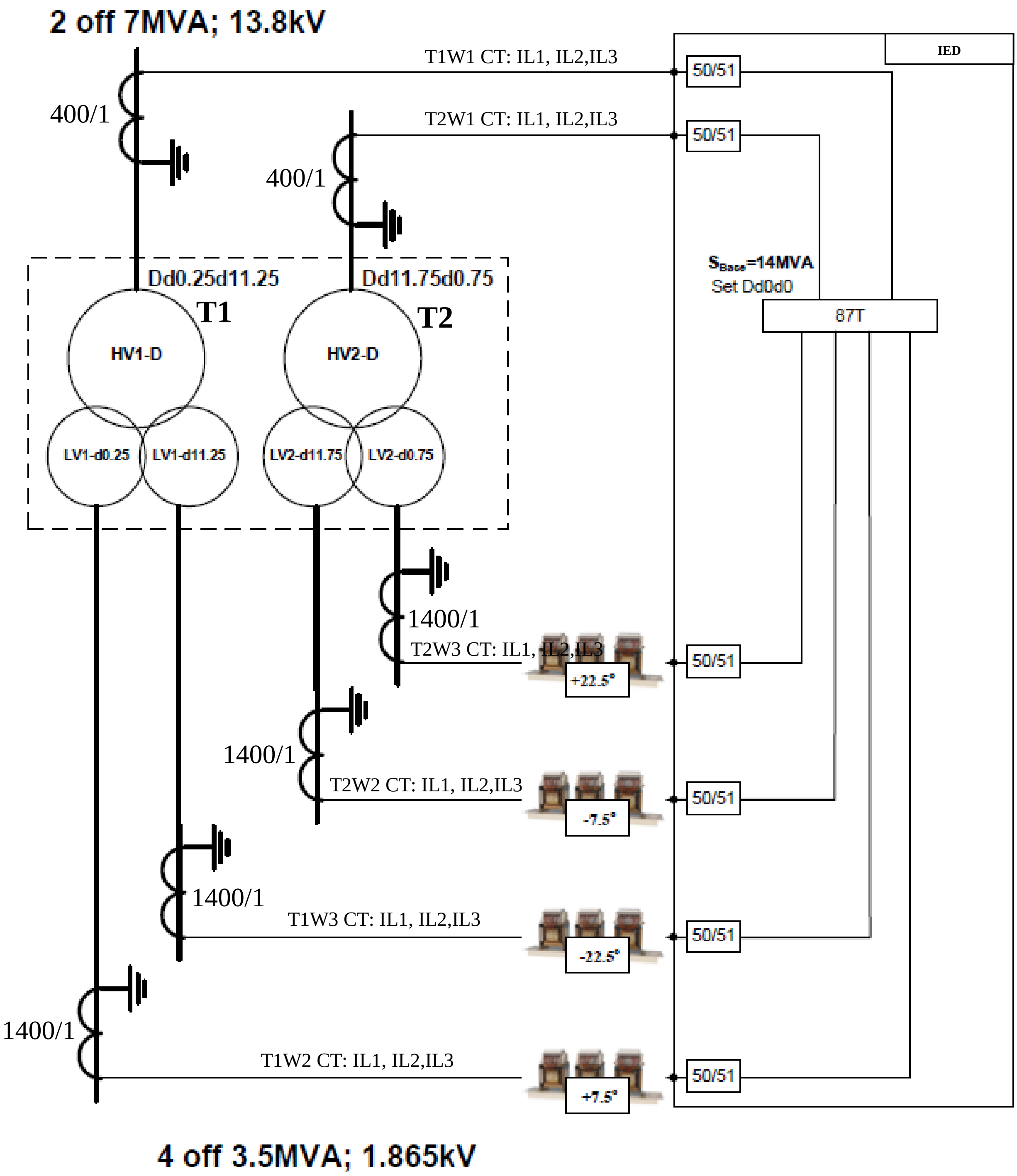

Figure 4 : 24-pulse Converter Transformer with associated 87T relay

Due to limited space only one recording captured by external disturbance recorder is presented in Figure 5. It was captured when the MV drive was fully loaded. The following traces are presented in this figure:

a) T1 W1 (i.e. HV side) CT secondary currents (i.e. in secondary amperes)
b) T1 W2 (i.e. LV1-d0.25 side) CT secondary currents
c) T1 W3 (i.e. LV1-d11.25 side) CT secondary currents
d) T2 W1 (i.e. HV side) CT secondary currents
e) T2 W2 (i.e. LV1-d11.75 side) CT secondary currents
f) T2 W3 (i.e. LV1-d0.75 side) CT secondary currents

From this record it can be clearly seen that currents from all four LV windings are of a “square nature” and consequently reach in harmonics. However the HV winding currents are already much closer to the “standard sine waveform shape” typically expected in the three-phase power system. Finally the sum of the two HV winding currents will be even closer to the ideal sine shape and thus the overall harmonic content from this MV drive towards the 13,8kV supply network will be substantially reduced.

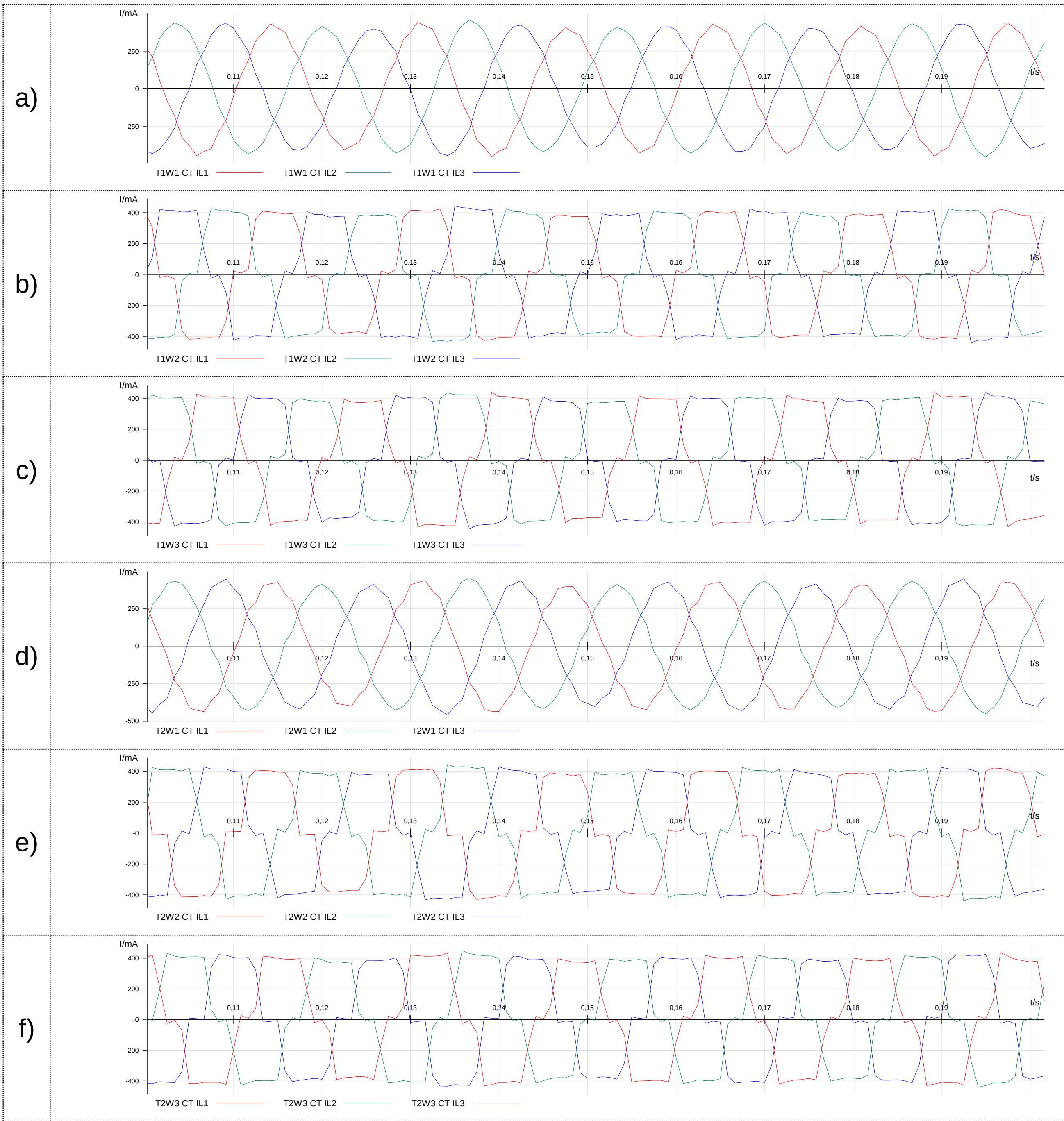

Figure 5 : Main CTs secondary load current waveforms captured by the disturbance recorder

5. Differential protection solution for a 36-pulse converter transformer

Differential protection application on the 36-pulse drive is given in Figure 6. Here as well two separate transformers are used to build the converter transformer. Interposing CTs are again used to put the overall transformer vector group to Yd11y0 for the differential relay.

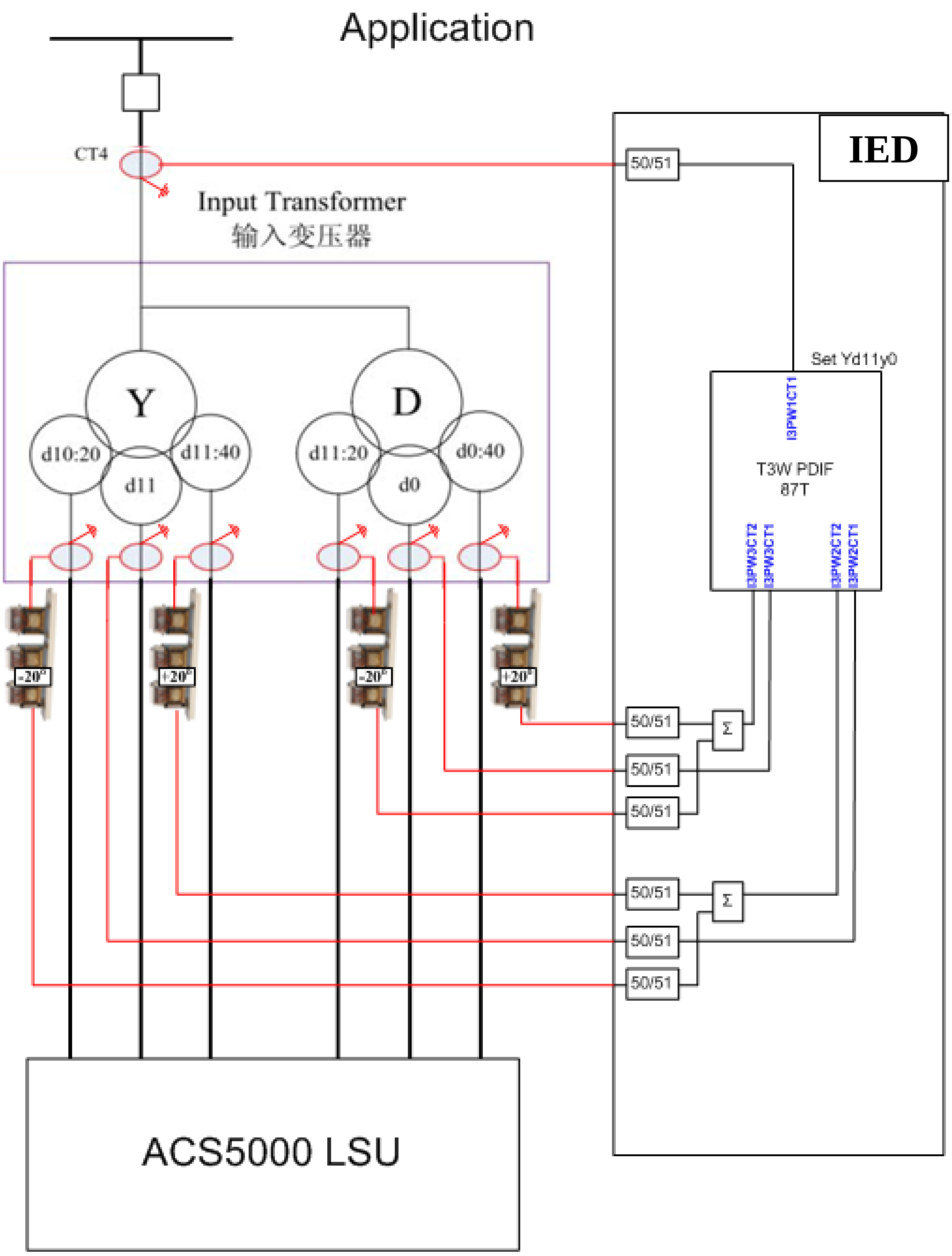

Figure 6: 36-pulse Converter Transformer with associated 87T relay

This differential protection scheme is still not in service.

6. Differential protection solution for a Cyclo-Converter Drive

MV drive installation based on the cyclo-converter principle is shown in Figure 7. Such installations are typical for mine and cement industries where low speed, high-power MV drives are required.

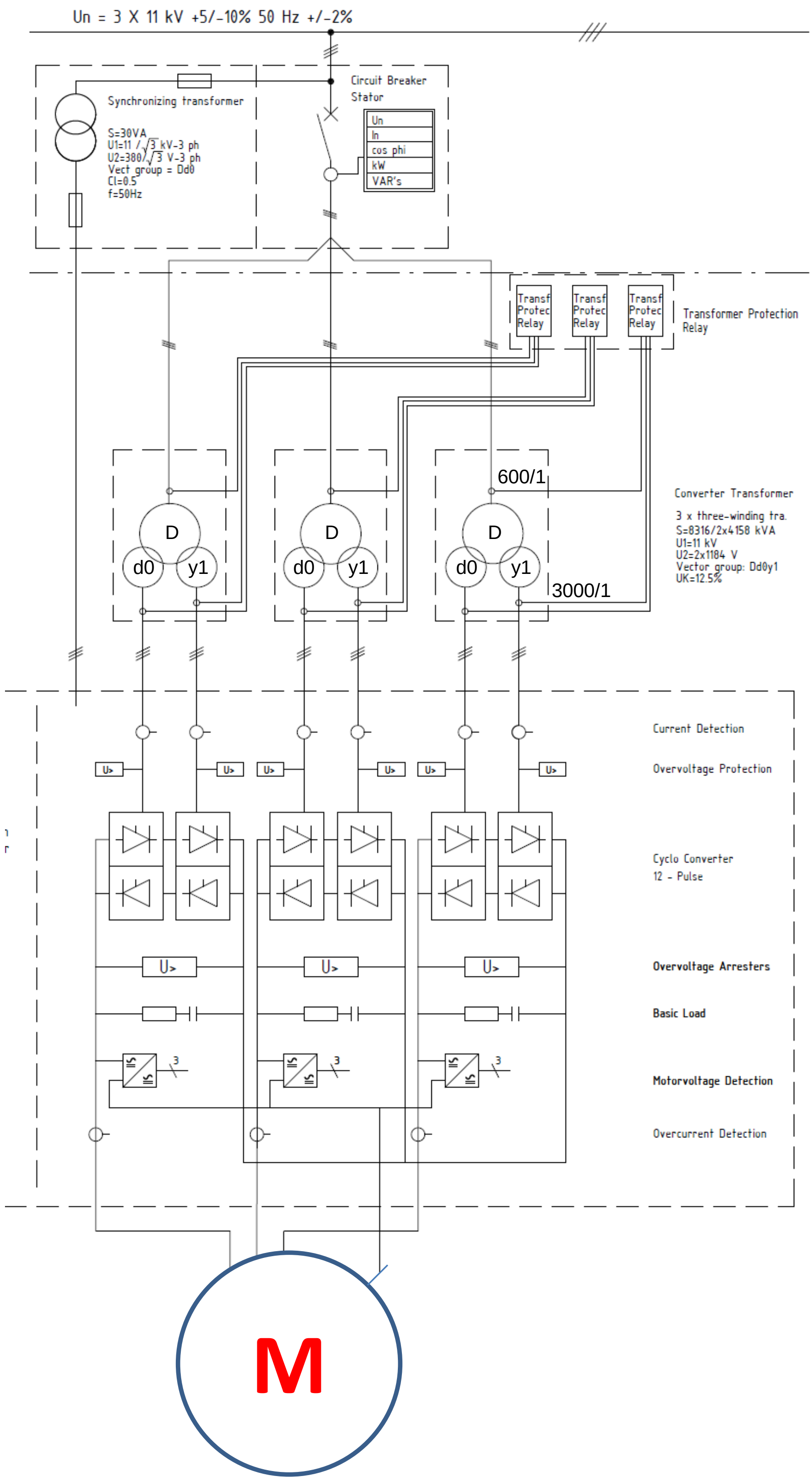

Figure 7: Cyclo-converter based MV drive application

For this application standard three-winding transformers are used as converter transformers because the twelve-pulse rectifiers are used (see Table 1). Particular thing here is that there are three such transformers connected in parallel on HV side in order to provide an AC, three-phase, variable low-frequency supply to the synchronous motor. Separate differential protection IED is provided for every one of these three, three-winding transformers. Note that these differential relays will see very specific through-load pattern, which is of a pulsating nature. Example of the typical load pattern for this MV drive is given in Figure 8. The following traces, captured by one 87T relay used in this installation, are presented in this figure:

a) HV delta winding CT secondary currents (i.e. in secondary amperes)
b) LV d0-connected winding CT secondary currents
c) LV y1-connected winding CT secondary currents

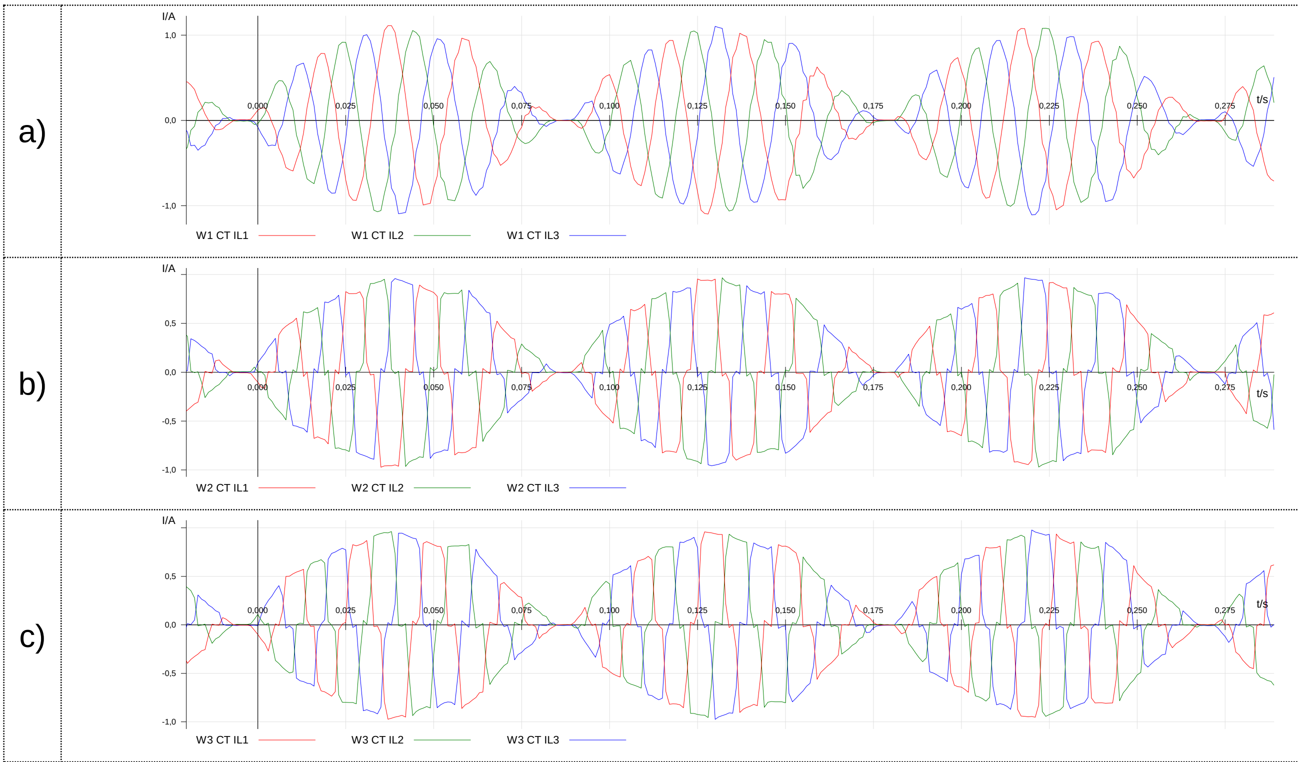

Figure 8: Main CTs secondary load current waveforms captured by the 87T relay of one transformer

From this record it can be clearly seen the pulsating nature of the load. The waveform shapes are similar to the ones in Figure 5, but on top of them there is a superimposed low frequency signal which creates the modulated (i.e. pulsating) load pattern. The frequency of this modulated signal in this figure is estimated to be around 5,5Hz. Regardless such special through-load currents the used differential relay is fully stable.

7. **Conclusion**

As shown in this paper, standard numerical differential protection IED [8] can be used for the differential protection of converter transformers. The only pre-request is that interposing CTs are used to adjust the actual non-standard vector group of the protected converter transformer to the closest standard vector group defined for the standard power transformers. In addition the used differential relay must be capable to handle quite a few number of three-phase CT inputs (e.g. seven).

Practical experience for such 87T applications has been good irrespective of the converter transformer pulse type and number of LV windings. Some of the presented 87T protection schemes are in full commercial operation for several years without any problems. Thus, this standardized way to provide differential protection for converter transformers has been successfully proven in practical installations.

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