Proc. of the 5th WSEAS/IASME Int. Conf. on Electric Power Systems, High Voltages, Electric Machines, Tenerife, Spain, December 16-18, 2005 (pp24-28)

The False Operation of the Tank Earth-Fault Protection of the Block Transformer

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Abstract: - In this paper we tackle the issues of false operation of the tank-earth protection of the block transformer during the one-phase-ground-fault on the other block transformer. Consequently two generators in a power plant were shut-down. This paper presents the results of the fault recorders and our results from computer simulations. This submission also includes our recommendations to prevent repetitive incorrect operation of this protection.

Key-Words: - Tank Earth-Fault Protection, Block Transformer, False Operation.

1 Introduction

The transformers faults may be divide into two groups: internal faults and faults caused by current flow through the transformer. Internal faults are: short-circuits in terminals, short-circuits in winding, ground-faults, wrong insulation of transformer core-laminations, cooling failure, incorrect voltage regulation etc.
Protection equipage of the transformers depends on their importance and their nominal rate.

2 The Tank Earth-Fault Protection

The tank earth-fault protection is a specific type of the transformer protection. This protection is used in electric nets where a neutral point of the transformer winding is grounded.
Principle of this protection consists in connection of the transformer frame with the earthing system through a current transformer (CT), fig. 1 [1]. The overcurrent protection is connected to the CT output terminals. This protection will act in case of all faults, when voltage will be on the transformer frame (e.g. a bush breakdown) and current will flow from frame to ground through CT. Therefore the transformer tank has to be insulated from the ground.
The tank earth-fault protection shouldn't act in case of faults in auxiliary circuits (e.g. cooling-air fan, tap changer). Therefore it is necessary to lead conductions of this devices through CT. Afterward fault F1 (fig. 1) doesn't raise a false trip of protection. And so this protection is selective [2].

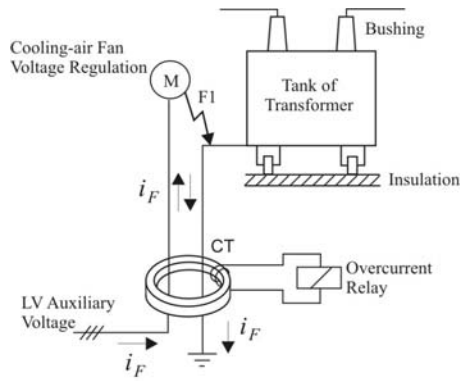

Fig.1.: Principle of the Tank Earth-Fault Protection

In practice the transformer tank earth-fault protection operates in an incorrect way. This is caused by a small value of the insulating resistance of the transformer tank (point C, fig. 2) and a resistance between the grounded point of the transformer tank (point B) and the grounding of the transformer winding neutral point.

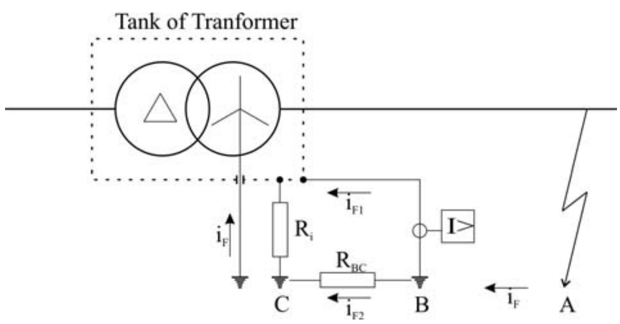

Fig.2.: False Operation of the Tank Earth-Fault Protection

During the ground fault in point "A" the fault current i_F is divided into two parts: the current i_{F2} flows from point "A" to the winding neutral point through resistance R_{BC}

and the current i_{F1} flows through the insulation resistance of the transformer tank.
For correct operation of this protection the following condition must be fulfilled:

$$R_i >> R_{BC} \quad (1)$$

The setting value of the tank earth-fault protection is given:

$$i > \frac{R_{BC}}{R_i + R_{BC}} i_{F\max} \quad (2)$$

where:

i – the setting value of the current on a overcurrent relay,
R_i – insulation resistance of the transformer tank,
R_{BC} – resistance between the grounded point of the transformer tank and the grounding of the transformer winding neutral point,
i_{Fmax} – maximal value of fault current through ground.

It is important to bear in mind an increased current density near point "C" and therefore an increase of resistance R_{BC} too.
The insulation resistance R_i is usually given by the insulation resistance of the concrete foundation. The rails, pipes etc. must not be connected with the iron armature of the concrete foundation or with the grounding system.
It is important (to ensure a right operation of the protection) to regard the fact that resistivity of concrete is within the limits from 10 to 10^6 Ωm (that mainly depends on its humidity).

2.1 Contradictory Requests to the Set up of the Tank Earth-Fault Protection

The general rule for the set up of overcurrent protections is, the protections have to be setting below value of the minimal short-circuit current.
Calculation of minimal short-circuit current is a little complicated for the set up of the tank earth-fault protection. The short-circuit can rise at any point of the transformer winding, in case of a fault near the winding neutral point short-circuit current which can be relatively small (smaller than the setting value on protection.)
Considering this, the protection set up should be minimal.
On the other hand "a wrong ratio" of the resistances R_i, R_{BC}, and the maximum fault current through the protection can cause a false operation of this protection. Therefore there is a second contradictory request that the protection set up must be maximal.
Two contradictory requests exist for a calculation of the tank earth-fault protection set up:

1. A minimal setting current value of protection in respect to fault near the transformer winding neutral point.
2. A maximal setting current value of protection in respect to maximal short-circuit current through the ground and a "wrong ratio" of resistances R_i and R_{BC}.

Concrete and correct set up of protection is important to know a value of the insulation resistance R_i and resistance R_{BC}, or their ratio.
The value of the insulation resistance varies markedly (results from protocols about protection set up are that R_i fall within limits 200 Ω to 50 kΩ). It is necessary to perform measurements of this resistance in the worst conditions, e.g. wet concrete foundation and to perform measurements of insulation resistance dependency on voltage. It is necessary to measure value of resistance R_{BC} for a correct set-up.

3 Description of an Event of the Protection False Operation

Shut-down of two generators in the power plant comes in consequence of the protection incorrect operation.

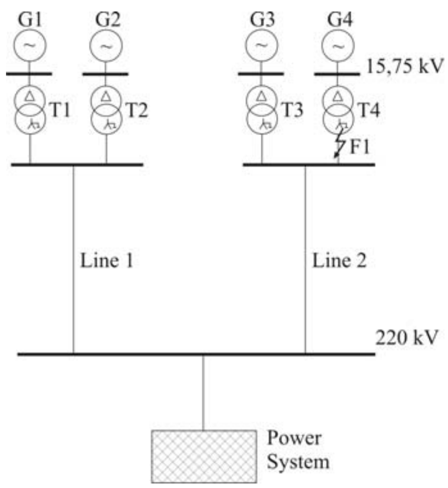

Fig.3.: Simplified Scheme of the Power Plant

The cause of this failure was the bushing breakdown on the 220 kV side of the block transformer T4 at phase L2. Afterwards, protections of this power plant unit act ed correctly and the block transformer T4 and the generator G4 were shut-down.
Following the incorrect action of the tank, the earth-fault protection of the second block transformer T3 incurred transformer shut-down and subsequently the generator G3 was shutdown.

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Operation of protection during ground-fault:

Time	Protection	Status
1:33:31.578	Tank earth-fault of T4	1
1:33:31.578	Tank earth-fault of T3	1
1:33:31.601	Differential protection of unit TG4	1
1:33:31.688	Buchholz relay of T4	1

The RMS values of the generator currents before one-phase-ground-fault and during this fault are in the following table. These values are obtained from the fault recorders of generators.

Table 1: RMS values of generator currents

Generator	Currents in phase L1 [A]		Currents in phase L2 [A]		Currents in phase L3 [A]	
	before fault	during fault	before fault	during fault	before fault	during fault
G1	7109	7892	7131	13085	7278	7749
G2	7447	7812	7432	12935	7593	7617
G3	7710	8221	7711	19745	7834	12675
G4	7698	8254	7656	19925	7842	12855

4 The Computer Simulations to Recognize a Reason of the Protection False Operation

Actual steady state was simulated before fault. Then we performed the one-phase-ground-fault at phase L2 of the block transformer T4. It was very important to model the grounding of all transformers in the right way.

The grounding of the transformer winding neutral point (on 220 kV side), the transformer tank grounding and insulation resistance of the transformer tank were performed according to fig. 4. This model was used for all four transformers T1-T4 with the same value of the resistances R_{z0}, R_i and R_{BC}

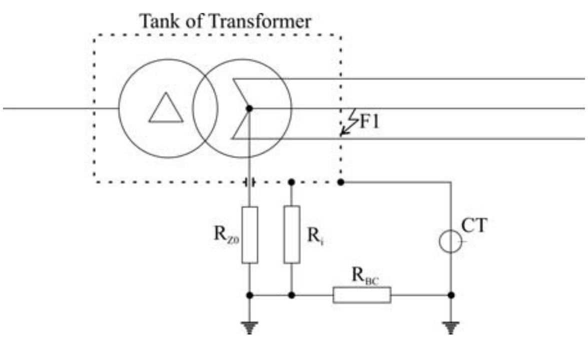

Fig.4.: Simulation Circuit of Transformer

In respect tothis events analysis we can write that the protection false operation wasn't caused by failure in secondary circuits of the current transformer or failure of the protection itself. Afterwards, current through the ground strap of transformer T3 tank had to be greater than 200 A (setting of the protection is 5 A, ratio of CT is 200 A/5 A)

The current through the ground strap of the transformer tank (primary current of CT) depends on the ratio of resistances R_i and R_{BC}, and value of fault current flows through ground to 220 kV winding neutral point

Current through the tank earth-fault protection depends on a volt drop on resistances R_{BC},R_i, and on value of the insulation resistance R_i.

Results from the protocols about protection set-up is that the value of the insulation resistance varies markedly (within limits 200 Ω to 50 kΩ)

That means, false operation of the tank earth-fault protection of transformer T3 was caused by a "wrong ratio" of resistance R_{BC} and R_i.

On the following figures we present time-behaviors of generator currents during the one-phase-ground-fault on transformer T4 from simulations.

Current values during this fault are co-equal to values from the fault recorders of generators.

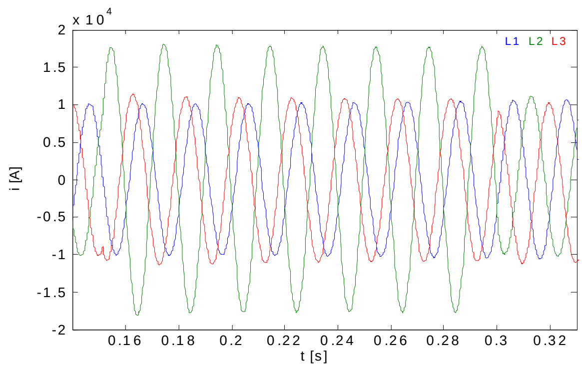

Fig.5.: Currents of Generator G1

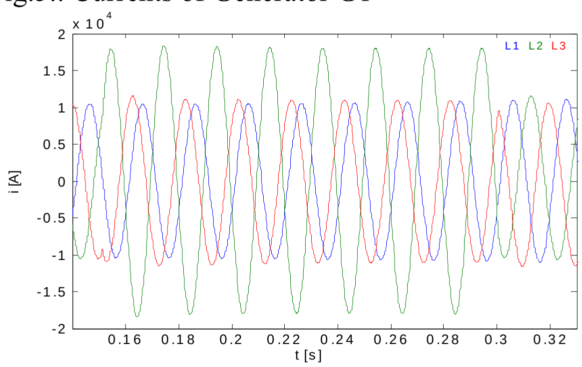

Fig.6.: Currents of Generator G2

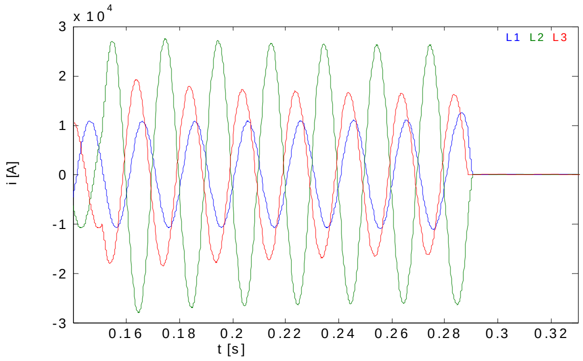

Fig.7.: Currents of Generator G3

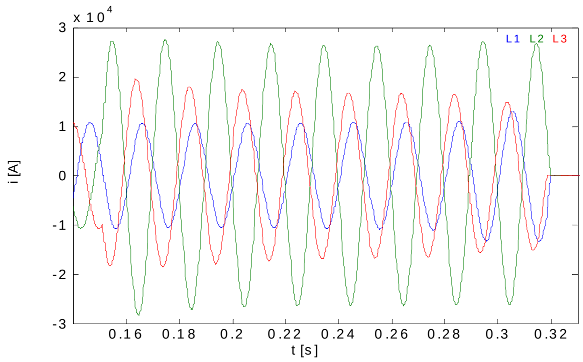

Fig.8.: Currents of Generator G4

Currents through the tank earth-fault protections of all transformers during the fault on transformer T4 are in figures 9 to 12.

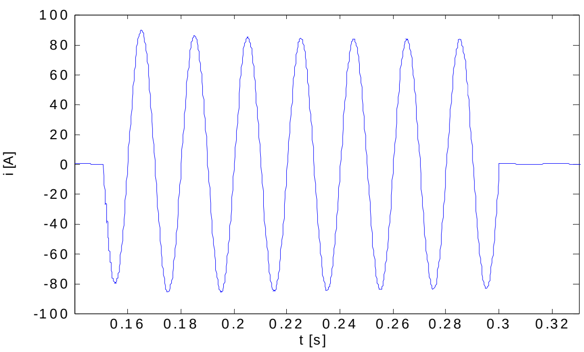

Fig.9.: Currents of Tank Earth-Fault Protection of Transformer T1

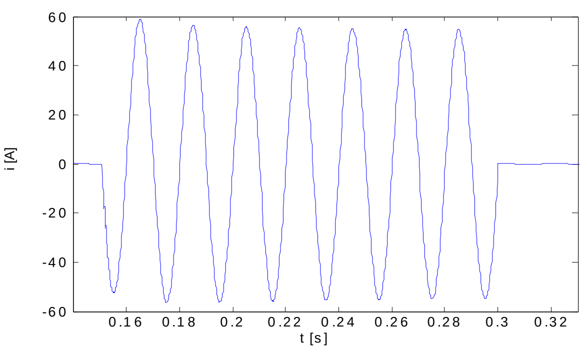

Fig.10.: Currents of Tank Earth-Fault Protection of Transformer T2

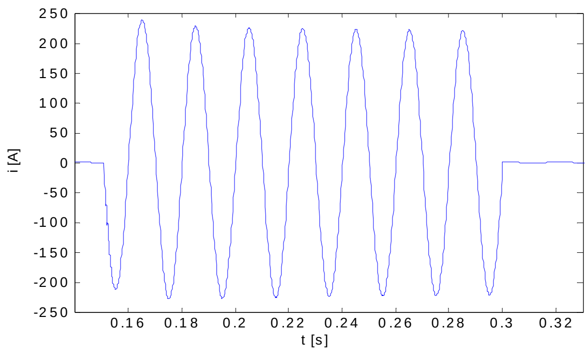

Fig.11.: Currents of Tank Earth-Fault Protection of Transformer T3

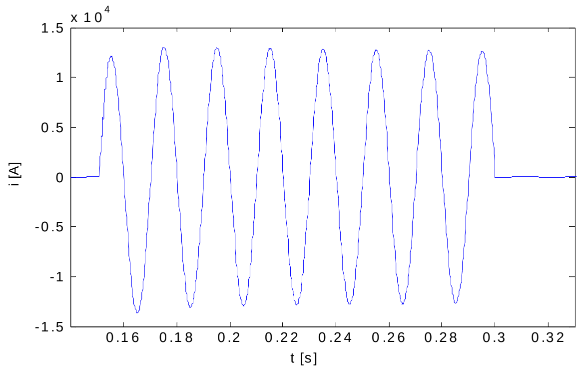

Fig.12.: Currents of Tank Earth-Fault Protection of Transformer T4

We can see that the tank earth-fault protection of transformer T3 should operate false because the current achieved greater value than the setting value on protection.

The protections of transformers T1 and T2 shouldn't act false because in this case currents are restricted by a relatively great value of zero-sequence impedance in lines 1 and 2.

The protection of transformers T4 should act correctly. The current through this protection is equal to a total fault current.

5 The Proposal of Solution to False Operation of the Tank Earth-Fault Protection Prevention

One of the possible solutions is set-up of protection greater values (maximal possible values is 10 A) to prevent their false operation. But there is a risk, the protection shouldn't operate in case of fault near a transformer winding neutral point.

From performed analysis of this problem, it is evident that in case of fault on transformer winding the fault current flows always from the tank to the grounding.

The case of fault at any points of the power system (e.g. fault on the other transformer) the current flows through the protection in opposite direction.
Therefore, our proposed solution is to use directional overcurrent relay to avoid false operation of the tank earth-fault protection.
Another solution is to replace the tank earth-fault protection by different types of protection:

- the ground-fault protection for transformer winding wye-connected (fig. 13),
- the combined differential and ground-fault protection (fig. 14).

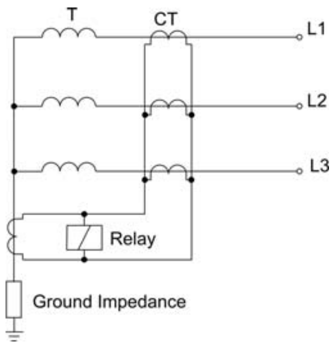

Fig.13.: Principal Scheme of Ground-Fault Protection for Transformer Winding Wye-Connected

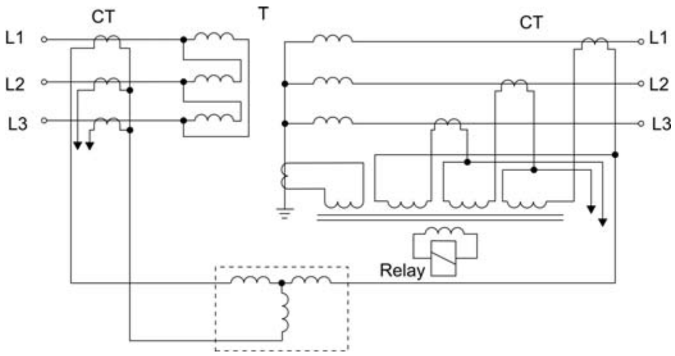

Fig.14.: Principal Scheme of Combined Differential and Ground-Fault Protection

6 Conclusion

There exist two contradictory requests for the set-up of the tank earth-fault protection.
For concrete and correct set-up of protection, it is important to know the value of the insulation resistance R_i and resistance R_{BC}, or their "wrong" ratio.
We propose three possible solutions to prevent false operation of this protection:

1. To set-up the protection on greater values (maximal possible value is 10 A) to prevent their false operation. However there is a risk that the protection will not operate in the case of fault near a transformer 220 kV winding neutral point.
2. To use directional overcurrent relay in this protection.
3. To use another type of protection: the ground-fault protection for the transformer winding wye-connected or the combined differential and ground-fault protection.

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This work was supported by Science and Technology Assistance Agency under the contract No. APVT-20-002004