

Identification of Power Transformer's Failure and Risk Source

Gerards Gavrilovs (*PhD student, RTU*), Sandra Vītoliņa (*assoc. prof., RTU*)

Abstract – Power transformer is vital link in the chain of components constituting a power system, the failure of which affects the supply of electric power to the consumers. The transformers are found to be very reliable, but in some power systems of different countries the transformer's tripping amount are quite high and majority of these accidents have ambient causes.

The paper describes types of risk and the probable causes of failure of major equipment-power transformer and power system at all. There are some data of power system's tripping causes and protective relaying. Also the proposals how to prevent fault or cause of failure are given.

Keywords – Risk assessment, failure, power transformer, technical condition assessment, protective relaying.

I. INTRODUCTION

Risk assessment is the process of characterizing, managing and informing others about existence, nature, magnitude, prevalence, contributing factors and uncertainties of the potential losses. From an engineering point of view, the risk or potential loss is associated with exposure of the recipients to hazards and can be expressed as a combination of the probability or frequency of the hazard and its consequences. Consequences to be considered include injury or loss of life, reconstruction costs, loss of economic activity, environmental losses, etc.

Generally speaking, a risk assessment amounts to addressing three very basic questions [2]:

- what can go wrong?
- how likely is it?
- what are the losses (consequences)?

The answer to the first question leads to identification of the set of undesirable (accident) event and further it is considered in the paper. The second question requires estimating the probabilities (or frequencies) of these event, while the third estimates the magnitude of potential losses. This triplet definition emphasizes development of accident events as an integral part of the definition and assessment of risk [1]. Risk events are in fact one of the most important products of risk assessment and it found really wide application in maintenance of power transformers.

These basic questions mentioned before concerning power transformer's risk assessment are defined rather often, particularly during the equipment commissioning process.

Power transformers age increases the risk of failure due to the aspect that internal condition degrades. Failures are usually triggered by severe conditions, such as lightning strikes,

switching overvoltages, short-circuits or other incidents. When the transformer is new, it has sufficient electrical and mechanical strength to withstand unusual system conditions. As transformers age, their insulation strength can degrade to the point that they cannot withstand system events such as short-circuit faults or overvoltages.

Preventing these failures of transformers and maintaining transformers in good operating condition is a very important issue for utilities. Traditionally, routine preventative maintenance programs combined with regular testing were used. With deregulation, it has become increasingly necessary to reduce maintenance costs and equipment inventories. This has led to reductions in routine maintenance. The need to reduce costs has also resulted in reductions in spare transformer capacity and increases in average loading. There is also a trend in the industry to move from traditional time-based maintenance programs to condition-based maintenance [8].

These changes occur at a time when the average service life of the transformers is increasing and approaching the end of nominal design life. Testing the transformer requires significant time with the associated direct and indirect costs to do it. On the other hand, reenergizing a faulted transformer can lead to catastrophic equipment failure. Analysis of abnormal state of power system and finding of its causes also is expedient and invaluable.

Fig. 1 represents risk assessment methodology during maintenance of power transformers.

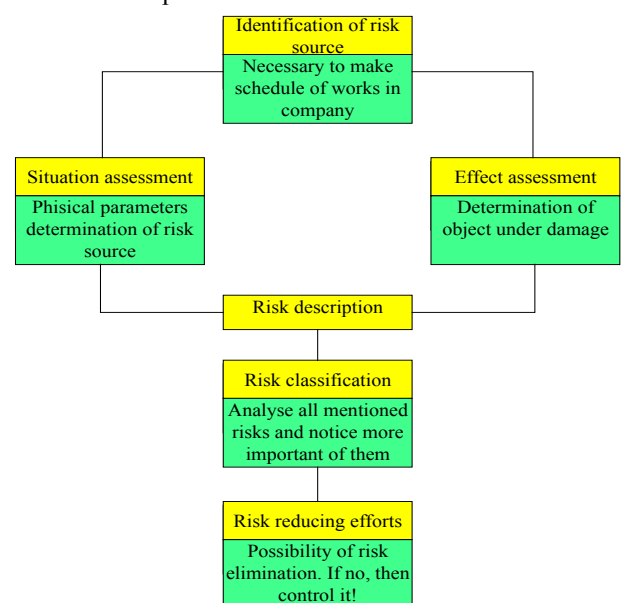


Fig. 1. Risk assessment methodology.

TABLE I
POWER TRANSFORMERS INCIPIENT FAULTS AND CAUSES

Causes	Faults			
	Arcing	Corona	Overheating of cellulose	Overheating of oil
Winding turn-to-turn short-circuit	X		X	
Winding open circuit	X		X	
Operation of build-in OLTC	X			
Winding distortion or displacement		X	X	
Lead distortion or displacement		X	X	
Loose connection to bushing terminals, tap leads, terminal boards	X	X	X	
Free water or excessive moisture in oil	X	X		
Floating metal particles	X	X		
Loose connection to corona shields		X		
Loose collars, spacers, core ground straps,		X		
Through fault			X	
Overloading			X	X
Damaged yoke bolt insulation				X
Rust or other damage on core				X
Damaged shunt packs of tank				X
Jammed oil circulating path				X
Cooling system malfunction				X

Each block of Fig. 1 should be particularly investigated and the decision of real situation must be clear. Situation assessment and identification of risk source blocks are under main attention in this paper.

II. POWER TRANSFORMER FAILURES AND SYSTEM SWITCHING

This part of paper is dedicated to analysis causes of power transformer failure.

The failure of power transformer mainly is the event of inadequate producing and/or incipient fault.

Incipient faults of power transformers can be classified into the following major categories [3,4]: electrical arcing, electrical corona, overheating of cellulose, overheating of oil. This classification standardized, but not the only one that is being use. According to Table 1, one fault type may have more than one cause [5]. This makes fault location very difficult.

Power transformer failures can be broadly categorized as electrical, mechanical or thermal. The cause of a failure can be internal or external, as shown in Table 2. This table lists typical causes of failures in the main tank. In addition failures can also occur in the bushings, in the tap changers or in the power transformer auxiliaries [6, 7].

A power transformer can fail from any combination of electrical, mechanical or thermal factors. While it is difficult to define a typical failure for a transformer due to its complexity, the most common actual failures involve and eventually result from the breakdown of the transformer's insulation system.

Electrically induced factors – typically result in damage to a transformer's insulation system. Some of the more common electrically induced factors are: operation of a transformer under transient or sustained over-voltage conditions; exposure to lightning surges and switching surges; partial discharge, which can be caused by poor insulation system design, by manufacturing defects and/or by contamination of the insulation system (both the solid insulation and oil).

Also static electrification can occur in which, a static charge is developed between the insulating oil and metal components of the transformer. These failure modes may be discovered in combination with one another or in combination with other mechanical or thermal evidence.

TABLE II
TYPICAL CAUSES OF TRANSFORMER FAILURES

Internal	Insulation deterioration
	Loss of winding clamping
	Overheating
	Oxygen
	Moisture
	Solid Contamination in the insulating oil
	Partial discharge
	Design and manufacture defects
External	Winding resonance
	Lightning strikes
	System switching operations
	System overload
	System faults (short circuit)

Mechanically induced factors typically result in the deformation of a transformer's windings, resulting in the abrasion or rupturing of its cellulose insulation. If the damage is severe enough, the transformer can fail electrically. It is difficult to predict how long a transformer can survive with this kind of damage and is entirely dependent upon its severity.

Thermally induced factors – the degradation of a cellulose insulation system is to be expected to appear over time. Thermal degradation results in the loss of physical strength of the insulation that will weaken the paper to the point. It can no longer withstand the mechanical duty imposed on it by the vibration and mechanical movement inside of a transformer. A well-designed and properly operated and maintained transformer's insulation system should be able to provide reliable service for 30 years or more [6].

The most common thermally induced factors are summarized as follows: overloading of the transformer beyond

its design capability for extended periods of time; failure of a transformer's cooling system, which can include blocking or fouling of the radiators or coolers, the failure of the oil pumps and the failure of a direct flow oil distribution system; blockage of axial oil duct spaces, limiting the amount of cooling oil to the windings in the immediate area; operation of the transformer under excessive ambient temperature conditions.

It is important for all factors to be evaluated together in order to develop an accurate failure assessment.

III. CASE STUDY

When a power transformer protective relaying operates with no obvious transformer fault, system operators have a serious decision to make. Is there a power transformer fault or did the relay operate incorrectly? The answer on this question can be found only after analysis of each particular situation.

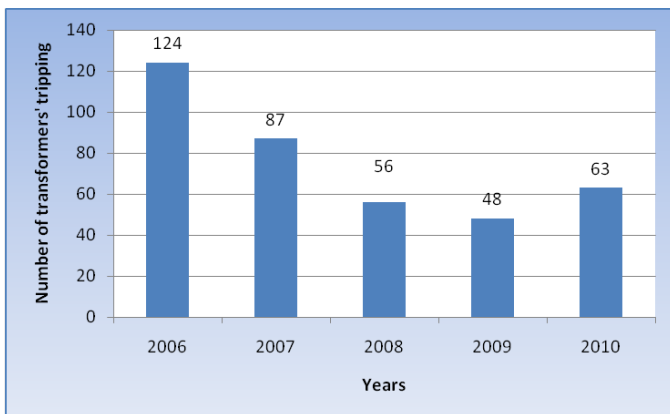


Fig. 2. Power transformers' tripping.

Useful information can be obtained by analyzing the statistical data on the number of transformer disconnection. For this purpose, data are evaluated for the period of 5 years: from 2006 till 2010.

Fig.2. shows the number of power transformers tripping due to operation of protective relaying, which is taken as basic data for further analysis

In mentioned example power transformers are two performance types: by UGS and IEC standards. The data analysis of these transformers tripping times, corresponding to manufacture, due to operation of protective relaying is not the aim of this paper.

To have a good prefiguration of causes and times of tripping, which has influence on power transformer normal working state in maintenance, let's have a look on this statistic data during years in figure of causes, Fig.3.

For example let's look at data from 2009 in Fig.3. The total number of power transformers tripping was 48:

- 21 due to Buchholz relay (BR gas protection),
- 14 due to transformer current differential protection (TCDP),
- 13 due to overcurrent protection (OCP).

Mainly power transformer's protection operation was raised by fault of power system (location of short current), by separate protective relaying or its fault operation. The amount of OCP tripping is described by element of nature in winter of 2010. The cause of tripping was overturned trees.

Only one incident of TCDP operation was recognized as fault of power transformer itself in 2009. Similar pattern can be observed in 2010, Fig.4.

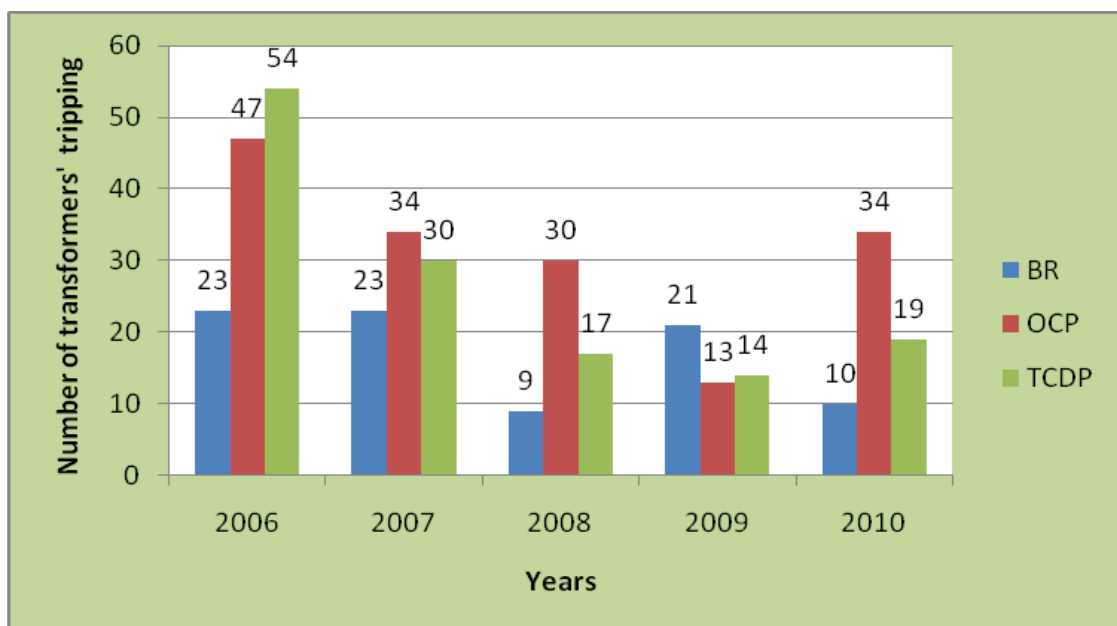


Fig.3. Density of operated protection.

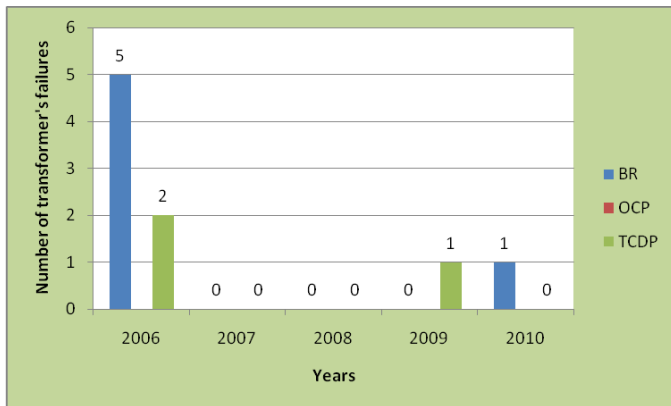


Fig. 4. Number of tripping due to power transformers' failures.

Transformer tripping due to fault of power transformer itself occurred once, and the reason of power transformer failure was short-circuit in high voltage windings.

Another survey about acquittal functionality of protective relaying during 5 years of maintenance since 2006 till 2011 was performed. It showed that approximately about 10% (37 transformer trips) were caused by false operation of relay protection; 3% (9 transformer trips) were due to failure of power transformer itself and approximately 87% (332 transformer trips) were due to faults in power system.

IV. CONCLUSIONS

Tripping of power transformers brings to many inconvenience related with maintenance and power supply for consumers. Analysis of transformers' tripping allows making a conclusion, that the highest proportion of causes of transformer tripping has power system faults (87%) which are followed by false operation of protective relaying (10%). Only 3% of the causes of tripping are due to failures in transformer itself.

The causes of transformer failure might be very different and the consequences could be unchangeable. The full analysis of abnormal regime must be done with step by step method, which is described and illustrated at the beginning of paper.

Technical experience and correct terms of maintenance with investigation of each fault, decrease amount of tripping and perfect operation of all power system. The figures in paper approve this acknowledgement.

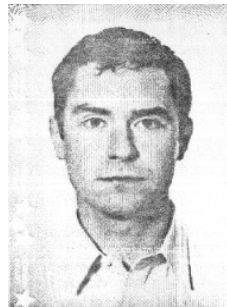
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Gerards Gavrilovs

PhD student
Riga Technical University,
Power Engineering Institute
Address: Kronvalda blv. 1, LV-1010, Riga, Latvia
Phone: +371 26472039
Email: gerards.gavrilovs@latvenergo.lv
Research interests: Prognosis and risk analyse of power transformers technical condition



Sandra Vitolina

Dr.sc.ing., associate professor
Riga Technical University,
Power Engineering Institute
Address: Kronvalda blv. 1, LV-1010, Riga, Latvia
Phone: +371 67089418, fax 67089418
Email: sandra.vitolina@rtu.lv
Research interests: technical condition's assessment of high-power electrical machines