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Reliability Enhancement of Power Transformer Protection System

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ABSTRACT

The power transformer is considered not only as an important and expensive component in power system; but also the most dangerous element because it contains a great quantity of oil in contact with high voltage elements. Thing which favors the risk of fire and explosion in case of abnormal circumstances or technical failures.
This paper presents an analytical approach allowing the reliability enhancement of power transformer protection system.
After indicating the different faults undergone by power transformer and their protections, failure modes model and protection system reliability evaluation are developed using two methods: a Fault Tree Analysis (FTA) and a Failure Mode Effect and Criticality Analysis (FMECA) which permit the identification of weak points in the protective system and hence reinforcing it in order to reduce the failure risk.
KEYWORDS: reliability, failure risk, power transformer, protection system.

I. INTRODUCTION

Power transformers are found at all levels of the power system from the generating station to the end user facility. And the availability as well as the quality of supply is mainly related to the health of transformers. The capital loss of an accidental power transformer outage is often counted in million dollars for output loss only, not to say the costs associated with equipment repair or replacement.

A transformer fire or explosion that involves several thousand gallons of combustible insulating oil can result in severe damage to nearby power plant structural components such as concrete walls and damage or destroy electrical components such as nearby transformers, buswork, and circuit breakers [1].

Under the deregulation policy of electric systems, each utility is trying to cut its cost. This pass evidently by the reduction of the failure of power system, where the reduction of the failure risks of power transformer represents a major marigold.

If a transformer experiences a fault, it is necessary to take it out of service as soon as possible in order to minimize the expected damage and avoid a catastrophic event. This passes necessary by the rational selection and design of the protection system.

Before thinking in the optimization of any system, it is necessary to determine their points of weakness like their degree of criticality. This makes it possible to plan and to focus the efforts by set of priorities with a general aim is to improve the reliability of the system, and consequently, to reduce their failure risk.

In this study, we will analyze the reliability of the protection system of power transformer using the fault tree method. After that, ordering of the criticality of failures allows the identification of the week links in the protection system.
Further, reliability improvement using the redundancy technique will be applied and analyzed.

II. FAILURES MODES AND THEIR CAUSES

Transformers are subjected to many external electrical stresses from both upstream and downstream. The consequences of any failure can be very great in terms of damage as well as in terms of operating losses. [2]
Fig1 illustrates the different failure modes of power transformer and their causes.

III. POWER TRANSFORMER PROTECTION SYSTEM

Protective system of power transformer is consisted of several elementary protections; each of them assures one or more than function. The performance of the system is depending on the choice of its components and the design of its general structure. The most common used protections are described below:

III.1. Overvoltage Protections

Overvoltage protection is assured by Earth wires, Spark gaps or Lightning arrestors.

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III.1.1 Earth wires

The earth wires placed above the power lines attract the thunderbolt, and hence avoid the thunder-striking on the phase conductors.

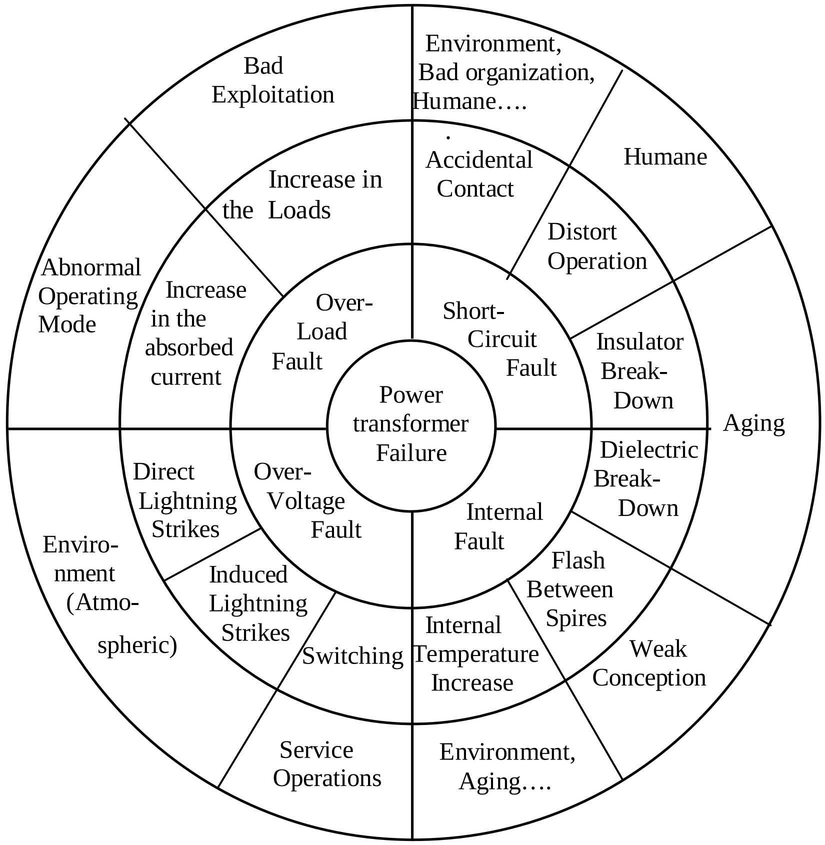


Fig. 1. Failure-cause diagram of power transformer

III.1.2 Spark gaps

The spark-gap is a simple device consists of two electrodes, the first connected to the conductor to be protected, the second connected to the ground. At the place where it is installed in the network, it presents a weak point for discharging the over-voltages to the ground and thus protects the equipments. The arcing-voltage setting of the spark-gap is adjusted by acting on the distance in the air between electrodes. [3]

III.1.3 Lightning arrestors

The lightning arrestors are apparatuses intended to limit the over-voltages imposed on electric transformers, instruments and machines by the lightning and by maneuvers of commutation. The upper part of the lightning arrestor is connected to one of wire of the power line to be protected and the lower part is connected to the ground by a low resistance earthing, generally with less than one ohm. Their principle of operation is based on strongly non-linear resistances which present an important reduction in their inner resistance above of a certain terminal voltage value.[4]

III.2. Overload Protections

The overload protection must act with a threshold values ranging between 110 and 150 % of the rated current and preferably operate in a time dependant manner .The protective devices that have above mentioned characteristics are fuses and thermal relays. [1]

The fuses are largely used in the distribution transformers, primarily because of simplicity and of the limited cost. However, the technological limits of their realization involve a certain number of disadvantages. This protection can be placed on either primary or secondary side of power transformer.

For low transformer power, the position of the protection is suitable on the low voltage side. While; for high power, the more chosen place of protection is on the HV side.

III.3. Short-circuit Protections

The protective devices that may be used for protecting the power transformer against the short circuits are: circuit breaker (electromagnetic relays) and fuses.

Due to disadvantages of the fuses such as they can be used once time only and they can't be adjusted but they are still used because of simplicity and its limited cost.

III.4. Internal faults Protections

The protection of the transformers against the internal defects (internal Breakdowns HV / Ground or between turns) is ensured through Buchholz relay and the temperature sensors.

IV. PROTECTION SYSTEM MODELING USING THE FAULT TREE METHOD

The Method of fault tree is widely used in the field of the Reliability. It offers a framework privileged to the deductive and inductive analysis by means of a tree structure of logical gates. This method is recognized by international standards (UTE C 20-3 18, CEI 1025, ECSS-Q-40-12) [5].

The principal treatments carried out on the fault tree are the research of the minimal cuts and the quantitative evaluation.

The minimal cuts represent the smallest combinations of events whose simultaneous realization involves that of the undesirable event. They have as an order the number of events which constitutes them.

For the modeling of the protection system of power transformer we will consider that is composed of:

- Protection against short circuit: Fuse.
- Protection against overvoltage: spark gaps.
- Protection against internal fault: temperature sensor.
- Protection against over load: Fuse.

Fig.2 illustrates the fault tree model of such protection system.

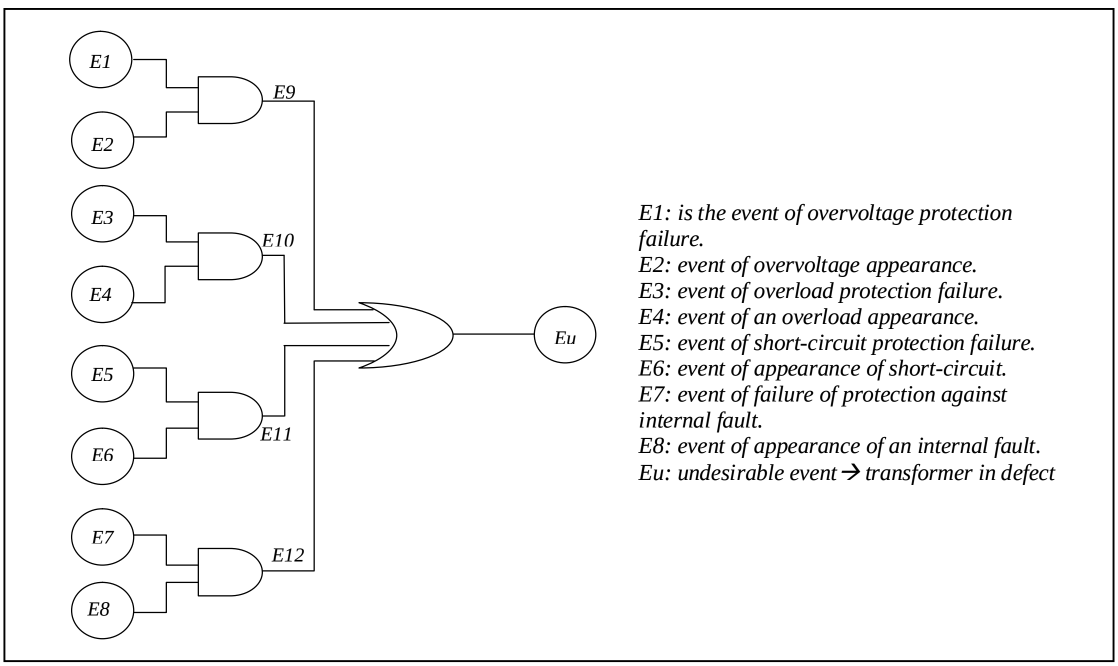


Fig. 2: Fault tree model of the protection system.

According to this model, there are four immediate causes of the top event Eu which are: E9,E10,E11,E12.

E9: overvoltage fault.
E10: Overload fault.
E11: Short circuit fault.
E12: Internal fault.
The decomposition of these events leads to the basic events E1,E2,E3,…,E8.

$$E9 = E1 \wedge E2$$
$$E10 = E3 \wedge E4$$
$$E11 = E5 \wedge E6$$
$$E12 = E7 \wedge E8$$

$$Eu = E9 \vee E10 \vee E11 \vee E12$$
$$= (E1 \wedge E2) \vee (E3 \wedge E4) \vee (E5 \wedge E6) \vee (E7 \wedge E8) \ldots (*)$$

Equation (*) represents the logical equation of this model.

V. FAILURE PROBABILITY QUANTIFICATION

Assuming that the failure rate (λ_i) of the different elements of the protection system is constant, then its reliability can be esteemed by the exponential law and the failure function will express as follows [6][7]:

$$R_i(t) = e^{-\lambda_i t}$$

$$F_i(t) = 1 - R_i(t) = 1 - e^{-\lambda_i . t}$$

The weighted failure probability values of the basic events of the fault tree model are given as follows [8]:

- Failure rate of overvoltage protection is 0.0570.
- Failure rate of overloads protection is 0.0690.
- Failure rate of short-circuits protection is 0.0750.
- Failure rate of internal protection is 0.0953.
- Probability of an overvoltage appearance is 0.1600.
- Probability of an overload appearance is 0.1900.
- Probability of an internal defect appearance is 0.0329.
- Probability of a short-circuit appearance is 0.0800.

The calculation carried out using ERPT[1] software (or Relex Architect) is represented in Fig. 3.

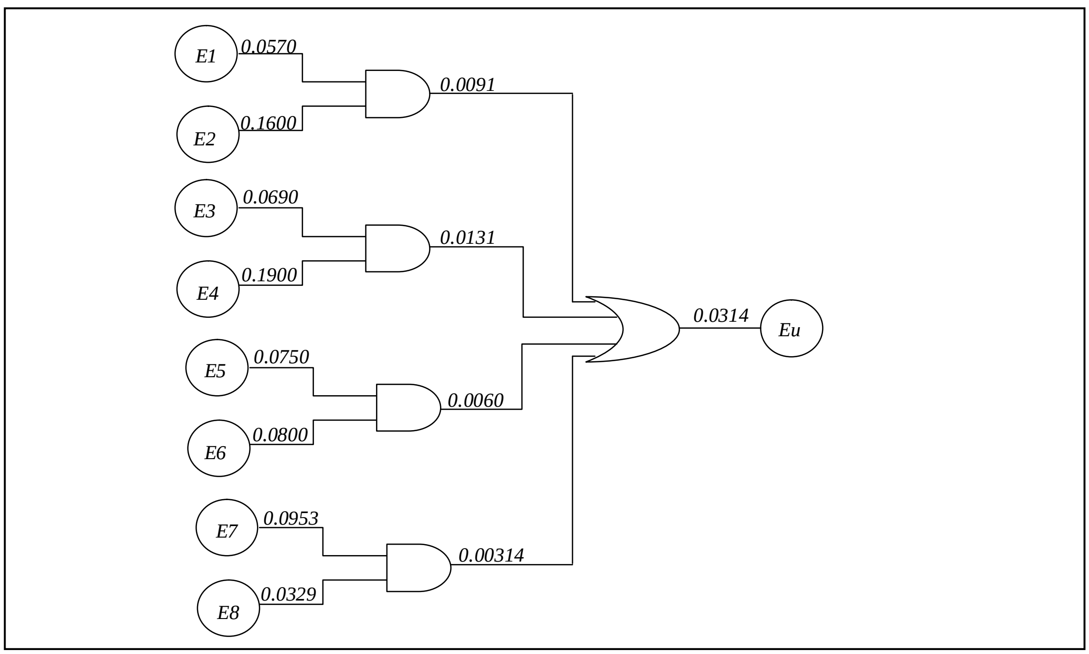


Fig. 3: Results of calculation of the fault tree model.

Reliabilities functions of the different elements of protective system, as well the reliability function of the whole system, are represented in Fig.4

[1] ERPT (version 1.1 2011) software of calculation and simulation developed by the authors in the university of Boumerdes, Algeria.

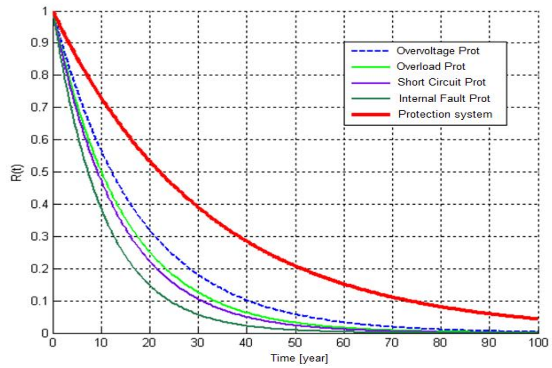


Fig. 4: Reliability functions of elements of protection

These curves allow the determination of the reliability function R(t) of elements in a given instant.
They also make it easy to classify failure rates of elements.
More the curve is concave; more the failure rate of the represented element is significant.

VI. ANALYZE OF THE CRITICALITY OF FAILURES

The FMECA, which is an inductive method, seeks to identify the origin of potential failures and weak points in this protection system, classifies them in term of criticality and then determines the way of reducing their probability of occurrence.
We can deduce the descending order arrangement of the failure probability of the different protective elements as follows:

$$\lambda_{IFP} > \lambda_{SCP} > \lambda_{OLP} > \lambda_{OVP}$$

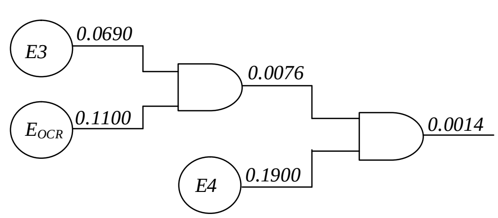
Where:
λ_{IFP}: failure rate of Internal Fault Protection.
λ_{SCP}: failure rate of Short-Circuit Protection.
λ_{OLP}: failure rate of Over Load Protection.
λ_{OVP}: failure rate of Over Voltage Protection.

So, the highest failure rate is that of protection against the internal faults. But the most critical link in the protective system is the protection against overload (see Fig.3).

VII. FAILURES PROBABILITY REDUCTION OF CRITICAL ELEMENT

After identifying the criticality of the different elements of the protection system; it will be clear where one must focus the efforts to reduce the failure risk of the critical bond (which is here the protection against overload) and, consequently, improve the reliability of the whole system.

The use of the redundancy (backup element) allows a significant reduction of failure rate. For example, if we use over current relay (its failure rate is EOCR=0.1100) as a backup protection against overload faults, the failure rate of this protection will be:



So, the failure rate is reduced by almost ten times comparing with the protection without redundant element (from 0.0131 to 0.0014).

The whole system failure rate is decreased from 0.0314 to 0.0197.

Thus, the addition of one element only in a specific point of the protection system leads to the reduction of the whole system's failure rate by about one third.

If the security level is not yet satisfy, one must reorder the failure rates and reclassify them. Then the reliability of the most critical element must be improved using a redundant protection element and so on until we arrive to the wanted security level.

VIII. CONCLUSIONS

The evaluation and the optimization of the reliability of protections are essential to conceive increasingly powerful systems and with high confidence level.

In this paper, we proposed a comprehensive approach allowing the reduction of the failure risk of power transformer by acting on the reliability of protections.

The use of the redundancy technique on the power transformer's protection system allows:

- to reduce the failure rate.
- to increase the reliability and the lifespan of the transformers.
- to ensure a continuity of service more reliable and more secure.
- to improve the technical and economic indices of the exploitation.

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