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# A novel validated solution for lightning and surge protection of distribution transformers

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ABSTRACT

This paper proposes an industrial solution (equipment) for lightning and surge protection of distribution transformers. The proposed protection equipment has been installed at 100 distribution transformers (sample) of the Public Power Corporation (PPC) of Greece. The article estimates the future transformer failures, considering two different cases: (a) transformer without the proposed protection system; and (b) transformer equipped with the proposed protection system. Three different methods are used to estimate the future transformer failures without the proposed protection system: Monte Carlo simulation, Poisson statistical distribution, and binomial statistical distribution. These three methods together with the *c* control chart method are also used in this paper, for the case of transformers equipped with the proposed protection system, to estimate the maximum allowable number of yearly transformer failures in order the proposed protection system to be considered as an effective protection means. Moreover, the article computes the satisfactory sample size of transformers in which the protection system has to be installed in order to be able to obtain statistically reliable results regarding the effectiveness of the proposed protection system. The results show that the proposed method is an excellent means for lightning and surge protection of distribution transformers, since zero transformer failures have been observed so far during the whole period of its operation (29 months), in contrast with 8.36 average lightning and surge related failures per year in the same sample of 100 transformers before the installation of the proposed protection equipment.



## Introduction

Distribution transformers are among the most expensive and critical units in a power system [1,2]. Transformer failures are sometimes catastrophic and almost always include irreversible internal damage [3]. Consequently, it is very important to install protection systems to the transformers of an electric power system [4].

A method for discrimination between magnetic inrush current and internal fault current in transformer differential protection can be found in [5]. Insulation failure in transformer winding is detected by artificial neural network (ANN) and k-nearest neighbors [6]. A transformer fault diagnosis system is developed in [7], which is based on dissolved gases analysis by extracting fuzzy rules from Kohonen self-organizing maps. An ANN is used to predict incipient transformer faults [8]. Diagnosis criteria for detection of low-level short circuit faults in transformer windings are obtained by sweep frequency response analysis [9]. A percentage differential relaying method for the protection of power transformers based on transient signal analysis and discrete wavelet transform is proposed in [10]. Chaos theory and surge arrester device based on metal oxide varistor are used for ferroresonance suppression in power transformers [11].

The electrical and mechanical design considerations for a transformer include lightning and switching surge voltages [1,12]. Both of these surge voltages can cause serious damage to the distribution transformer [1]. Both lightning and switching surge voltages are large magnitude traveling waves, which travel at the speed of light. The distribution transformer is designed and manufactured with a user-specified basic impulse level (BIL) rating. The BIL rating determines the level of lightning and switching surge voltages that the transformer can withstand without damage [1].

The protection of distribution transformers from the low voltage side is an important subject that has triggered the interest of the electric utilities, the manufacturers of protection systems,

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and the international scientific community [13–16]. The work [13] describes the problem of failures of distribution transformers due to low-side surge phenomena and how it is being addressed by the industry. Some Brazilian electric companies (CEMIG, CEEE, COPEL, CEMAR, COELCE, LIGHT, CPFL Energy Group, DME Poços de Caldas and CELESC) suggest the application of low voltage lightning arresters as an efficient way to shield the transformer against overvoltages caused by surges of atmospheric discharges [17]. Studies from these electric companies point out the induced overvoltages as responsible for more than 55% of total transformers' failures [17].

This paper proposes an industrial solution (equipment) for lightning and surge protection of distribution transformers. The proposed protection equipment has been installed at 100 distribution transformers (sample) of the Public Power Corporation of Greece, at the specific substation locations of Lakonia shown in Table 1, providing excellent protection with zero transformer failures during the whole period of its operation so far, namely 29 months, from January 2012 when the equipment was installed till today (May 2014). Based on eleven-year statistics of failures of this sample collected before the installation of the protection equipment, the future transformer failures are estimated in this article, considering two different cases: (a) transformer without the proposed protection system and (b) transformer equipped with the proposed protection system. Three different methods are used to estimate the future transformer failures without the proposed protection system: Monte Carlo simulation, Poisson statistical distribution, and binomial statistical distribution. These three methods together with the $c$ control chart method are also used in this paper, for the case of transformers equipped with the proposed protection system, to estimate the maximum allowable number of yearly transformer failures in order the proposed protection system to be considered as an effective protection means. Moreover, the article computes the satisfactory sample size of transformers in which the protection system has to be installed in order to be able to obtain statistically reliable results regarding the effectiveness of the proposed protection system. The results show that the proposed solution is an excellent means for lightning and surge protection of distribution transformers.

## Proposed lightning and surge protection system

### *Rayvoss transformer protection system*

The lightning and switching overvoltages and overcurrents that are developed at the conductors of an electrical installation constitute the most important cause for electrical equipment destruction. Additionally to the cost of repair and replacement of the destroyed equipment, there are also the consequences of the interruption of production processes and the loss of revenue for the enterprise. The protection from lightning and switching overvoltages and overcurrents is implemented with the installation of surge protection devices (SPDs).

**Table 1**
Locations of the 100 distribution transformers at which the proposed protection system has been installed.

| No | Location | Municipality | Regional administration |
|---|---|---|---|
| 1 | Areopoli | East Mani | Lakonia |
| 2 | Vathia | East Mani | Lakonia |
| 3 | Karies | Sparti | Lakonia |
| 4 | Kounos | East Mani | Lakonia |
| 5 | Lagia | East Mani | Lakonia |
| 6 | Richea | Monemvasia | Lakonia |
| 7 | Tsikkalia | East Mani | Lakonia |

This article introduces Rayvoss, a new protection system specifically designed to provide lightning and surge protection for distribution transformers. The proposed Rayvoss protection system is based on Strikesorb surge protection module (Section Strikesorb surge protection module). It should be noted that Strikesorb is a general purpose surge protection module that is used worldwide in a wide range of applications including telecommunications, renewable energy, industrial, medical, residential and governmental sectors [18].

### *Strikesorb surge protection module*

#### *Protector requirements and features*

The requirements for a reliable surge protector are the following:

- The protected equipment should never be exposed to damaging transients/surges regardless of the condition of the protector.
- The protector should operate in such a way as to preclude safety risks with regard to smoke, fire, and explosion without sacrificing any of its performance capabilities.
- The reliability and lifetime of the protector has to be greater than those of the equipment being protected.
- The protector should be able to continuously protect critical equipment under all abnormal line conditions and at all times.

These requirements mean that the protector should have the following features:

- No flammable material should be used in the protector. For example, no potting material.
- The protector must be physically robust in order to sustain high amounts of energy without disintegrating.
- The protector should not require any internal fusing in order to meet the UL-1449 safety standard.
- The protector should become a short circuit at its end of life.
- The protector should exhibit a life span of several years in a surge exposed environment without maintenance requirements.
- The protector should be able to dissipate absorbed transient/surge energy safely without undue heating.
- The protector should exhibit minimal internal dynamic resistance and minimal inductance.

The Strikesorb surge protection module shown in Fig. 1 is designed to meet the above requirements [19]. The Strikesorb technology is protected worldwide by several patents, e.g., [20,21]. Strikesorb uses a compressed distribution grade Metal Oxide Varistor (MOV). The innovative deployment of field proven, large diameter MOVs, allows Strikesorb modules to provide premium performance under extreme conditions. Independent test data confirm that a Strikesorb 40 module can withstand 140 kA strikes without degradation in performance characteristics. The Strikesorb 80 module can withstand strikes up to 200 kA thus, safeguarding critical electrical and electronic infrastructure against any potential threat. Detailed presentation of Strikesorb technology and comparison with conventional surge protection technologies can be found in [19].

#### *Protector mechanical design features*

Each Strikesorb protector (Fig. 1) is constructed with a single 40 mm or 80 mm distribution grade zinc oxide varistor that is housed inside a robust, hermetically sealed metal casing. No potting or other flammable materials are utilized by the protector or contained within the casing. The zinc oxide varistor is placed between two electrodes that exhibit high thermal capacity and