MAINTENANCE PRIORITIES IN DISTRIBUTION TRANSFORMERS BASED ON IMPORTANCE AND RISK

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ABSTRACT

Maintenance of transformer is an activity which is done on non-defective transformers to reduce or eliminate the weak points. This is one of the main strategies in asset management. The aim of this work is to increase the useful life time of transformers and decrease their failure rates which will prevent their outages and troubleshoot problem. Over last years, many strategies have been presented for service and maintenance of distribution system components such as transformer. Which each of them depending on funding and liquidity of Distribution Company takes action about maintenance planning process. This paper, in addition of reviewing the existing methods in the service and maintenance of transformers, presents a new method which is based on distribution companies performance in Iran. In this method, determination of each transformer failure probability and priority is attempted for service and maintenance, according to available operation information.

INTRODUCTION

Due to the nature of power systems which are in expose to failure, maintenance of these systems has been always one of major programs of electrical power company. Corrective maintenance (CM) is one of the primary methods which is based on changing and modifying the failure component and returning it to the service. In this method there is no additional inspection, therefore after system fail, corrective actions are made [1]. With preventing maintenance (PM) method, the system reliability is improved by increasing the life time of assets or equipment. It can be done by controlling the frequency or duration of outages. Preventing maintenance is categorized into two groups: time based maintenance (TBM) and condition based maintenance (CBM) [1-2]. TBM method is based on previous equipment service, proceeds regular programs through the time. But CBM method is programmed based on status of equipment, for example repair process is programmed when equipment status decreased below acceptable standard indices in their planning. Generally, by preventing maintenance, a better outages planning, operational flexibility, efficient management for spare elements and efficiency improvement can be achieved.

The method based on reliability and preventing maintenance is known as reliability base maintenance (RCM). In fact this method improves TBM and CBM [3-4]. Since 1980s, this method was into the electrical power system planning. The purpose is to optimize maintenance activity in a regular way. Actually the purpose of this method is to control the performance to achieve cost effectiveness that can use of interaction between corrective actions, preventing maintenance and optimal methods. The prominent feature of this approach is to focus on keeping the system performance to prioritize the important component based on system reliability for preventing maintenance activation. But this method usually doesn't have the ability to show maintenance advantages in system reliability and costs [5].

In the method of asset maintenance based on reliability (RCAM) there is a quantitative relationship between preventing maintenance of equipment and the total cost of maintenance [6]. This method with expansion of RCM principled, tries to reach on close relationship between maintenance effect on costs and system reliability. To implement this method, there is a need for comprehensive study on the components reliability input data. This information includes outage data which is used to estimate predictive failure rates and aging information. One of the biggest challenges and problems in use of RCAM is identifying required information to prepare the model.

Effective-cost prioritizing distribution system maintenance method based on minimizing the average system reliability index. In this method, an objective function is defined which weighs each reliability indices and then minimize this objective function. Obviously, this method is a process that requires comprehensive information about reliability index and it is a comprehensive way to planning the overall distribution system maintenance [7].

Considering the benefits and problems of current methods, and to improve the current maintenance methods and repairing distribution system equipment, a new method which is based on worthiness is introduced in which the maintenance planning is done by some expert operators help.

INTRODUCING PRIORITY METHOD OF MAINTENANCE BASED ON IMPORTANCE (ICPM) IN DISTRIBUTION NETWORKS

From the view of the operator, each equipment or part of distribution network can have more importance than other equipment or parts. Importance is a quality issue and depending on the perspective of each operator, each area or any perception can change. Therefore to understand the relative importance and understanding the perception, we need to ask some question to fund out the importance of that equipment. Table 1 is about some questions to determine the distribution network transformer importance. The number of these questions can be more or less, and they can also differ in distribution companies. From the perspective of operators who do not have documented information or did not document before, each response would be as yes or no, which it is possible that some of them cannot be expressed obviously. But each zero or one answer (yes means one and no is equal to zero) can have variable weight and importance.

TABLE I
THE ASKING OF EVER TRANSFORMER AND WEIGHTING

Asking	weight
Does transformer load go over the 70% of its nominal capacity?	7.8%
Is transformer's lifetime more than 15 years?	6.6%
Is the capacity of the transformer more than 400 kVA?	7.1%
Isn't the transformer' primary protective devices complete?	7.7%
Isn't the transformer' secondary protective devices complete?	8%
Is oil insulation of transformer base on IEC standard less than 30 kV?	7.7%
Does transformer feed an important costumer?	7.8%
Isn't transformer availability easy?	6.1%
Isn't there any possibility to move the transformer load in some situations?	4.9%
Is the transformer exposed to natural disasters?	6.1%
Is the transformer under sever overload?	8%
Is the transformer under short circuit?	6.8%
Is the number of switching of transformer high?	5.3%
Does the transformer in peak load connected and disconnected?	6%
Isn't the transformer manufactured in internal companies?	4.1%

Therefore, it is necessary to weight questions. For this reason, we ask for the expert operators to weight the question by valuation and polls which this weighting is variable due to condition of each distribution company and perspective of operators. A shown in the left side of table 1, the weight of each question has been obtained with this method. In the ICPM method, maintenance plan is prioritized by determining the importance and the failure probability of equipment. So in addition to determining the importance of each transformer, the failure probability function should be obtained. Therefore by using Weibull distribution function and following relations, the accumulation probability function, probability density function and time variable failure rate are determined [8].

$$F(t) = 1 - \exp\left[- \left(t/\eta \right)^{m} \right] \tag{1}$$

$$f(t) = \frac{m}{\eta}\left(t/\eta \right)^{m-1} \exp\left[- \left(t/\eta \right)^{m} \right] \tag{2}$$

$$\lambda(t) = m/\eta \left(t/\eta \right)^{m-1} \tag{3}$$

In above equations, η is the scale parameter and m is the shape parameter. Obviously, the failure probability of each transformer can be estimated by considering its operating years. Accordingly and considering the transformer importance, status of each transformer can be shown in failure probability-importance coordinate.

DETERMINING THE AVERAGE AND TIME VARIABLE FAILURE RATE OF TRANSFOMRES

Since 2002, to reduce the number of defective transformers and their overall maintenance time in Guilan Electrical Power Distribution Company, a regular program was started to inspection, service and repair transformers. In this process, transformers with over 20 years of operating life are transferred to repair workshops to reconstruct them completely. Despite of implementation of this program during the last 10 years, still failed transformers are inevitable. Therefore in spite of substantial reduction in transformers failure, consequently the high costs and labor to implement this process is needed to review and evaluate. Considering that a number of transformers are added to set of distribution company's transformers annually, therefore their overall operating years isn't even and all available transformers have different working years.

Therefore according to failure transformers information in each year and the number of available transformers, the average failure rate can be obtained by following equation [8]:

$$\lambda = \frac{number \quad of \;\; failure \quad tarnsforme \quad r}{\sum nt_i + \sum mt_j} \tag{4}$$

In the above equation, n is the number of failure transformers, t_i is their operation years and m the number of proper transformers and t_j is their operation years. Accordingly, regarding the above equation, to calculate the average failure rate in 2010, the number of failure transformers is equal to 29 which everyone has different operating years, therefore:

$\sum nt_i$ = 589 unit .years , $\sum mt_j$ = 158779 unit .years,

λ = 0.0001826 failure/unit .years

Regarding this fact that the number of available transformers in 2010 is equal to 12032 units, then expected failure in this year is:

Expected Failure = 12032 × 0.0001826 = 2.19 failure/years

Based on IEEE standard, the failure rate of distribution network failure transformers is over 0.59 failure per year which this number in some countries even reaches to 1 to 2 failure per year. It can be seen that failure rate in Guilan Power Distribution Company is more than two times in the IEEE standard. In fact, during the recent years at a cost of over two million dollars, despite reduction in failure probability, still its amount is beyond the standards.

To achieve the time variable failure rate of transformer with the Weibull distribution network, Equations of (1) to (3) is used to provide cumulative probability function, probability density function and time variable failure rate. Horizontal and vertical axis of Weibull probability curve show the life time logarithm and estimative probability of failure equipment during the time, so:

$$\ln \ln\left[1/(1-F(t))\right] = m\ln(t) - m\ln(\eta) \qquad (5)$$

The above equation is a first order equation, so its parameters can be obtained through regression. The shape parameter m, and the slope of line and scale parameter are equal to $\exp(-k/m)$ which k is line distance from the origin coordinate. In equation (5), t is operating year of transformer and $F(t)$ is cumulative probability of failure in transformers in a specific year.

Considering the data related to curve processing, the time variable failure rate and probability density function and cumulative probability function of failure transformers can be shown as Fig. 1, therefore the annual probability of failure and failure rate of transformers can be estimated.

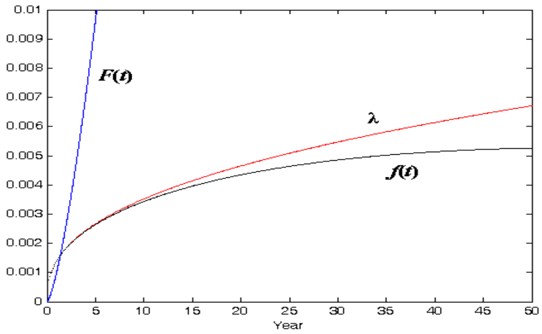

Fig. 1. The curve of failure rate(λ), probability density($f(t)$) and cumulative probability ($F(t)$) variable with time failures transformers.

IMPLEMENTATION OF A PRACTICAL EXAMPLE

To perform a practical example, the Fajr feeder from the South of Rasht substation (63/20 kV) with 27 transformer units is examined.

Status and importance of all transformers are questioned by operation employees based on table 1 questions and for each transformer the mentioned table is completed. The result of questions, each transformer importance and its operating years are presented in table 2.

Now according to each transformer operating years and by time variable failure probability curve in Fig. 3, the failure probability curve based on transformers importance can be plotted which is shown in Fig. 3. The fitted curve is plotted as the exponential curve as following:

$$y = a_0 e^{a_1 x} \qquad (6)$$

That X-axis and Y-axis are transformer importance percentage and its failure probability respectively. Based on table 1 and Fig. 2, the a_0 and a_1 coefficients are equal to 0.002 and 0.00407. This curve is descending because with increasing x (increasing the transformer importance) the failure probability should be close to zero. This curve cuts Y-axis (transformer failure probability) in one point, which means that service and maintenance of transformers with failure probability higher than this level should be considered.

TABLE II

THE RESULT OF ASKING AND TRANSFORMER IMPORTANCE AND OPERATING YEAR

Num. of Trans.	Power(kVA)	Operating Year	Importance,%
1	500	26	19.7
2	315	4	6
3	315	17	6.6
4	400	7	6
5	500	2	44
6	200	7	0
7	400	8	0
8	315	8	0
9	500	3	14.9
10	250	12	6
11	100	16	13.8
12	315	7	11.3
13	400	7	6
14	500	3	13.1
15	315	4	10.9
16	1000	3	18
17	1000	7	23.3
18	315	16	12.6
19	400	6	6
20	315	20	12.6
21	1000	6	13.8
22	400	12	6
23	400	1	6
24	400	1	13.8
25	100	3	4.9
26	400	32	20.4
27	400	10	6

Now, according to fitted curve, transformers with more importance and higher failure probability are in priority in maintenance planning. Therefore based on the curve, transformers with equal importance which have higher failure probability can be selected. So the transformers which are above the fitting curve, are in priority for maintenance. This process should be done annually for all transformers to select transformers with high priority. In this method because transformer is very important element of power system, and due to operation sensitivities in addition to service and maintenance, qualifying of other things like protection availability and the proper place are also reviewed, and problems can be solved.

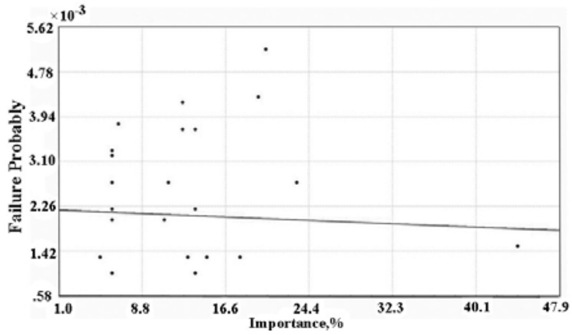

Fig. 2. Curve of failure probability versus transformer importance

THE PROCESS BUDGET FOR HIGH PRIORITY TARNSFORMERS

Table 3 shows the transformers which are selected in this process. Lack and limitation of budget are part of operation problems. So maybe there is not enough budget for service and maintenance of all transformers with high priority, therefore based on annual budget limitation, to determine the process order of these transformers, an index is used which is equal to importance multiple in transformers failure (MIFPI).

TABLE III
TRANSFORMERS OF SELECTED AFTER FITTING

Num. of Trans.	Importance,%	Failure probability	MIFPI
26	20.4	.0052	.10605
1	19.7	.0043	.08471
17	23.3	.0027	.06291
20	12.6	.0042	.05292
11	13.8	.0037	.05106
18	12.6	.0037	.04662
12	11.3	.0027	.03051
21	13.8	.0022	.03036
3	6.6	.0038	.02508
15	10.9	.002	.0218
27	6	.0033	.0198
22	6	.0032	.0192
10	6	.0032	.0192
4	6	.0027	.0162
13	6	.0027	.0162
19	6	.0022	.0132
2	6	.002	.012

This index is an effective factor to determine priority. Based on this definition, transformers with higher index, are organized as downward or upward and according to the budget, transformers maintenance are processed until the end of budget from top to bottom in table, service and maintenance is selected.

CONCLUSION

In this paper, a new method is presented which comply Iran distribution networks structure and can be applied with the minimum data. In this method by poll of expert operators, questions related to transformer statues are weighted. Then based on this pattern, each transformers importance is determined and according to their life time and using transformer failure probability, each transformer is prioritized. With this method, important transformers from operation view are selected annually and due to lack of distribution companies liquidity, transformers which need more attention are candidate for maintenance. To select the most important transformer by this method based on the budget, a new index is introduced which according to that, transformers are arranged upward and downward based on budget they are selected for maintenance.
This method can be used for each distribution company based on their operation needs and with the minimum information and considering the operation perspective, transformers can be prioritized.

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