Risk based asset management of electrical distribution network

Kiril Anguelov
Department of Industrial Engineering and Management
Technical University of Sofia
Sofia, Bulgaria
ang@tu-sofia.bg

Dimo Stoilov
Electric Power Systems Department
Technical University of Sofia
Sofia, Bulgaria
dstoilov@tu-sofia.bg

***Abstract*: The paper presents methodological approach for asset management of electric distribution company through a policy, built upon the Risk based asset management. Here are shown the indicators by which the reliability of a distribution network is estimated and consequent cost of failure of equipment and missed benefits are determined. Using the described methodology the distribution companies could perform: qualitative and quantitative assessment of the risk, determination of measures to reduce the risk, and asset management based on the wise policy of the maximum acceptable risk.**

Keywords— Risk based asset management, Reliability of the Electrical Distribution Network

I. INTRODUCTION

During the creation or use of the power supply systems, they are influenced by different factors, because of internal or external for the electric distribution company reasons. The impact takes place gradually, such as wear and tear, aging, etc. or during a specific event: human error, intentional causing of a damage, especially natural occurrence, machine damage because of defect, etc. The rate of random (unplanned) negative effects is determined by the term "risk". These concepts may characterize the impact of uncertainty (random events) at a separate life stage, to separate physical/natural resources on a single industrial or financial activity, but they can also refer to a set of them or for the unification of all the assets of the company. The reaction of the company against potential negative and positive impacts constitute the approach/policy/ of the asset management. When this approach is subject to the criterion of optimizing risk it's said that assets are managed on the basis of Risk based asset management.

The defined problem has both its technical and economic aspects. On the one hand – the reliability of the distribution networks, and of each component (e.g. sub-stations) is a matter of technical maintenance. On the other hand, the maintenance of a certain degree of reliability of the technical system is related to certain costs, and the insufficient reliability causes losses. The comparison of the costs necessary for maintenance of the technical system with the potential losses due to unreliability is a typically economic issue. The definition of reliability policy based on evaluation of the expected loss and the costs necessary for maintaining the technical system is the purpose of this article.

II. METHODOLOGY FOR ESTIMATION OF MAXIMUM ACCEPTABLE RISK

A. *Indicators for reliability*

The measure of the reliability of the supply of electricity to all consumer units from one system is average value of the number of users fed by this system. According to IEEE Standard 1366-2012, 12 indicators for duration, for series and for loads of interruption, called indices are set: eight to permanent breaks, two for the loads and three others. The main used indicators are:

- SAIDI, or System Average Interruption Duration Index, that shows the average duration of interruptions in minutes, which shall be calculated for a (conditional) consumer for one year.

$$SAIDI = \frac{\sum_{i}^{I} t_i n_i}{N} \text{ , minutes} \quad (1)$$

where: i – index of the consecutive interruption, i=1,2, …, I, I – total number of interruptions; n_i – the number of consumers affected during the i-interruption; t_i – the duration of the i-interruption (min.); N – the total number of supplied consumers.

- SAIFI, or System Average Interruption Frequency Index, which shows the average number of interruptions of a consumer for one year. It is defined as the ratio of the total number of the interruptions of the affected consumers to the total number of the supplied consumers in the network.

$$SAIFI = \frac{\sum_{i}^{I} n_i}{N} \text{ , p.u.} \quad (2)$$

where: i – index for consecutive interruption, i=1,2, …, I, I – total number of interruptions; n_i – the number of consumers affected during the i-interruption; N – total number of supplied consumers.

- CAIDI, or Customer Average Interruption Duration Index, that shows the average duration of an interruption in minutes or hours that is not for all customers, but for one disturbed customer for one year.

$$CAIDI = \frac{\sum_{i}^{I} t_i n_i}{\sum_{i}^{I} n_i} = \frac{SAIDI}{SAIFI}, \text{ minutes} \qquad (3)$$

where: i – index for consecutive interruption, i=1,2, …, I, I – total number of interruptions; n_i – the number of consumers affected during the i-interruption; t_i – the duration of the i-interruption (min.).

- Average Service Availability Index or ASAI, that shows a weighted average availability/reliability for all **N** customers in the system.

$$ASAI = \frac{N.8760 - \sum_{i}^{I} t_i n_i}{N.8760} = 1 - \frac{SAIDI}{8760}, \text{ p.u.} \qquad (4)$$

where it is considered that the total time for the use of the network is 8760 hours, based on a normal year.

Table 1 illustrates reliabilities in % and time for non-availability as a function of the number of nine-s in the reliability degree [2].

TABLE I. RELIABILITY (AVAILABILITY) IN % AND NINE-S AND THE RESPECTIVE TIME OF OUTAGE OR OUT-OF-QUALITY SUPPLY

Reliability (availability) в %	Reliability (availability) in number of nine-s	Outage or sub-quality supply
90	1	36.5 дни
99	2	3.65 дни
99.9	3	8.76 часа
99.99	4	52.6 минути
99.999	5	5.26 минути
99.9999	6	31.5 секунди
99.99999	7	3.15 секунди
99.999999	8	0.315 секунди
99.9999999	9	1.5 периода от 50 Hz

The indices are calculated for each section with the relevant number of sub-stations/transformer stations and the consumers connected to them. The sum of the coefficients by sections that are part of an event, form the total coefficient SAIDI and SAIFI for this event. Unfortunately, the implementation of this requirement faces significant difficulties as a result of lack of complete input data for defining the reliability of separate power lines or sections of power lines.

B. Reliability analysis

The power supply reliability for the entire power system (PS) is pre-determined by the reliability of the included sub-systems and parts: the generation sub-system, the transmission and distribution systems, as well as the efficiency of the control and protection systems and devices. The reliabilities of the transmission and distribution systems depend on the individual reliability of the network components, their mutual connectivity (topology), protection and controllability. The reliability requirements are satisfied through maintenance of operational state, selective disconnection and reservation of the damaged network components.

The non-reliability/uncertainty/non-availability costs (damages, losses) have a stochastic nature. They are estimated through the financial risk of the consequences of the event or the random failure. The risk management implies performance of at least the following three activities:

1. Analysis and quantification of the value of the risk;
2. Determination of the risk reduction measures;
3. Identifying the acceptable level of risk.

The value of the risk depends on the magnitude of the negative consequences that the event provokes and on the probability for the event occurrence. Therefore, the probabilistic assessments for occurrence of certain failures are necessary to quantify the existing risk that shall be borne in case of arising of the specific event.

The risk - R_i is defined [8] as the product of the probability of occurrence - P_i of the i-event and the amount of expected loss/damage. It is expressed with the formula:

$$R_i = P_i \,.\, G_i.\; D_i = P_i \,.\, S_i \qquad (5)$$

where: **i** is the index of a specific event; $\mathbf{P_i}$ is the probability (from 0 to 1) for the fulfilment of the **i** event during a specified time, for example one hour; $\mathbf{D_i}$ is the duration of the restoration time of the normal power supply in minutes or hours; $\mathbf{G_i}$ is gravity of the consequences of the **i** event, expressed e.g. by break of certain functional or qualitative criteria or the size of the non-delivered power in MW; $\mathbf{S_i}$ is severity of the consequences of the **i** event, expressed for example by the loss of load in MWh.

In case we want to define the average probability for occurrence of the event during a day-and-night, we shall be aware of the frequency of exposure.

Then

$$R_i = P_i \,.\, S_i.\; f_i \qquad (6)$$

where

f_i is the frequency of exposure of the event as a percentage of the analyzed period.

When the risk determination is for the quantity of the non-supplied energy, as in (5) and (6), or for a distortion of a quality criterion, we speak about a natural risk. In order to define the financial risk, we shall use the unserved energy price or the price of losses aroused as a result of the respective distorted criterion. Then the value of the financial risk C_i, for example in BGN, shall be

$$C_i = R_i \,.\, p \tag{7}$$

where p is the unserved energy price in BGN/MWh.

C. *The policy for reliability*

The typical for the European power system operators policy [11] for reliability, based on maximum acceptable risk is presented in fig.1.

Here, the known probabilities of random failures are ordered along the horizontal axis, and along the vertical axis – the losses that correspond to these failures. Therefore, the rectangle area illustrates the quantity of the risk for all probable failures. The main hyperbolic line corresponding to the maximum acceptable equal risk of these random failures is the so called "iso-risk" line. It divides the risk area into two zones – acceptable and unacceptable. Above them is illustrated the zone of unacceptable consequences. The least probable incidents (failure of large power stations or of entire system sub-stations or of more than two power lines simultaneously etc.) form the first, by size of losses, respectively risk, zone, regardless of the fact they have extremely low probability and are not system dimensioning contingencies/disturbances.

Dimensioning are the contingencies for which appropriate measures are planned, that shall return the system into the zone of acceptable risk after the accident.

This approach enables defining the following four risk zones:

- Zone 1 – of the exceptional, abnormal contingencies/accidents

- Zone 2 – of the unacceptable consequences, including cascading effects on neighbors.

- Zone 3 – of the unacceptable risk

- Zone 4 – of the acceptable risk

Another illustration for the application of the methodology could be given with a Risk Matrix, which compares the two already determined indicators: probability of failure of a component part of the network and the cost of overcoming the consequences of this failure.

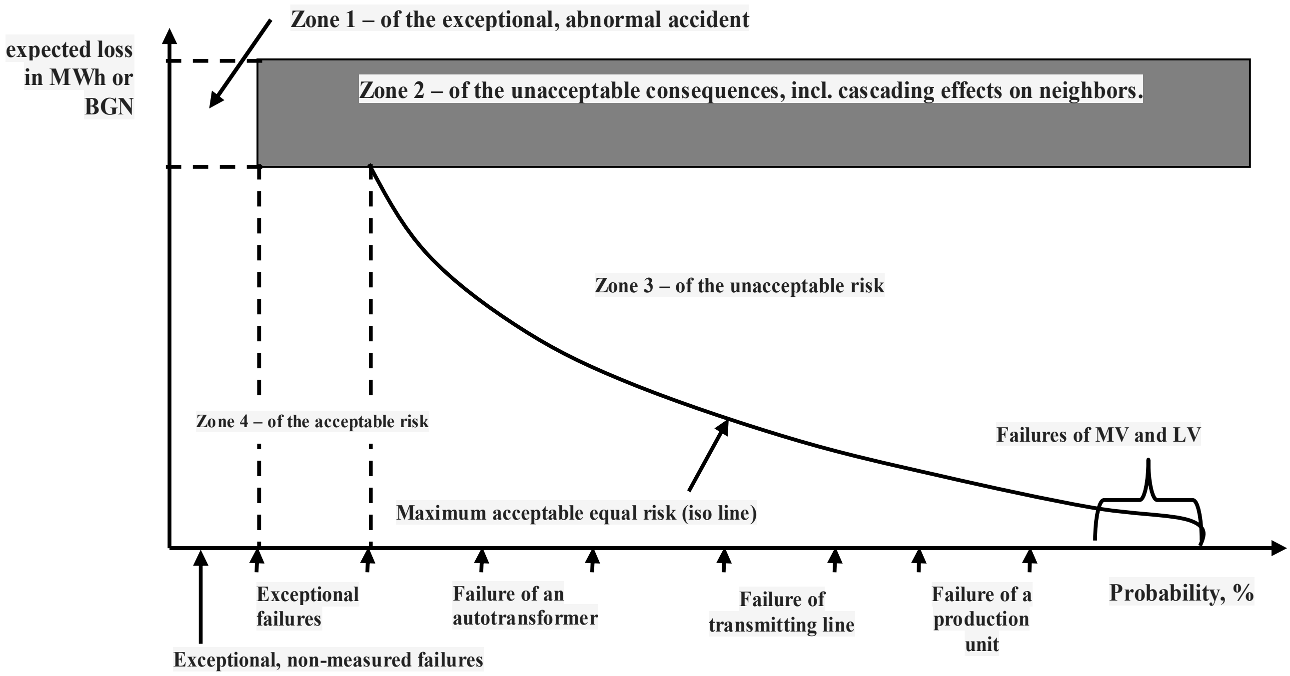

Fig. 1. llustration of policy, based on maximum acceptable risk.

D. Steps for Methodology realisation

1. Collection of as much as possibly complete input data for determination of the reliability of individual power lines or sections of power lines: number and duration of failures, type of failures, unfavorable consequences of failures.

2. Determination of the indices for each distribution grid region with a certain number of sub-stations and transformer stations middle to low voltage and with the consumers connected to them. Indices from (1) to (4) are used. The sum of the coefficients by grid regions that are part of an event (i.e. regions affected by this event) form the overall coefficients SAIDI and SAIFI for this event.

3. Analysis and quantity assessment of risk. The financial risk related to the consequences of the respective event/contingency is defined, by using the formulae (5), (6) and (7).

4. Deciding the measures to reduce the risk. On the basis of the information in the previous item it is possible to identify the most threatened components of the system. Improving the reliability of these components leads to overall reduction of the financial risk. Risk matrixes may also be used, through which the risk to be classified in the following three categories: acceptable risk, unacceptable risk and components with risk between the acceptable and the unacceptable. The risk reduction measures are taken according to this grouping, starting from the components with the most unacceptable risk.

5. The obtained values for each component of the technical system enable the definition of the policy for reliability. The current and the desired location of the components regarding the four risk zones is determined and activities are envisaged to provide their introduction into the desired zones.

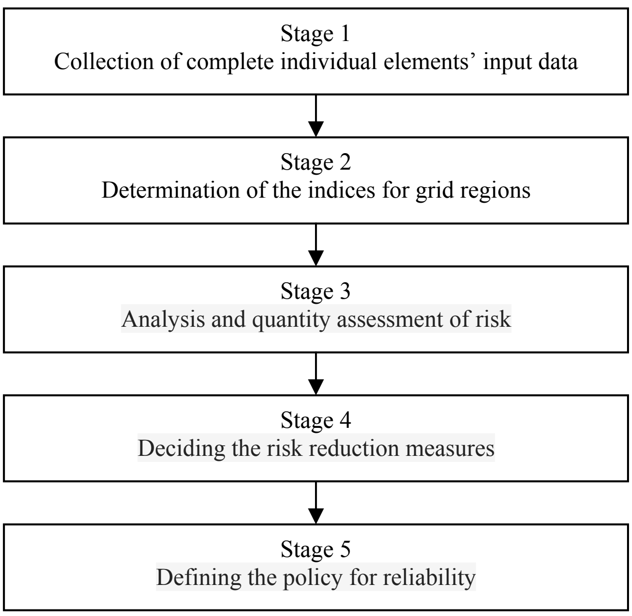

Fig. 2. Block scheme of the methodologie for Risk based asset management.

Conclusions

Here we present a methodology for Risk based asset management of the Electrical Distribution Network based on probability of failure of a component part of the network and the cost of overcoming the consequences of this failure of equipment.

The methodology is based on: Indicators/indices for reliability, assessment of the financial risk related to the consequences of the respective contingency/event (including also the expected MWh or money loss), and the definition of four risk zones (varying from acceptable to fully unacceptable).

Using the methodology the distribution companies could achieve the followings: analysis, i.e. qualitative and quantitative assessment, of the risk; defining the measures to reduce risk and asset management based on the wise policy of the maximum acceptable risk.

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