Analysis of risk assessment algorithm from power supply interruption due to transmission line fault

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Abstract. The guaranteed reliable and uninterrupted supply of electrical energy to consumers is an important task. It can be noted that currently there is no well-structured system for ensuring reliability or security and preventing risk occurrence. In this report, risk assessment algorithms in case of accidents on transmission line are developed and tested by means of the analytical example.

1 Introduction

Reliability of consumer or consumer groups electricity supply is related to the technical state and operating conditions of external distribution networks, through which they are fed.

Decreasing of reliability from transmission line faults leads to a shortage of electricity to consumers, which is called "damage from electricity sacrifice" in cash-equivalent term, thus the study of risks from transmission line faults is relevant. The problem of reliability and risk is discussed by Billington R., Allan R., Beehler M, Guk Yu.B., [2, 3, 6]. In addition to this, modern authors such as Syrri A.L.A., Mancarella P., Junlakarn S., Ciapessoni E., consider this problem in their articles [9, 8, 5].

Nowadays, requirements that regulate the risk assessment and reliability calculation are either absent or obsolete. Consequently, the utility practice requires the theory and methods for reliability calculation taking into account the risks from faults.

2 What is Reliability?

Reliability refers to reliability connected with electrical mode (henceforth referred to as reliability) or service security. [7, 8]

Generally, reliability is the ability of a power system to hold over a new state due to disturbances without violation of power system stability. It characterizes the emergency procedures by the criterion (*n-i*), where $n -$ is the total number of components and $i -$ is the number of suddenly disconnected system components [6].

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Reliability of consumer energy supply can be defined as the difference between electrical supply with full consumer demand (W_C) and electricity sacrifice due to accidents and other events (ΔW) to W_C [4]:

$$H_W = \frac{W_C - \Delta W}{W_C} \cdot 100\%.$$ (1)

Service security is determined by the level of physical reliability of individual components and component connection layout.

The main indicators of service security are:
–   failure flow parameter [ω, failure per year] called SAIFI in [3] is the ratio of component number that failed per a time unit to the total number of the same tested components;
–   recovery time [T_r, hour] − the ratio of total recovery time of technical devices for the selected fixed period to the number of its failures for the same fixed period.

The main reliability indicators of systems with various connections of recoverable components are calculated according to the serial and parallel connection of components [2].

3 Calculation of the damage from electricity sacrifice

Estimation of the damage from electricity sacrifice costs can be calculated as

$$D_s = d_0 \cdot W_s,$$ (2)

where W_s is the expected load at the delivery point, kWh; d_0, is the specific cost for energy which is not supplied, \$/kWh [1].

4 Risk Assessments from power supply interruption

Qualitative analysis corresponds to the stage of risk identification, quantitative analysis allows determining the size of individual risks numerically and risks in general. [9]

4.1 Quantitative method

The calculation of this indicator is carried out by the assumption that production costs can be divided into conditionally variable $C_{con-var}$ (depending on the volume of production B_p) and conditionally constant $C_{con-fix}$ (independent of the volume of production).

$$V_{cr} = \frac{C_{con-fix}}{B_p - C_{con-var}} \cdot 100\%,$$ (3)

where V_{cr} − the critical volume of transferred electricity, %.

To calculate the break-even point, the planning interval, for example, the year is chosen and full production capacity is achieved. The project is considered sustainable if V_{cr} <75 - 80% from normal level. Advantages of calculation of the break-even point are the simplicity and clarity. [5]

4.2 Qualitative method

For a qualitative risk assessment of electricity supply, it is necessary to determine the main components of the risk and the severity of fault consequences (Table 1).

Table 1. Scales for establishing the severity category of failure consequences.

Severity category of failure consequences	Severity characteristics of failure consequences
IV-catastrophic failure	The failure, which rapidly and with high probability can cause significant damage to the object and / or the environment, death or serious injuries of people, failure of the task
III-critical failure	The failure, which rapidly and with high probability can cause significant damage to the facility itself and/or the environment, disrupts the task, but creates a negligible threat to life and health of people
II-not critical failure	The failure that leads to delaying in the fulfillment of the task, decreasing the readiness and efficiency of facilities, but does not pose a threat to the environment, facilities themselves and human health
I-with small consequences	The failure, which leads to decreasing the quality of the function of facilities, does not pose a threat to the environment and human health

To perform this type of analysis, each type of failure must be assigned. The level of occurrence probability is illustrated in Table 2.

Table 2. Levels of occurrence probability.

Level probability of failure	Description	Analysis
A	Frequent failure. The probability of failure exceeds 0.2	In-depth quantitative analysis of criticality is required
B	Probable failure. The probability of failure from 0.1 to 0.2	Quantitative analysis of criticality is desirable
C	Possible failure. The probability of failure from 0.01 to 0.1	Only qualitative analysis is required
D	Rare failure. The probability of failure is from 0.001 to 0.01	Analysis is not required
E	Remote failure. The probability of failure during a given time is below 0.001	Analysis is not required

The procedure for qualitative analysis of criticality consists of assigning priorities for corrective and compensative actions to the types of failures, depending on the failure category and given level of failure probability.

Types of failures are distributed according to the criticality schedule, where on the horizontal axis the values of failure categories are shown, and on the vertical axis the failure probability levels are illustrated (Figure 1).
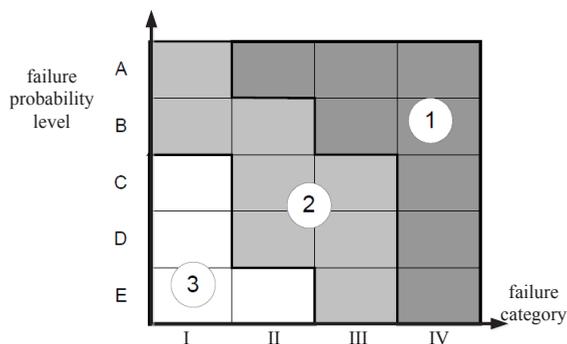
Fig. 1. Characteristics of the severity of failure consequences in a power supply system.

According to the schedule in Figure 1, areas of equal priorities are singled out:

1 − high. A component whose failure requires special attention in the design.

2 − medium. A component whose failures require attention during development.

3 − low. A component that requires careful analysis of species, consequences and criticality of failures to confirm priority values.

The advantage of qualitative analysis is that it is performed in early stages of development, when the design of products is not fully defined and there is no quantitative data on reliability of all components; as a result, it is simple and evident.

5 Calculation of practical objectives

The problem situation: The plant is fed from two power sources: CHPP (Combined Heat and Power Plant) and System (Figure 2). Each transmission line can transfer total power required by the plant. However, CHPP can not produce more than 15.5 MW. Parameters are conventionally accepted and given in Table 3.
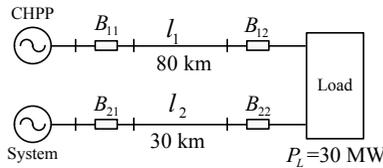
Fig. 2. Scheme of the power supply system.

The task is to define parameters of the failure flow in this system, the probability of failure, damage from the electricity sacrifice in a year, and then identify the risks.

Given: V_{nom}=110 kV.

Lines: r_0=0.118 Om, l_1=80 km, l_2=30 km.

Load: $\cos\varphi = 0.9$, P_l=30 MWh.

Table 3. Power Transmission Reliability Parameters.

Indicators of reliability	System component					
	B_{11}	l_1	B_{12}	B_{21}	l_2	B_{22}
ω_0 ,1/(km per year)	-	0.051	-	-	0.051	-
ω , 1/year	0.02	-	0.02	0.02	-	0.02
T_r , hour	7	8	20	20	7	20

It is assumed that unintentional disconnections of series-connected circuit components are combined in time.

Calculations:

Probability of failure for circuits I and II:

$$q_I = \omega_{B_{11}} \cdot T_{rB_{11}} + \omega_{0l_1} \cdot l_1 \cdot T_{rl_1} + \omega_{B_{21}} \cdot T_{rB_{21}} = (0.02 \cdot 7 + 0.051 \cdot 80 \cdot 8 + 0.02 \cdot 7)/8760 = 3.78 \cdot 10^{-3};$$

$$q_{II} = \omega_{B_{21}} \cdot T_{rB_{21}} + \omega_{0l_2} \cdot l_2 \cdot T_{rl_2} + \omega_{B_{22}} \cdot T_{rB_{22}} = (0.02 \cdot 7 + 0.051 \cdot 30 \cdot 8 + 0.02 \cdot 7)/8760 = 1.437 \cdot 10^{-3}.$$

Failure can be classified as category III i.e. the critical failure. The probability of failure of all components is defined separately.

$$q_{B_{11}} = q_{B_{12}} = q_{B_{21}} = q_{B_{22}} = \omega_{B_{11}} \cdot T_{BB_{11}} = 0.02 \cdot 7 / 8760 = 0.00002 ;$$

$$q_{l_1} = \omega_{l_1} \cdot T_{rl_1} = 0.051 \cdot 80 \cdot 8 / 8760 = 0.004 ;$$

$$q_{l_2} = \omega_{l_2} \cdot T_{rl_2} = 0.051 \cdot 30 \cdot 8 / 8760 = 0.0014 .$$

Based on these calculations, the breakers can be assigned for group E, transmission lines for group D, therefore, no analysis is required for the components. Comparing the obtained data according to the graph, shown in Figure 1, it can be concluded that all considered components of the system belong to the second priority of the component classification and it is not necessary to enter control systems and compensate the failure.

In the steady-state mode the risk assessment is defined by quantitative method (break-even point) from the electricity sacrifice.

Total investment: $I_\Sigma = 1921000$ \$.

Conditional-fixed costs: $C_{con-fix} = 94090$ \$.

Conditional-variable costs:

$$C_{con-var} = \Delta W_{zod} \cdot T_{trans} = 8100 \cdot 10^3 \cdot 0.013 = 108100 \text{ \$},$$

where T_{trans} – tariff for electricity transmission, \$/kWh;

ΔW – losses of energy per year, kWh.

The volume of production:

$$B_p = W_{year} \cdot T_{trans} = 30 \cdot 10^3 \cdot 8760 \cdot 0.013 = 3508000 \text{ \$}.$$

Breakeven point:

$$V_{cr} = \frac{C_{con-fix}}{B_p - C_{con-var}} \cdot 100\% = \frac{94090}{3508000 - 108100} \cdot 100\% = 2.78\% .$$

The scheme is reliable since V_{cr} <75 - 80% from the normal level.

When an accident on transmission line occurs the risk assessment is calculated by quantitative method.

$$H_W = \frac{W_C - \Delta W}{W_C} \cdot 100\% = \frac{30 - 15}{30} \cdot 100\% = 50\% .$$

Taking into account the average recovery time of the line, the estimated damage from electricity sacrifice costs:

$$D_s = d_0 \cdot W_s = 0.313 \cdot 15 \cdot 8 \cdot 10^3 = 37720 \text{ \$}.$$

The proceeds from the sale of products are changed

$$B'_p = B_p - D_s = 3508000 - 37720 = 3470000 \text{ \$}.$$

Break-even point:

$$V_{cr} = \frac{C_{con-fix}}{B'_p - C_{con-var}} \cdot 100\% = \frac{94090}{3470000 - 108100} \cdot 100\% = 3\% .$$

Based on the calculation results, it can be noticed that the critical sale volume when one line is out of service has slightly increased, the project is remaining reliable.

6 The total algorithm of risk assessment

Based on the analytical problem solution, the algorithm is developed taking into account risks from accidents on transmission lines:
1. Visually determine the sections of the circuit with weak circuit reliability.
2. Modeling electric modes that detect "narrow" places by regime reliability, capturing areas with weak circuit reliability.
3. Define reliability indicators.
4. Determine the probability of failure.
5. Determine the damage from under-supply of electrical energy.

6. Range failure by category: with small consequences, no critical failure, and critical failure. To determine the method of risk research depending on the category.
7. Identify risk by quantitative and/or qualitative method.
8. Compare the damage from the electricity sacrifice with investments for measures to improve reliability.

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