THE RELIABILITY CHARACTERISTIC OF POWER PLANT UNIT

Zbyněk MARTÍNEK, Veronika KRÁLOVCOVÁ
Department of Electric Power Engineering and Ecology, Faculty of Electrical Engineering,
University of West Bohemia in Pilsen, Univerzitní 26, 306 14 Pilsen, Czech Republic,
tel.: +420 377 634 347, e-mail: martinek@kee.zcu.cz, tel.: +420 377 634 399, e-mail: kralovco@kee.zcu.cz

ABSTRACT

The application of reliability theory is in a fast progress today. There are high expectances on power plant units because of its higher performance, better parameters, complex technologies, higher control level and further cooperation between devices. Experience shows that with higher performance there is a decrease of reliability demonstrated by higher blackout number, lower maintenance and decreased lifetime period of mostly used parts of device. Criteria and normative of reliability enable more precise programming of network operation, failure free time planning for aggregate and output backup, order and time of preventive inspections and selection of appropriate correctional provisions. It also enables prognosis of quantity and sort of material and other sources for recovery, normal operation and device ageing. Applications are useful for both the producer and user of power devices, who in past few years worked on a progress in practical usage of these applications. One of the most used applications are those which deals with the prediction of reliability indicator of new devices, their parts and system of unit control which are used for blackout analyses of lower output level. The final goal of this prediction is design, construction and operation of devices with wanted reliability

Keywords: *Power Engineering, Reliability, Power Plant, Electrical Network, Weibull Distribution*

1. INTRODUCTION

This are equation for calculation of reliability of failure-free time, mean time to operation for reliability characteristic of “in-repairable” power plant unit with exponential and Weibull distribution of time of repairs. Given equations for Weibull distribution respects the operation prediction of actual running hours from the last stoppage.

In our project we assume that the time of failure and failure-free time of each power plant block are known from the reliability information system, which is extracted every month from information given by power plants. The first task is to bring order to data - the mathematical statistic processing. The position of distribution is characterized by a mean value on an axis where we put data.

2. THE ANALYSIS FOR IN-REPAIRABLE UNIT ($\mu = 0$)

We presume that $\mu = 0$ for a very short time.

2.1. Characteristic with exponential distribution of failure-free time

If we have a device with constant failure rate λ the probability of failure does not depend on running time of the device ($\tau = T$ see Figure 1).

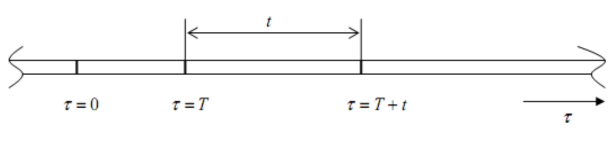

Fig. 1 Running time of the device

Running time of the device can be separated to there intervals:
$(0; \tau = 0)$ … repair
$(\tau = 0;\ \tau = T)$ … actual running hours
$(\tau = T;\ \tau = T + t)$ … prediction

We can do the mathematical prove in the equation for conditional probability.

$$P_{B(A)} = \frac{P_{(B \cap A)}}{P_{(B)}} \tag{1}$$

Event A … unit will malfunction in time t, it means that in time from T to T+t; $P_{(A)}$ is probability of event A

Event B … unit will be operable in time T; $P_{(B)}$ is probability of event B

Event $B \cap A$ … unit will be operable in time T unit will malfunction in time t, it means that in time from T to T+t; $P_{(B \cap A)}$ is probability of event $B \cap A$

$P_{B(A)}$ … conditional probability; unit will be operable in time t and here at it function without failure until time T

T … actual running hours of the unit from the last start till requested time when the prediction started

t … requested time of failure-free operation prediction

The probability of failure-free time till time T is determined by the equation

$$P_{(B)} = P_{0(t)} = \exp(-\lambda T) \tag{2}$$

and the probability of event $B \cap A$

$$P_{(B \cap A)} = \int_T^{T+t} f_{(t)} dt = \int_T^{T+t} \lambda \exp(-\lambda t)\, dt \tag{3}$$

By inserting (3) and (2) in (1) we obtain well known formula

$$P_{B(A)} = \frac{\exp(-\lambda T) - \exp(-\lambda T)\cdot\exp(-\lambda T)}{\exp(-\lambda T)} = 1 - \exp(-\lambda t) \quad (4)$$

The probability $P_{B(A)}$ is independent on the number of running hours of the unit *T* from the last start.

2.2. Characteristic with Weibull distribution of failure-free operation time

We educe the $P_{B(A)}$, it is the probability of failure in time *t*, if we know that the failure did not occur in time *T*. This probability is dependent on running hours of the unit *T* from the last start.

If we express the probability of failure-free time till time *T*

$$P_{(B)} = P_{0(t)} = 1 - \int_0^T f_{(t)}dt = 1 - \int_0^T kt^m \exp\left(-\frac{k}{m+1}t^{m+1}\right)dt \quad (5)$$

By inserting into (1) we set the conditional probability

$$P_{B(A)} = \frac{\int_T^{T+t} f_{(t)}dt}{1 - \int_0^T f_{(t)}dt} \quad (6)$$

To solve the conditional probability we must solve the $\int f_{(t)}dt$ integral for the Weibull distribution. This can be done by a substitution.

After calculation, adjustments and reductions we obtain:

$$P_{B(A)} = 1 - \exp\left[\frac{k}{m+1}T^{m+1} - \frac{k}{m+1}(T+t)^{m+1}\right] \quad (7)$$

For the second form for Weibull distribution expressing

$$P_{B(A)} = \frac{\left\{\exp\left[-\left(\frac{t}{d}\right)^b\right]\right\}_T^{T+t}}{1 - \left\{\exp\left[-\left(\frac{t}{d}\right)^b\right]\right\}_0^T} = 1 - \exp\left[\left(\frac{T}{d}\right)^b - \left(\frac{T+t}{d}\right)^b\right] \quad (8)$$

We set $m = 0$ to control the (7) formula and we must receive the equation independent on T.

$$P_{B(A)} = 1 - \exp\left[-k\left(T + t - T\right)\right] = 1 - \exp\left[-kt\right] \quad (9)$$

Similarly we controlled the (8) equation.

Now we receive the final equation for failure probability of the unit in time *t*, if we know that unit was in operation for time *T*, which is

$$P_{B(A)} = P_{1(t)} = 1 - \exp\left[\frac{k}{m+1}T^{m+1} - \frac{k}{m+1}(T+t)^{m+1}\right] \quad (10)$$

If we use the (11) equation to express continuous Weibull distribution we obtain for this probability (12) equation

$$F_{(t)} = 1 - \exp\left[-\left(\frac{t}{d}\right)^b\right] \quad (11)$$

$$P_{1(t)} = 1.\exp\left[\left(\frac{T}{d}\right)^b - \left(\frac{T+t}{d}\right)^b\right] \quad (12)$$

3. THE MEAN TIME OF OPERATION DERIVATION

3.1. Exponential distribution of failure-free time

The equation for the mean time of operation is

$$m_S = \int_0^\infty t\, f_{(t)}dt = \int_0^\infty t\cdot\lambda\exp(-\lambda t)\,dt = \frac{1}{\lambda} \quad (13)$$

3.2. Weibull distribution of failure-free time

$$m_S = \int_0^\infty t k t^m \exp\left(-\frac{k}{m+1}t^{m+1}\right)dt \quad (14)$$

Substitution

$$kt^{m+1} = x$$
$$t = \sqrt[m+1]{\frac{x}{k}} \quad (15)$$
$$k(m+1)t^m dt = dx$$

Limits

$$t \to 0, \infty$$
$$x \to 0, \infty$$

$$m_S = \int_0^\infty \frac{1}{m+1}k(m+1)t^m t\exp\left(-\frac{kt^{m+1}}{m+1}\right)dt = \frac{1}{m+1}\int_0^\infty \sqrt[m+1]{\frac{x}{k}}\exp\left(-\frac{x}{m+1}\right)dx \quad (16)$$

For the second expression of Weibull distribution

$$m_S = \frac{1}{b}\int_0^\infty \sqrt[b]{\frac{xd^b}{b}}\exp\left(-\frac{x}{b}\right)dx = \sqrt[b]{\frac{d^b}{b}}\frac{1}{b}\int_0^\infty \sqrt[b]{x}\exp\left(-\frac{x}{b}\right)dx$$
$$m_S = \frac{d}{\sqrt[b]{b^{b+1}}}\int_0^\infty \sqrt[b]{x}\exp\left(-\frac{x}{b}\right)dx \quad (17)$$

If we check the formulas for $m = 0$ and $b = 1$, these formulas must convert on exponential distribution. For equation (16)

$$m_S = \int_0^\infty \frac{x}{k}\exp(-x)\,dx = \int_0^\infty kt\exp(-kt)\,dt = \frac{1}{k}$$

We get the same result after substitute $b = 1$ to (17).

After calculation, adjustments and reductions we obtain:

$$m_S = \frac{1}{m+1}\int_0^\infty \sqrt[m+1]{\frac{x}{k}}\cdot\exp\left(-\frac{x}{m+1}\right)dx \pm \tag{18}$$

Now we use the formula for density of probability

$$f_{(t)} = \frac{b}{d}\left(\frac{t}{d}\right)^{b-1}\cdot\exp\left[-\left(\frac{t}{d}\right)^{b}\right] \tag{19}$$

We insert it into equation (18) and obtain

$$m_S = \frac{d}{\sqrt[b]{b^{b+1}}}\int_0^\infty \sqrt[b]{x}\cdot\exp\left(-\frac{x}{b}\right)dx \tag{20}$$

Integrals in equation (19) and (20) can not be exactly solved; therefore we must use some numerical method.

3.3. Derivation for unit, that has been in operation for T hours

For Weibull distribution is the failure probability of power plant unit in time *t*, if the unit is in operation T hours, is set by equation (7) and for the second expression of Weibull distribution it is set by equation (8). We obtain the density of probability of failure $f_{(t)}$ by derivation of following equations.

The mean time is

$$m_S = \int_0^\infty t\, f_{(t)}dt = \int_0^\infty kt(T+t)^m \exp\left[\frac{k}{m+1}T^{m+1} - \frac{k}{m+1}(T+t)\right]dt$$

For equation (7)

$$f_{(t)} = \exp\left[\frac{k}{m+1}T^{m+1} - \frac{k}{m+1}(T+t)^{m+1}\right]\left(-\frac{k}{m+1}\right)(m+1)(T+t)^m$$

The substitution

$$k(T+t)^{m+1} = z$$
$$k(m+1)(T+t)^m\, dt = dz$$
$$k(T+t)^m\, dt = \frac{dz}{m+1}$$
$$t = \sqrt[m+1]{\frac{z}{k}} - T$$

Limits

$$t \to 0, \infty$$
$$z \to kT^{m+1}, \infty$$

$$m_S = \frac{1}{m+1}\int_0^\infty \left(\sqrt[m+1]{\frac{z}{k}} - T\right)\exp\left[\frac{k}{m+1}T^{m+1} - \frac{z}{m+1}\right]dz =$$
$$= \frac{1}{(m+1)\sqrt[m+1]{k}}\int_0^\infty \sqrt[m+1]{z}\circ\exp\left[\frac{k}{m+1}T^{m+1} - \frac{z}{m+1}\right]dz -$$
$$-\frac{T}{m+1}\int_0^\infty \exp\left[\frac{k}{m+1}T^{m+1} - \frac{z}{m+1}\right]dz$$

Substitution

$$-\frac{k}{m+1}T^{m+1} + \frac{z}{m+1} = x$$
$$\frac{dz}{m+1} = dx \qquad -kT^{m+1} + z = (m+1)x$$
$$dz = (m+1)dx \qquad z = kT^{m+1} + (m+1)x$$

Limits

$$z \to kT^{m+1}, \infty$$
$$x \to 0, \infty$$

$$m_S = \frac{1}{(m+1)\sqrt[m+1]{k}}\int_0^\infty \sqrt[m+1]{kT^{m+1} + (m+1)x}\cdot\exp(-x)(m+1)dx -$$
$$-\frac{T}{m+1}\int_0^\infty \exp(-x)(m+1)dx =$$
$$= \frac{1}{\sqrt[m+1]{k}}\int_0^\infty \sqrt[m+1]{kT^{m+1} + (m+1)x}\cdot\exp(-x)dx - T$$

$$m_S = \sqrt[m+1]{k}\int_0^\infty \sqrt[m+1]{x + \frac{kT^{m+1}}{(m+1)}}\cdot\exp(-x)dx - T \tag{21}$$

To check our calculation we put $m = 0$ into equation (20).

$$m_S = \frac{1}{k}\int_0^\infty (x + kT)\exp(-x)dx - T = \frac{1}{k}\int_0^\infty x\cdot\exp(-x)dx +$$
$$+\frac{1}{k}\int_0^\infty kT\exp(-x)dx - T = \frac{1}{k}\int_0^\infty x\cdot\exp(-x)dx = \frac{1}{k}$$

For the second Weibull distribution we obtain

$$m+1 = b \qquad \frac{m+1}{k} = d^b$$

$$m_S = \sqrt[b]{d^b}\int_0^\infty \sqrt[b]{x + \frac{T^b}{d^b}}\exp(-x)dx - T$$

$$m_S = d\int_0^\infty \sqrt[b]{x + \frac{T^b}{d^b}}\exp(-x)dx - T \tag{22}$$

Again to check our calculation we put $b = 1$

$$m_S = d\int_0^\infty \left(x + \frac{T}{d}\right)\exp(-x)dx - T =$$
$$= d\int_0^\infty x\cdot\exp(-x)dx + T\int_0^\infty x\cdot\exp(-x)dx - T = d$$

By solving previous equation we obtain

$$m_S = \sqrt[m+1]{\frac{m+1}{k}}\int_0^\infty \sqrt[m+1]{x + \frac{kT^{m+1}}{m+1}}\cdot\exp(-x)dx - T \tag{23}$$

For second Weibull distribution is following equation

$$m_S = d\int_0^\infty \sqrt[b]{x + \frac{T^b}{d^b}}\exp(-x)dx - T \tag{24}$$

Integrals in equation (23) and (24) can not be exactly solved. Therefore we must use a software tool.

In Table 1 there is an example of calculation $m_S = f_{(m,k,T)}$ for reliability characteristic of power plant unit leveled by a Weibull distribution. Mean time of operation is getting shorter with the number of operation hours (see Table 1).

Table 1 Calculation of reliability characteristic

T	0	72	120	168	300	500
m_S	62.7	34.5	27.6	23.3	17.0	12.6

4. RESULTS

This contribution is connected with the previous contribution published by same authors at EPE 2009 IEEE Kouty nad Desnou, CZ.

The important question is how to set the time for parameters of reliability characteristic determination. We can show this on example of failure free time distribution calculated by the Weibull distribution. This distribution can concisely describe processes of run-in period, normal operation and aging period. If we use data collected through many year we can also see the run-in period which is long in condition of Czech power plant units.

5. CONCLUSIONS

The reliability of power plant unit is one of the most important attribute which defines the quality and high expectations and standards. The precaution in increasing the reliability and quality is forefront in economical interests all over the world. The experience shows that with growing size of blocks there is a lower reliability which is indicated by increasing number of stoppage and blackouts, lower captive time and lower lifetime period [1]. Therefore there are a precaution witch are focused on increasing the reliability.

The application of theory of reliability is in nowadays in fast progress. There are high expectations and standards for reliability of power plant unit because of higher level of regulation, high requests for reliability of power plants, blocks and whole networks.

This contribution is a theoretical base for other calculation. Nowadays we are in the state of collecting and validating reliability data. The calculation it-self will be another part of this whole project.

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BIOGRAPHIES

Doc. Ing. Zbyněk Martínek, CSc., was born on 22.04.1955. In 1983 he graduated (MSc) with distinction at the department of Power Engineering of the Faculty of Electrical Engineering at University of West Bohemia in Pilsen. He defended his PhD in the field of Reliability of Power grid in 1990; his habilitation title was "Synthesis of reliability of power plant unit in the Czech Republic". Since 1990 he is working as a tutor with the Department of Computers and Informatics. His scientific research is focusing on reliability of power grid and devices in power engineering, heating industry and electrical installation design. From the year 1990 he is regularly named as a member of commission at final exams. These commissions are at the Department of Electric Power Engineering and Ecology and also a chairman of bachelor commission from the year 2005.

Ing. Veronika Královcová was born on 26.4.1984. In 2008 she graduated with distinction at the department of Technologies and Measurement at University of West Bohemia in Pilsen. Nowadays she is a PhD. student at the Department of Electric Power Engineering and Ecology, thesis is focused on Reliability, quality and safety of power generation. Her adviser is doc. Ing. Zbyněk Martínek, CSc.