IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 1 Issue 9, November 2014.
www.ijiset.com
ISSN 2348 – 7968

Reliability Study of Renewable Energy Sources Components

Angel Tanev[1],

[1] Probability, Statistics and Operational Research, Sofia University St Kliment Ohridski,
Sofia, 1000, Bulgaria

Abstract
During the technical operation of renewable energy sources, there is an interesting problem associated with ensuring their reliability set by their manufacturers. Renewable energy sources (RES) must consist of parts of approximately equal reliability. This problem determines the interval of the variances of the life of the individual details of the RES. It must be located within the boundaries of the life of the whole system. In this report was carried out a research on the reliability of RES through the use of the criterion of fatigue of the individual parts.
Keywords: *reliability, fatigue, renewable energy sources.*

1. Introduction

Renewable energy resources exist over wide geographical areas, in contrast to other energy sources, which are located or concentrated in a limited number of countries. The rapid deployment and growth of renewable energy and energy efficiency is leading to significant energy security, climate change mitigation, and economic benefits. Many renewable energy projects are large-scale so their reliability is becoming more and more challenging task today. Different studies analyzing the reliability problems on risk technical systems can be found [7,8,9,10,11]. This paper addresses the following important topics to the practitioners- how to evaluate the parts reliability from fatigue point of view of a RES system.

2. Theoretical Background

The results from the experiments show that the life of the parts of RES in cyclic loads are distributed according to the law of Weibull, having the form [1]:

$$F(t) = 1 - \exp\left[-\left(\frac{t-\mu}{\beta} \right)^k \right], \ \mu \le t < \infty \quad (1)$$

where: μ, β, k - location, scale and shape factors.

The location parameter μ is the smallest value of life on the parts T_{PKE} until the end of their operation. It is determined according to the formula (2.1.8) of reference [2]:

$$T_{PKE} = \int_0^{T_{OTP,i}} P_{БP}(\Delta t).dt \quad (2)$$

where: $P_{БP}(\Delta t)$ - the probability of reliable operation of the relevant part in the individual observed intervals Δt; $T_{OTP,i}$ - amount of time to perform the *i-th* basic and routine repairs.

The probability for a reliable operation of the relevant part of the RES is determined by the formula:

$$P_{БP}(\Delta t) = \exp\left[-\int_0^{T_{PKE}} \bar{\omega}(\Delta t).dt \right] \quad (3)$$

where: $\bar{\omega}(\Delta t)$ - assessment of the failure rate for the interval Δt , by using algorithm for solving nonlinear differential equations, describing the process of aging of RES [6].

The evaluation of the location parameter μ of the Weibull distribution is asymptotically normally distributed and there's variance $D(\mu)$ is defined by [1]:

$$D(\mu) = \frac{\beta^{-2/k}}{N(k-1)^2 . \ \Gamma(1-2/k)} \quad (4)$$

where: N - sample size; $\Gamma(*)$ - gamma function.

3. Applications

The limit state of RES is determined by the uniform stability of their parts concerning fatigue failure mechanism. The following conditions must be fulfilled:

ISSN 2348 – 7968

- ensuring their reliable work during their specified life $T_{P,ЗАД}$ from the producer;
- minimum variance of the parts life, yielding minor deviations of the life of the RES

The first condition follows from the definition of the lower limit of the life of the parts in the system, according to:

$$T_{P,ДГ} = \mu - u_{\gamma}.\sqrt{D(\mu)} \tag{5}$$

where: u_{γ} - quintile of standard normal distribution with level γ. The second condition implies that the variance $D(\beta,k)$ will converge to the minimum value, i.e. the equation is satisfied:

$$D(\beta,k) = \beta^2.\left[\Gamma(1+2/k) - \Gamma^2(1+1/k)\right] \to \min \tag{6}$$

In this situation, the question arises how to realize the implementation of the conditions of equations (4) and (5) in the process of RES usage. This implies that the parts are run to failure, i.e. use the maintenance strategy by condition [2, 6].

$$T_P = \frac{a_i.\sigma_{-1g}^m.N_0}{N_Ц.\sum \sigma_{a_i}^m.t_i} \tag{7}$$

where:

a_i - a correction factor, taking into account the non-regular loadings;

σ_{-1g} - parts wear-out limit in *MPa*;

$N_Ц$ - number of loadings cycles for 1s;

N_0 - number of loading cycles corresponding to the bending of the fatigue curve;

σ_{a_i} - stress amplitude of the i-th level in *MPa*;

t_i - time for action on i-th stress amplitude in tension in *s*;

m - fatigue parameter.

By using of the statistical theory of pattern of destruction from fatigue [3], one can determine the wear-out limit of the parts as the limit of wear-out of a smooth specimen by the formula:

$$\sigma_{-1g} = \frac{\sigma_{-1}}{\left(\frac{2\alpha_\sigma}{1+(L/88,3.I)^{-\nu_\sigma}} + \frac{1}{\beta_1} - 1\right).\beta_y^{-1}} \tag{8}$$

where:

σ_{-1} -the wear-out limit of smooth specimen detail in *MPa*;

α_σ -theoretical coefficient of stress concentration in the parts;

L - circumference of the working section in mm;

I - relative gradient of pressure at first mainly stress in mm^{-1};

ν_σ - coefficient determined experimentally for each steel (material), from which it is created the part;

β_1 - coefficient, taking into account the quality of the surface of the part;

β_y - coefficient, taking into account the material strength.

As a substitute of expression (8) in equation (7), one obtains the following:

$$T_P = \frac{a_i.N_0}{N_Ц.\sum \sigma_{a_i}^m.t_i} \cdot \left\{ \frac{\sigma_{-1}}{\left(\frac{2\alpha_\sigma}{1+(L/88,3.I)^{-\nu_\sigma}} + \frac{1}{\beta_1} - 1\right).\beta_y^{-1}} \right\}^m \tag{9}$$

In this formula for each steel (material), from which is made the part with the appropriate type of heat treatment, the following random variables are considered: load; wear-out limit of the master-detail; coefficient, taking into account the fatigue of the part and the parameter of the fatigue curve of the specimen. For the design of test specimen is necessary to obtain information about these random variables.

Using the method of statistical tests can be defined for respective case of loading of an experimental model of the set of life distributions to parts in different variants of their performance (steel's mark, dimensions, type of heat treatment, strengthening approach, etc.). After approximating the curve with the Weibull law, then we choose the optimal variant, proceeding from conditions (5) and (6). This option shall be verified by the fatigue accelerated tests on the parts directly on special installations.

The progress of failures relating to wear-out/fatigue is the result of an accumulation of damage in detail. The tests carried out [4] show that in 30% of cases of wear-out is seen by noticeable deviation from the linear hypothesis of Palmgren-Miner. For such cases, it is a characteristic monotone change of the average speed of wear-out. In this case the linear hypothesis of Palmgren-Miner can be regarded as a particular case of power trend hypothesis. It is represented by the equation:

$$U = c.t^{d} \tag{10}$$

where:
U - value of the accumulated wear-out;
c, d - coefficients of power trend approximation.

When the variation of the wear-out rate within one realization is negligible, equation (5) gives a good approximation for random processes with low and medium intensity. From the ensemble of random implementations functions of wear, the greatest impact on the life of the parts has a maximum value of the scale factor c from formula (10). Such an implementation defines the minimum value of the parts life. In accordance with the literature [5] the maximum life values of the samples are described by the Fisher-Tippett limiting distribution having the form:

$$F(c) = 1 - \exp\left[-\left(\frac{b-c}{\beta}\right)^{-k}\right] \tag{11}$$

where: β, k, b - scale, shape and location parameters.

The displacement parameter b in this case is the maximum value of the coefficient c. The evaluation of this parameter on a sample with volume N is asymptotically normal with a variance $D(b)$:

$$D(b) = \frac{\beta^{2/k}}{N.(k+1)^{2}.\Gamma(1+2/k)} \tag{12}$$

Assuming that the distribution of coefficient c, described by equation (11), and the variance of exponent d can be ignored. From the theorem of transformation of random variables, one obtains for the density of parts life distribution the following equation:

$$f(t) = \frac{k.d.B}{t^{d+1}} \cdot \left(A - B.t^{-d}\right)^{-k-1}.\exp\left[-\left(A - B.t^{-d}\right)^{-k}\right] \tag{13}$$

where: $A = b/\beta$; $B = U_{\Pi P}/\beta$;
$U_{\Pi P}$ -upper limit of components wear-out.

The resulting life distribution is shifted on the time scale, such as a physical sense of drift is analogous to the shift parameter from the Weibull law (1) and is expressed by:

$$\mu = \left(\frac{U_{\Pi P}}{b}\right)^{1/d} \tag{14}$$

An uniform parts stability can be assured through minimization of the variance of the coefficient of approximation c from equation (5). This is achieved by increasing the shape parameter k from 5 to 20.
The condition for ensuring reliable work on the parts of the RES at the whole lifetime is determined by the inequality:

$$T_P \le \left\{\frac{U_{\Pi P}}{b + u_{\gamma}\sqrt{D(b)}}\right\}^{1/d} \tag{15}$$

where: $U_{\Pi P}$ -the wear-out limit of the parts specified after the transformation of the equation (14) in the form:

$$U_{\Pi P} = b.\mu^{d} \tag{16}$$

4. Results

Ten models were studied– parts of RES created by thermal treatment of steel brand 45 subject to wear-out on a special installation. The installation is designed for modeling the work of friction damper composed of a couple samples of the alloy brand 45 and mark U8. The load is 1 MPa, and the tensioning rate- 0.18 m/s.

Studies have shown that actually such kind of oxidative deterioration led to linear hypothesis for an amendment of the accumulated damage, i.e. the coefficient $d = 1$. For each piece of steel were obtained experimentally four values of wear-out rates, from which it is selected the maximum. In this way is obtained a sample of maximum wear-out rates, respectively: 6.67; 4.27; 3.59; 4.44; 4.62; 4.27; 6.59; 4.96; 5.30 mg/h.

Processing of the results by applying the maximum likelihood method allows to obtain the corresponding values of the parameters of the distribution of formula (11): $\beta = 1,4076$; $k = 1,3721$; $b = 7,2202$. The variance of the parameter b is defined in (12), i.e. $D(b) = 0,02266$.

It follows from the above that the wear-out limit $U_{ПР} = 1000\ mg$ the lifetime will be calculated by the formula (8), with the assumption of $u_{\gamma} = 1,65$, when the confidence level will be $\gamma = 0,95$ [5]. Respectively, after calculations of the lifetime, one obtained the value of $T_P = 133,9\ \ h$.

5. Conclusions

5.1. The presented model (7), (8) and (9) of this reliability study on renewable energy sources, provides the ability to process information for external factors impacting on the RES parts and causing fatigue.

5.2. The model (15) can be used for forecasting the lifetime of parts of any type of technical system.

Acknowledgments

I would like to thank to professor Nikolay Petrov from Technical University-Sofia, Sliven branch for his kind support during this study.

References

[1]. *Гиндев Е.Г.* Увод в теорията и практиката на надеждността. Част 1. Основи на приложната надеждност. Академично издателство "Професор Марин Дринов", София, 2000.

[2]. *Петров Н.И.* Експлоатационна надеждност на рискови технически системи. Издателска къща "Учков", Ямбол, 2002.

[3]. *Серенсен С.В., В.П. Когаев., Р.М. Шнейдерович.* Несуща я способность и расчет деталей машин на прочность. М., Изд. „Машиностроение", 1995.

[4]. *Кугель Р.В., В.Г. Кухтов.* Динамика изнашивания деталей. Вестник машиностроения, 1984.

[5]. *Petrov, N.* About Philosophical Sence of the Category Relia bility. International Journal of Engineering Science and Innovative Technology (IJESIT), ISO 9001-2008, vol. 2, issue 5, sept. 2013, pp. 59-63.

[6]. *Stamov, G., N. Petrov.* Lyapunov-Razumikhin Method for Existence of Almost Periodic Solutions of Impulsive Differential-Difference Equations. Journal „Nonlinear Studies", 2008.

[7]. *Petrov, N.* An Indicator of Reliability in the Space Dimen sions. Bulletin of Society for Mathematical Services and Standards (BMSA). 2014, pp. 120-125.

[8]. *Petrov, N., N. Atanasov.* Probability and Orderlines is the Nature. IJMSEA, v. 7, № III, 2013, pp. 287-293.

[9]. *Петров, Н.* Принцип на целесъобразността за структурата на кибернетичната система и нейната надеждност. Сп. „Наука, Образование, Култура",бр. 4, 8.03.2014, с. 19-29

[10]. *Petrov, N.* Method of the Excession for Resource Researches of Technical Economical Systems. Bulletin of Society for Mathematical Services & Standards, Vol. 3, № 2, 2014, pp. 101-112.

[11]. *Petrov, N.I., Sn. Yordanova.* Extrapolation Prediction of the Technical Resource via Forced Testing. IEEE, WSES, CSCC-MSP-MCME 2000, Athens, Greece, 10.07.2000, p.p. 353-356.

Angel Tanev is a Dr-Ing. **(**2009) and MSc in Automation and System engineering (2002). He is currently working in the scientific field of reliability and safety engineering. His research interests include also stochastic systems, risk theory, forecasting, time series.