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Prediction Model of the Transmission Line Lightning Strike Probability Base on the Generalized Pareto Distribution

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Abstract: In recent years, the lightning disasters occur frequently and the uncertainty of lightning brought more and more challenges to transmission line lightning protection and disaster mitigation work.Based on the characteristics of the lightning obey the extreme value distribution, In this study, use an overhead transmission line lightning strike probability prediction method base on the Generalized Pareto Distribution (GPD).According to the statistics in month, Using the method of average overrun function and probability weighted moment estimation method of GPD estimate the parameters of the model.Establishing regional GPD model of ground lightning density proposed the overhead transmission line lightning probability prediction method in extreme weather conditions.The analysis results base on the compare with the actual lightning trip-out rate show that: the proposed method can be well fitted lightning distribution, evaluation level of risk of transmission lines, provide support for transmission line lightning protection and disaster mitigation.

Key words: Overhead transmission line, generalized pareto distribution, ground lightning density, lightning probability prediction

INTRODUCTION

Lightning is the main reason for the malfunction of overhead transmission lines (Sheng *et al*., 2011).

To determine the reasonable lightning protection measures is great significance to reduce the lightning accidents (Armstrong *et al*., 1968), ensure the safe operation of overhead transmission lines (McDermott *et al*., 2000).In this study, based on the study of the distribution regularity of ground lightning density (Sakae *et al*., 2010) put forward a regional ground lightning density model of GPD and establish overhead transmission line lightning probability prediction and then example calculation by a double circuits on the same tower 220 kV overhead transmission line.With the actual results of contrast analysis: the proposed approach can be a very good fitting lightning distribution, predict the probability of lightning stroke in a transmission line, provide support for transmission line lightning protection and disaster mitigation.

DISTRIBUTION CHARACTERISTICS OF REGIONAL GROUND LIGHTING DENSITY

The GuangXi grid electric power research institute studied base tower in each monthly ground lightning density along a 220 kV overhead transmission lines, in twelve months this line's base tower monthly average ground lightning density statistics on the ground (from #30 base tower to #40 base tower) as shown in Fig. 1 and in Table 1.

From Table 1 and Fig. 1: July and August, the ground lightning density is significantly higher than other months show that the area frequent lightning activity in July and August a special period of lightning protection of overhead transmission lines need the key consider the influence of surface ground lightning density of lightning trip-out rate.

The region's average ground lightning density is single peak distribution statistical analysis of ground lightning density is more than a certain threshold can get the corresponding distribution of lightning used for the calculation of the probability of a lightning stroke overhead transmission lines (Du *et al*., 2001).

Table 1: Monthly average ground lightning density

Month	1	2	3	4
	0.0000	0.0217	0.0244	0.0704
month	5.0000	6.0000	7.0000	8.0000
	0.1002	0.1842	0.3847	0.4687
month	9.0000	10.0000	11.0000	12.0000
	0.2330	0.1057	0.0596	0.0108

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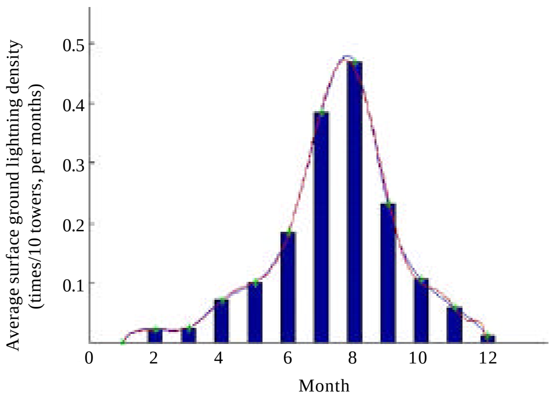

Fig. 1: Monthly statistics of average ground lightning density

GPD MODEL

In recent years, extreme value theory is introduced to the study of risk measurement (Embrechts and Resnick, 1999).

In general, when using the theory of extreme value measure risk mainly has two kinds of model.

One kind is Block Maxim Model (BMM), This kind of model is aimed at a maximum set modeling. Another kind of extreme value model is generalized Pareto model (Hosking *et al*., 1987) hereinafter referred to as GPD model.This model of data modeling for observing all over a gate limit.Due to GPD model effectively use the limited extreme observations, therefore, GPD model more widely used in practice (Cebrian *et al*., 2003).The Generalized Pareto Distribution (GPD) is a power law distribution from a large number of phenomena of real world, using random variable order statistic to study overrun nature greater than one set of threshold (Bali, 2003), deduce the distribution of extreme weather events, widely applied in study of extreme weather conditions like the strong precipitation, very short temperature estimation (Zhang *et al*., 2005).

This article will use the GPD distribution model to analysis the probability distribution of the data set beyond a certain threshold of all lightning position system monitoring value.

Samples above threshold of ground lightning density GPD model: This study use extreme value theory to establish the number of the model for modeling the data requirement is less (Bali, 2003) can better adapt to the volatility and randomness of the thunderbolt.

By the literature Cebrian *et al*. (2003), assume that the number of samples for ground lightning density γ sequence is Nr distribution function is F (γ), definition $F_\beta(\bar{\gamma})$ is Conditional Excess Distribution function which is the conditional distribution function when variable γ more than threshold β indicated as:

$$F_\beta(\bar{\gamma}) = P(\gamma - \beta \le \bar{\gamma} \mid \gamma > \beta) \quad \bar{\gamma} \ge 0$$
$$= \frac{F(\beta + \bar{\gamma}) - F(\beta)}{1 - F(\beta)} = \frac{F(\gamma) - F(\beta)}{1 - F(\beta)} \tag{1}$$

Take out sample which larger than β from $\{\gamma_i\}$, use $\bar{\gamma}_i = \gamma_i - \beta$ get transfinite sample sequence $\{\bar{\gamma}_i\}$ when γ is greater than the threshold β, the number of samples is N_β. Using transfinite sample number to calculate button function of β can get F (β):

$$F(\beta) = 1 - \frac{N_\beta}{N_\gamma} \tag{2}$$

Combination Eq. 1 and 2, the probability distribution model of surface ground lightning density is:

$$F(\gamma) = F_\beta(\bar{\gamma})(1 - F(\beta)) + F(\beta)$$
$$= 1 - \frac{N_\beta}{N_\gamma} + \frac{N_\beta}{N_\gamma} F_\beta(\bar{\gamma}) \quad \gamma \ge \beta \tag{3}$$

Because this study aim at extreme lightning events, therefore, get transfinite sample GPD model of ground lightning density γ just need analysis and calculation of $F_\beta(\bar{\gamma})$.

When β is large enough, conditions of transfinite distribution function $F_\beta(\bar{\gamma})$ have GPD distribution function $F_\beta(\bar{\gamma} \mid k, \alpha)$:

$$F_\beta(\bar{\gamma} \mid k, \alpha) = \begin{cases} 1 - [1 + k\frac{\bar{\gamma}}{\alpha}]^{-\frac{1}{k}}, k \ne 0 \\ 1 - \exp[-(\frac{\bar{\gamma}}{\alpha})], k = 0 \end{cases} \tag{4}$$

In the equation, β is the threshold, α is scale parameter, k is the shape (linear) parameter, $\bar{\gamma}$ is transfinite samples.

The conditions transfinite probability density function of ground flash density γ:

$$f(\gamma) = \begin{cases} \frac{1}{\alpha}[1 + k\frac{\gamma - \beta}{\alpha}]^{-\frac{1}{k}-1}, \quad k \ne 0 \\ -\frac{1}{\alpha}\exp[-(\frac{\gamma - \beta}{\alpha})], \quad k = 0 \end{cases} \tag{5}$$

Determine the threshold value β, scale parameter α and shape parameter is the key work to accurately establish the transfinite samples GPD model of Ground flash density and choose threshold value β is the premise to formation $\bar{\gamma}$, parameter α and k.

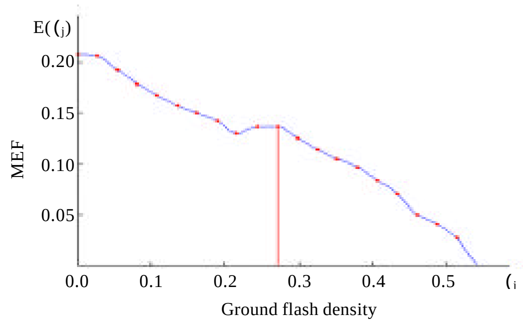

Fig. 2: MEF curve and threshold of ground lightning density

Selection of thunderstorm: Due to different of the around the country, threshold should be adjusted according to the actual circumstances of the stations (Cebrian *et al*., 2003).The selection of threshold should be able to ensure both the selected extreme value is in line with distribution of GPD and there are enough samples to estimate model-parameter. The article uses the Mean Excess Function (MEF) method to estimate threshold.

Assume $\gamma_1<\gamma_2<\ldots<\gamma_j<\gamma_i<\gamma_N$, get the expressions of MEF:

$$e(\gamma_j)=\frac{1}{N_\gamma-k+1}\sum_{i-k}^{N_\gamma}(\gamma_i-\gamma_j) \quad (6)$$

In the equation, $k=\min\{i|\gamma_i>\gamma_j|\}$, N_γ-k+1 means the number of greater than γ_j in $\{\gamma_i|i>j|\}$. Point (γ_j, e(γ_j)) consume ME Fcurve, as shown in Fig. 2.When $\gamma\geq\gamma_j$, e(γ_j) is the approximate linear function, select the γ_j as a threshold β.

Scale parameter α and shape parameter k estimation: Using the daily measured lightning data of monitoring stations to simulation area of thunderstorms.Using the Probability Moments Weighted (PMW) method to calculate distribution parameters (Peter, 2001). At the same time, meet the minimum standard of skewness and error of mean square to improve model accuracy (Efron and Tibshirani, 1986).

Assume F (x) is the Generalized Pareto Distribution (GPD) distribution function, θ = (k, α) is stay estimate parameters the probability weighted moments can be defined as (Hosking *et al*., 1985):

$$\begin{aligned}M_{p,r,s}&=E\left\{[X(F)]^p[F(X)]^r[1-F(X)]^s\right\}\\&=\int_0^1X^p[F(X)]^r[1-F(X)]^s dF(X)\end{aligned} \quad (7)$$

In the equation, X(F) is the inverse function of F(X).

Take p = 1, r = 0, s = 1, when 0<k<1, can get:

$$\begin{aligned}M_{1,0,1}&=E[X(1-F)]=\int_0^1X[1-F]dF\\&=\int_0^1\left\{\beta+\frac{\alpha}{k}[(1-F)^{-k}-1]\right\}(1-F)dF\\&=\frac{\beta}{2}+\frac{\alpha}{2(2-\alpha)}\end{aligned} \quad (8)$$

Take p = 1, r = 1, s = 0, when 0<k<1, can get:

$$\begin{aligned}M_{1,1,0}&=E[XF]=\int_0^1XFdF\\&=\int_0^1\left\{\beta+\frac{\alpha}{k}[(1-F)^{-k}-1]\right\}FdF\\&=\frac{\beta}{2}-\frac{\alpha}{2k}+\frac{\alpha}{k(2-k)(1-k)}\end{aligned} \quad (9)$$

In the actual problem, $M_{1,0,1}$ and $M_{1,1,0}$ are unknown, need to estimate.

Set the sample $x_1, x_2,\ldots, x_n$ is random sample from the distribution function, order samples is $x_1, x_2,\ldots, x_n$. Take Y = XF = (X), $y_i = x_i F(x_i)$, I = 1, 2…, n, can get:

$$M_{1,1,0}=E[y] \quad (10)$$

$$\begin{aligned}\bar{y}&=\frac{1}{n}\sum_{i=1}^{n}x_iF(x_i)=\frac{1}{n}\sum_{i=1}^{n}x_{(i)}F(x_{(i)})\\&\approx\frac{1}{n}\sum_{i=1}^{n}\frac{i}{n+1}\end{aligned} \quad (11)$$

From Eq. 9 get the estimate of $M_{1,1,0}$ is:

$$\bar{\bar{M}}_{1,1,0}=\frac{1}{n}\sum_{i=1}^{n}\frac{i}{n+1}x_{(i)} \quad (12)$$

In a similar way, From Eq. 8 get the estimate of $M_{1,0,1}$ is:

$$\bar{\bar{M}}_{1,0,1}=\frac{1}{n}\sum_{i=1}^{n}\frac{n+1-i}{n+1}x_{(i)} \quad (13)$$

From Eq. 8 and 9 can get estimate probability weighted moments of α and k is:

$$\hat{\alpha}=(2\bar{\bar{M}}_{1,0,1}-\beta)(2-\bar{\bar{\delta}}) \quad (14)$$

$$\hat{k}=\frac{\bar{\bar{M}}_{1,1,0}-3\bar{\bar{M}}_{1,0,1}+\beta}{\bar{\bar{M}}_{1,1,0}-\bar{\bar{M}}_{1,0,1}} \quad (15)$$

From this can get probability weighted moments of the parameter estimates $\hat{\alpha}$ and $\hat{k}$.

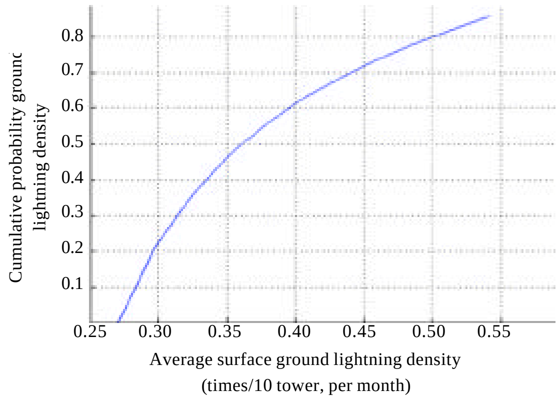

Fig. 3: GDP curve fitting of ground lightning density over the threshold value

SAMPLE VERIFICATION

Use a 220kv lines in section 1 (# 30 to # 40 base tower) as an example, to validation the surface ground lightning density GPD model that this study puts forward.

Establish of GPD model

Calculate the ground lightning density threshold: According to the method mentioned in section 3.2 to determine the threshold value, get the threshold value of ground lightning density is 0.2709.

Model parameters estimation: According to ground lightning density statistics in ten years (120 months), use Probability Weighted Moment Estimator (PMW) method to calculate (mentioned in section 2.3): The estimate of scale parameter α is 0.2244, the estimate of shape parameter k is $\hat{k}$.

Build the GPD model: From 4.4.1 and 4.1.2 can get the estimated value of ground lightning density threshold β, Scale Parameters α, shape parameter k, substitute them into Eq. 4, get ground lightning density GDP distribution model as shown in Eq. 16.

Cumulative probability GPD model of surface ground lightning density exceed the threshold fitting curve is shown in Fig. 3.

$$F(\gamma) = 1-(1+k\frac{\gamma-\beta}{\alpha})^{-1/k} = 1-[1+14.3632(\gamma-0.2709)]^{-0.31} \quad (16)$$

From Fig. 3 can be seen, when ground lightning density monthly average more than threshold value of 0.2709, the cumulative probability of ground lightning density increases with the increase of surface ground lightning density, but growth is slow, eventually tend to be 0.9, consistent with statistics.

CONCLUSION

From statistical analysis of a 220 kV line show that: July and August the ground lightning density is significantly higher than other months which is a special period of lightning protection of overhead transmission lines.The average ground lightning density is single peak distribution, in line with the extreme value distribution.

Research GPD model fitting lightning distribution, can predict the trend of the thunder and lightning, provide reference for transmission line lightning protection and disaster mitigation, has important practical significance.

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REFERENCES

Armstrong, H.R. and E.R. Whitehead, 1968. Field and analytical studies of transmission line shielding. Trans. Power Apparatus Syst., 87: 270-281.

Bali, T.G., 2003. An extreme value approach to estimating volatility and value at risk. J. Busi., 76: 83-108.

Cebrian, A.C., M. Denuit and P. Lambert, 2003. Generalized pareto fit to the society of actuaries large claims database. North Am. Actuarial J., 20: 18-36.

Du, Y., S.M. Chen and B. John, 2001. Experimental and numerical evaluation of surge current distribution in building during a direct lightning stroke. Trans. Hongkong Instit. Eng., 23: 43-49.

Efron, B. and R. Tibshirani, 1986. Bootstrap methods for standard errors, confidence intervals and other measures of statistical accuracy. Stat. Sci., 1: 54-75.

Embrechts, P. and S. Resnick, 1999. Extreme value theory as a risk management tool. North Am. Actuarial J., 3: 30-41.

Hosking, J.R.M. and J.R. Wallis, 1987. Parameter and quantile estimation for the Generalized Pareto distribution. Technometrics, 29: 339-349.

Hosking, J.R.M., J.R. Wallis and E.F. Wood, 1985. Estimation of the generalized extreme-value distribution by the method of probability-weighted moments. Technometrics, 3: 251-261.

McDermott, T.E. and V.J. Longo, 2000. Advanced computational methods in lightning performance the EPRI lightning protection design workstation. Proceedings of the Power Engineering Society, Power Engineering Society Winter Meeting, Vol. 33, January 23-27, 2000, New York, USA., 17-21.

Peter, F.R., 2001. Generalized probability weighted moments: Application to the generalized pareto distribution. Water Resour. Res., 37: 1745-1751.

Sakae, T., T. Tsuboi, S. Okabe, Y. Nagaraki, J. Takami and H. Ota, 2010. Method of calculating the lightning outage rate of large-sized transmission lines. Trans. Dielectr. Elect. Insulation, 117: 1276-1283.

Sheng, H.B., W. Chen, S. Wang, Z. He and Y. Chen, 2011. Simulation tests on lightning stroke-caused wire-breakage of 10 kV overhead transmission line. Power Syst. Technol., 35: 117-121.

Zhang, Z.J., W.X. Sima, X.L. Jiang, C.X. Sun and L.C. Shu, 2005. Study on the lightning protection performance of shielding failure for UHV&EHV transmission lines. Proc. CSEE, 25: 1-6.