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Risk Assessment of Power System under Typhoon Disaster

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Abstract

The paper focuses on the research of typhoon disaster and its influence on power system security. A typhoon disaster simulation model is established to track the average impact of a large number of typhoon simulations in Guangdong province in China. The main parameters in the typhoon model includes typhoon frequency, landing position, approach angle, translation velocity, central pressure difference, radius to maximum wind, decay rate, wind field profile, etc. Then the typhoon simulation and power system risk assessment as well as the system loss evaluation are linked together. The results can provide a potential reference for the government policy makers as well as the power system planners and runners for power system risk assessment, planning and operation.

Keywords: *typhoon, risk assessment, power system, Monte Carlo simulation, disaster*

1. Introduction

In recent years, extreme weather events occurred frequently. It influenced people's life seriously and brought great economic and social loss. It is estimated that during the ten years of 1991~2000, the average population affected by meteorological disaster reached 211 million around the world every year. That is 7 times more than the population affected by war. Asia is one of the lands that are hit by natural disasters most frequently. During 1990 and 2000, this region's natural disaster reached 43% in globally extreme weather events. According to recent statistics data, the economic loss caused by the global climate changes and extreme weather in the past 40 years has risen by an average of 10 times.

China has a vast territory, which means a higher rate of local natural disasters in all. The disaster-inducing factors are various and the disaster-inducing environment conditions are complex. Therefore it is one of the countries that are affected by natural disasters most seriously in Asia and even in the world. Statistics show that China ranked No. 24 in the 20th century top 100 events of natural disasters with the most death population. And for the greatest economic loss, China ranked No. 17 [1-3]. Since the 21th century, the economic losses caused by natural disasters in China have increased dramatically. It has become one of the major factors constraining the social economic and sustainable development of China. Almost all the natural disaster types have been occurred in China.

At present, the major natural disasters that influence China are the meteorological disasters such as drought, flood, typhoon and snowstorm; and geological disasters such as earthquakes,

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landslides and debris flow. Among them, typhoon, earthquake and ice disasters should have the most serious influence on power system.

Power system is people's lifeline project. With a large amount of overhead transmission lines and power towers dispersed in different geographical range, the power system infrastructures are somewhat vulnerable to the threat of severe weather. It may cause long-lasting power outages range from several hours or even days. For example, the hurricane Katerina in 2005 caused the power outage as well as communication, water supply and traffic problems lasting for several days in New Orleans region in United States. In China, the typhoon Damrey landed in Hainan province in 2005 caused several hours’ blackout on the whole Hainan island, which area is as large as the country Belgium.

For a long time the researches on power system accidents mainly concentrated on stability disruption or cascading events. However the power system dismemberment caused by external forces (such as typhoon, ice, and war) was rarely investigated. Therefore the paper mainly focuses on the most frequent meteorological disaster typhoon disaster and its influence on power system security, since typhoon disaster may be one of the most frequent natural disasters with the highest loss in power system.

2. Typhoon Disaster Simulation

Typhoon is the cyclone vortex happened in tropical or subtropical ocean. It has a very wide activity range. Its movement is often accompanied by high wind and heavy rain and storm surges. It has strong destructive power for human-beings and facilities in coastal areas [3, 4].

According to statistics data, in the past 50 years, there were 25 provinces in China influenced by different level typhoon [4]. The occurrence opportunity of typhoon varies in different seasons of a year. Generally speaking, typhoon usually land in China’s coastal areas from May to September, especially in July and August. The typhoon influencing China generally comes from the west Pacific Ocean. Statistics show the average trip length that the typhoons come inland is about 500 km, while the longest length can reach up to 1500 km. Therefore, the influence caused by typhoon was not only confined to the coastal provinces, but also some inland provinces.

From the frequency point of view, the eastern coastal provinces were hit by typhoons the most while the other inland provinces and cities had lower frequency. Among the eastern coastal provinces, Guangdong province ranked the first. Every year nearly three typhoons landed in Guangdong in average [5]. Therefore the paper takes Guangdong province as an example to simulate the typhoons landed in China.

Due to the uncertainty of typhoon, it brings certain difficulty in its mathematical simulation. In recent years, the research organizations had carried out a lot of researches on typhoon simulation and its forecasting according to different regions in the world [6]-[14]. However, most researches only concentrate on one or more aspects in typhoon simulation, such as wind speed, gust factors, decay speed, etc. The model that simulate typhoon comprehensively was rare. The paper set up the typhoon simulation model in order to estimate the risks and losses in power system caused by typhoon based on data from China Meteorological Administration and China Typhoon Web. The typhoon model’s intention is to simulate the average effect of typhoons during a period of time, rather than duplicate a certain way of the typhoon in the past. The result of the simulation could estimate the risks and its losses brought by typhoon in power system for decision-makers' reference.

2.1. Typhoon Model Assumptions

Typhoons are driven by a series of complex atmospheric metrology elements and there are so many uncertainties during its development and decay period. Since the typhoon simulation is designed to track the average impact of a large number of simulations rather than track every single possible typhoon scenarios. Therefore, a few assumptions are made for this typhoon model accordingly [6].

(i) Only the typhoons landed within Guangdong province were considered. Other typhoons landed on neighboring provinces and coastal areas were not included.

(ii) Only one landfall is considered for each typhoon. If by rare chance the typhoon landed twice or more, each landing is simplified as a single separated typhoon.

2.2. Typhoon Frequency

The typhoon frequency model is considered as Poisson distribution in previous researches. The Poisson distribution is:

$$P(x=k)=\frac{\lambda^{k}}{k!}e^{-\lambda} \tag{1}$$

where k is the number of typhoons happened per year and λ is the expected number of typhoons during the given period interval (one year in this case). The average occurrence number of Guangdong province's typhoon on each month as well as a whole year is shown in Table 1 [2].

Table 1. Average Occurrence Number of Guangdong Typhoon

Landing place	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Sep.	Sum of a year	**Ave. of a year**
Guangdong	**4**	**19**	**39**	**31**	**37**	**11**	**4**	**1**	**146**	**2.92**

2.3. Landing Position

The landing position is simulated based on the historical data of typhoons landing in Guangdong province. The coastline of Guangdong province is divided into a certain number of bins. The bins are equally divided by latitude and longitude. The distribution of historical typhoon landing positions among those bins form the base for assigning the landfall location for each simulated typhoon so that the simulated landing position is consistent with the probability distribution of historical data [7].

2.4. Approach Angle

In order to investigate the relationship between moving path and the coastline, the approaching angle is introduced. According to the characteristic of Guangdong coastline, we draw two auxiliary lines from east to west. The first auxiliary line is from Shantou to Zhuhai. The other auxiliary line is from Zhuhai to Zhanjiang. When the typhoon moved near the coastline, the angle between its moving direction and the auxiliary line (or its extension line) is defined as the approach angle. The approach angle is modeled as a bi-normal distribution [8].

$$f(x,y)=\frac{1}{2\pi\sigma_x\sigma_y\sqrt{1-r^2}}\mathrm{e}^{-\frac{1}{2(1-r^2)}\left[\frac{(x-\mu_x)^2}{\sigma_x^2}-\frac{2r(x-\mu_x)(y-\mu_y)}{\sigma_x\sigma_y}+\frac{(y-\mu_y)^2}{\sigma_y^2}\right]} \tag{2}$$

where μ_x and μ_y is means for two normal distributions, respectively, σ_x and σ_y are their standard deviations, and r is the weighting factor; these parameters are to be identified from historical data.

2.5. Translation Velocity

The translation velocity of a hurricane (m/s) on its landfall can be modeled as a lognormal distribution [9]:

The probability density function of a log-normal distribution is:

$$f_x(x,\mu,\sigma)=\frac{1}{x\sigma\sqrt{2\pi}}e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}} \tag{3}$$

where x is the translation velocity, μ is the logarithmic mean, and σ is the logarithmic standard deviation to be identified from historical data.

2.6. Central Pressure Difference

The central pressure difference (millibar) is modeled as the Weibull distribution, where k and λ is a constant to be identified from historical data. The probability density function of a Weibull random variable x is [10]:

$$f_x(x,\lambda,k)=\frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1}e^{-\left(\frac{x}{\lambda}\right)^k} \tag{4}$$

2.7. Maximum Wind Speed

The maximum wind speed is roughly modeled based on the typhoon categories shown in Table 2 [2]. For example, if the typhoon falls in category Severe Tropical Storm (STS), then we roughly model the maximum wind speed as some random number between 24.5~32.6 m/s.

Table 2. Typhoon Grade Categories

Tropical cyclone level	Maximum average wind speed	**Maximum wind near the centre**
Tropical cyclone level	Maximum average wind speed	**Maximum wind near the centre**
Tropical Depression(TD)	10.8~17.1	**6~7 level**
Tropical Storm(TS)	17.2~24.4	**8~9 level**
Severe Tropical Storm(STS)	24.5~32.6	**10~11 level**
Typhoon(TY)	32.7~41.4	**12~13 level**
Severe Typhoon(STY)	**41.5~50.9**	**14~15 level**

2.8. Radius to Maximum Wind

The radius of maximum wind (RMW) is the distance between the center of a typhoon and its band of strongest winds.The radius of maximum wind $R_{\max}$ can be described by an empirical model [11, 12].

$$\ln R_{\max}=2.556-0.000050255\Delta p^2+0.042243032\psi \tag{5}$$

where ψ is the storm latitude, Δp is the center pressure difference.

2.9. Decay Rate

After typhoon's landing, the wind speed would decay because of the land mass frictions. For easy calculation, the authors adopt the generally accepted typhoon decay models which estimate the decayed wind speed after its landfall.

$$V(t) = V_b + (RV_0 - V_b)e^{-\alpha t} \tag{6}$$

where R=0.9 is a constant factor to estimate the wind speed reduction after landfall. V_0 is the maximum surface wind speed at landfall, V_b=13.75m/s, $\alpha = 0.095\mathrm{h}-1$.

2.10. Wind Field Profile

The wind field model developed by Holland is a commonly used model. It describes the radial profile of winds in a typhoon. The detailed model information could be reviewed in the references [13-14]. In this work, a simpler application is applied.

$$V_g = \left[\frac{AB(p_n - p)e^{-A/r^B}}{\rho r^B} + \frac{r^2 f^2}{4} \right]^{\frac{1}{2}} - \frac{rf}{2} \tag{7}$$

where V_g is the gradient wind at radius r, $\rho = 1.15 kg/m^3$ is the air density, p is the central pressure, p_n is the ambient pressure (with typical value of 1013 mbars or 101.3 Pascal's), and f is the Coriolis parameter:

$$f = 2\Omega \sin \phi \tag{8}$$

where $\Omega = 7.292 \times 10^{-5}$ is the Earth's angular velocity, and ϕ is the local latitude.

3. Power System Risk Assessment

Using the model features described above, a complete typhoon track for Guangdong province can be simulated. Using MICAPS (Meteorological Information Comprehensive Analysis and Process System), an example figure of the probabilistic typhoon model simulation in Guangdong province is shown in Figure 1. MICAPS is now the standard graphics workbench for Chinese forecasters.

Figure 1. A Probabilistic Typhoon Track in Guangdong China

Using this approach, the basic wind field over the typhoon affected area can be generated for each simulated typhoon. Since the intent of this research is to track the average effect of a large group of simulated typhoons instead of trying to reproduce a specific typhoon in the past, a randomly-generated typhoon year from this probabilistic model must be repeated many times using Monte Carlo simulation. With the Monte Carlo simulation, this probabilistic typhoon model can be linked with the financial lost induced by typhoon, in order to assess the potential risks during the period of a typhoon year.

Generally speaking, forecast the typhoon is feasible these days. However, to link the meteorological disaster with economic and social lost of power system is somewhat complicated. Some in-depth researches still need to be carried out in the future. In this paper the power system financial lost are considered in two categories. One is that although the typhoon destroys some power system utilities, it doesn’t cause power supply interruption. The other is the typhoon not only damages some power system facilities but also causes blackout accidents. In the first situation we only count in the power system utility lost and its repairing cost. However in the second situation we should also count in the lost caused by blackout. A threshold valve is set to distinguish the two situations.

3.1. Damage Lost Without Blackout

When the typhoon is not so fierce, there would only be some utility’s damage lost.

$$f(w) = \sum_{i=1}^{n} L_i(w) \tag{9}$$

where $f(w)$ is the sum of all power equipments damage lost caused by typhoon. $L_i(w)$ is the lost of individual equipment. When there is too much equipment damage, the power grid would be separated and may cause some blackout accidents. The relationship between the equipment damage and blackout is complicated. In this paper we roughly set a valve value to distinguish if there would be blackout after the equipment damage.

$$f(w) \geq 50\% \, f(w)_{all} \tag{10}$$

When $f(w)$ exceeds the value of all equipment’s total value, there would probably occur some blackout accident.

3.2. Damage Lost with Blackout Accident

When there is blackout accident the lost should also count in the energy that is not supplied. We use the internationally accepted index LOLP (Loss of Load Probability) and EENS (Expected Energy Not Supplied) to calculate the lost caused by blackout.

$$\mathrm{LOLP} = \sum_{i=1}^{\mathrm{NL}} \Big(\sum_{s \in F_i} P(s)\Big) \frac{T_i}{T} \tag{11}$$

$$\mathrm{EENS} = \sum_{i=1}^{\mathrm{NL}} \Big(\sum_{s \in F_i} P(s) \cdot C(s)\Big) \cdot T_i \tag{12}$$

where $P(s)$ is the probability of status s . $C(s)$ is the load shedding (MW) under status s . F_i is the mathematical set of all system failure status under load level i . And NL is load level classification number. T_i is the time duration under the load level i . And T is the whole time duration of the load curve. For system development and planning research, the whole time duration is generally a whole year, just suitable for our research on the whole typhoon year. The calculation of probability $P(s)$ can use the Monte Carlo simulation method that is commonly used in the power system risk assessment. The Specific algorithm of $P(s)$ can be found in references [15-17].

The whole lost should be the sum of EENS and the lost of equipments value.

$$f(w) = \sum_{i=1}^{n} L_i(w) + EENS \tag{13}$$

As our goal of this work is to analyze the average effect of a typhoon year but not the tracking of a single typhoon and its lost, therefore according to the Monte Carlo simulation above, the average financial lost in a whole typhoon year can be estimated as shown in Figure 2. Color depth level represents the extent of damage size. The darker the color is, the more lost it represents.

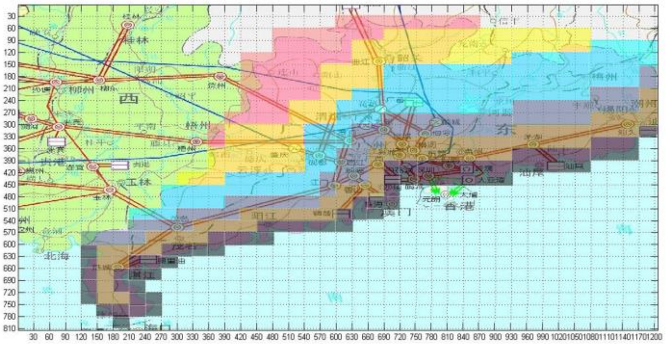

Figure 2. Average Financial Lost in a Whole Typhoon Year

4. Conclusion

Extreme meteorological disaster threats the global security. The power system blackout accidents and power system equipment damage caused by the meteorological disaster can also cause serious loss. The paper takes one of the most frequent and fierce meteorological disaster typhoons as an example. Set up the typhoon simulation model and then analyze the average effect in a whole typhoon year in power system in Guangdong China using Monte Carlo simulation. The author tried to link the typhoon simulation and power system risk assessment and loss evaluation together and divide the situation into two categories: with or without blackout occurrence. The results of the typhoon simulation and its risk assessment as well as the general financial loss of power system could provide a potential reference for the policy makers.

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