The Resilience of The Grid from The Risk of Failure Due to Kite Thread Disturbance

Case Study Khatulistiwa Grid

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***Abstract*— The kite thread disturbance is one of the major disturbances on the high voltage transmission line in countries, such as Indonesia, where kite-playing is a cultural activity. The kite thread destructive disturbance has a low probability. However, the impact of the disturbance can lead to a blackout in the huge area. Therefore, the kite thread disturbance can be defined as a resilience problem of a man-made attack. The lost cost of energy not served (ENSd) during every disturbance event can be defined as the cost of resilience. In the proposed assessment method, the power system modelling, and simulation are carried out to determine the impact of the disturbance to the grid as basic to calculate the energy not served. Any mitigation cost should be lower than the resilience cost.**

Keywords—energy not served, kite-thread disturbance, manmade-attack, power system, resilience

I. Introduction

Resilience was first introduced by Holling [1] in 1972 as a concept in the ecological system, which was referred to "a measure of the persistence of systems and of their ability to absorb changes and disturbances and still maintain the same relationships between populations or state variables". Then, the resilience as definition to describe persistence of systems and ability to absorb change and disturbances was adopted in several areas of knowledge, including electrical power systems.

In the electrical power system, the general definition of resilience is the ability to prepare for, withstand, recover from, and reduce the magnitude and/or duration of disruptive incidents, which includes the capability to prepare for, absorb, adapt to, and/or rapidly recover from such situation. Following the general definition, resiliency deals with low-frequency, high-impact incidents. [2] [5]. The high impact incidents are extreme events. Several research defines the extreme incidents as natural disaster [3], [4]. However, a man-made attack can also be defined as extreme events [6]. Cyber-Physical Attacks and terrorism attacks can define as extreme events which are dealing with low-frequency, high impacts. Even, it is difficult to find research that categorizes kite thread interruption as a type of man-made attack on the grid, in countries where kite-flying has become a culture, grid operator report incidents of black out caused by kite threads interruption.

In Indonesia, where kite-flying has become a culture, system blackout due to kite thread interruption is a type of disturbance that often occurs in the operation of electric power, especially in transmission systems. The last recorded disturbance occurred in July 2020 at part of the Java Bali System. Kite thread interruption occurs in *Pesugihan* Subsystem lead black out in part of West Java and Jogjakarta. The utility cannot serve about 511 MW of electricity to the customer. In *Khatulistiwa* Grid, another grid system outside of the Java Bali system, 72 recorded disturbances had occurred due to kite thread interruption in only 2 months, from February 2017 to March 2017. Thus, kite thread interruption is a problem in the operation of the transmission system in Indonesia.

Since the kite-flying is operated by man, then the kite thread interruption can define as part of man-made attack. However, the disturbance frequency of kite thread interruption is low. Even the impact of them will be high. Extensive blackouts can occur in the grid. Therefore, the kite thread interruption can be defined as high-impacts events. The resilience of the grid from kite thread interruption should be modelled. It can help utility increase their resilience level.

This paper is one of the first paper which is defined the kite thread disturbance as resilience problem in grid where kite-playing is cultural activity or a norm. This paper is organized as follows : Section II describes the resilience model and assessment. Section III presents the case study in West Kalimantan, Indonesia. Section IV concludes the paper, resilience model and assessment.

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II. RESILIENCE MODEL AND ASESSMENT

A. Resilience Evaluation Method

There are two approaches in the resilience evaluation method: a) quantitative resilience evaluation method and b) qualitative resilience evaluation method [5]. The quantitative resilience evaluation method consists of the simulation-based method, analytical method, and statistical analysis of historic outage data. Since the most important impact of the kite-thread disturbance is revenue loss of the utility during the disturbance, then the cost of resilience measure will be the appropriate method to determine the level of grid resilience. In the simulation-based method to determine the cost of resilience, power flow analysis is adopted as the analytical method.

B. Resilience Evaluation Asessment

The duration of disturbance can determine from the resilience trapezoid where the duration of disturbance is divided into 3 phases following: Phase I (the disturbance progress), Phase II (post-disturbance degraded state) and Phase III (restorative state) [2], as shown in Fig. 1

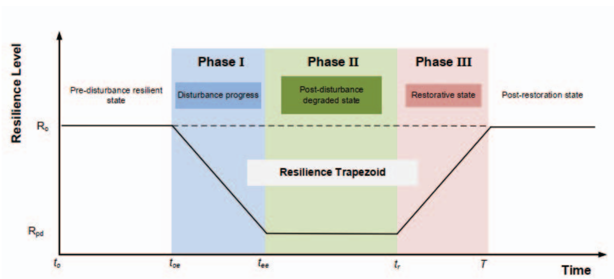

Figure 1 Duration of disturbance [2]

The cost of resilience proposed in this research is based on the concept of energy that is not served when the disturbance occurs in the line due to kite thread disturbance. Therefore, the mathematical model for the proposed concept is as follows:

$$ENS_d = P_d \, \Delta t \quad (1)$$

$$\Delta t = t_{phase1} + t_{phase2} + t_{phase3} \quad (2)$$

where ENS_d = energy not served during conductor out of service due to kite thread disturbance, P_d = the active power lost during conductor out of service due to kite thread disturbance, Δt = duration of disturbance.

The stages on resilience evaluation assessment are as follows:

Stage 1 : Identification of the probability of the disturbance and the duration disturbance due to the kite thread interruptions.

Stage 2 : Simulation of the power system parameters during high probability disturbance due to the kite thread interruptions.

Stage 3 : Calculate Δt, P_d, ENS_d

III. CASE STUDY

A. Kite Thread in Khatulistiwa Grid

The case study of resilience assessment due to the kite thread disturbance is *Khatulistiwa* Grid in West Kalimantan Province, Indonesia. The *Khatulistiwa* Grid is one of the grids that are most frequently disturbed by kites. The *Khatulistiwa* grid is shown in Fig. 2. According to PLN as Indonesia Utility Company data, the disturbance of the transmission line in the *Khatulistiwa* Grid is shown in Table I. As shown in the table, the major disturbance is kite thread disturbance.

Furthermore, the probability of kite thread disturbance for each line in the *Khatulistiwa* Grid is shown in Table II. As shown in the table, the probability of the transmission line disturbance due to the kite thread is relatively low. Thus, the kite thread disturbance meets the criteria of the low probability disturbance.

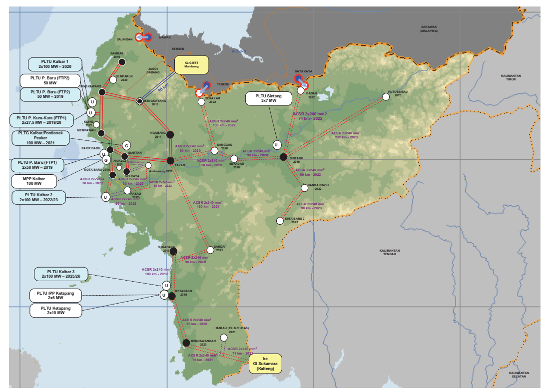

Figure 2 The *Khatulistiwa* Grid [7]

TABLE I. DISTURBANCE HISTORY 2019-2020

Years	Type of Disturbance			
	Kite Thread	Tree	Lightning	Relay
2019	211	12	47	2
2020	292	4	94	3

TABLE II. HIGH DISTURBANCE PROBABILITY 2019-2020

150 kV Transmission Line	Probability
Line 2 Sei Raya-Siantan	0.193832599
Line 1 Sei Raya-Siantan	0.126651982
Line Siantan-Parit Baru	0.110132159
Line Senggiring-PLTU Bengkayang	0.098017621
Line 1 Parit Baru-Senggiring	0.072687225

B. The impact of Kite Thread Disturbance to Grid

The impact of kite thread disturbance in the *Khatulistiwa* grid is simulated through Digsilent Power Factory. The simulation is carried out on both static conditions and dynamic conditions. The simulation of the static condition is load flow. In comparison, the dynamic conditions simulations are transient and frequency stability. The load flow is carried out in both scenarios as follows: 1) normal condition and 2) kite thread disturbance condition. Since the kite only hit one phase of the line, the kite thread disturbance simulates as a single phase to ground fault. The results of the load flow in both scenarios are shown in Table III and Fig.3. The blackout will occur if the kite hits the 150 kV line Siantan-Sei Raya.

TABLE III. RESULTS OF THE LOAD FLOW

Scenarios		Blackout	Overloading
Normal Condition		×	×
Kite Thread Disturbance	150 kV Line Senggiring-CFPP Bengkayang	×	×
	!50 kV Senggiring-Parit Baru Line 1	×	×
	150 kV Parit Baru-Siantan	×	×
	150 kV Siantan-Sei Raya	✓	×

The result of transient stability during kite thread disturbance is shown in Table IV. Since the blackout will occur only if the kite hits the 150-kV transmission line Sei Raya-Siantan then the profile of rotor angle and voltage is shown in Fig 4 and Fig 5. As shown in Fig 4, during the kite thread disturbance, the rotor angle of all generations in the *Khatulistiwa* grid will fluctuating and changing. Even though, the new rotor angle can keep in the new stability. There aren't generators experiencing out of step. While the voltage bus during the kite thread disturbance will fluctuating, instantaneously but can back to stable condition. Thus, it can conclude there are not any issues in the transient stability when the kite hits the transmission line, including the 150 kV transmission line Sei Raya – Siantan.

The result of frequency stability during kite thread disturbance is shown in Table V. Since the blackout will occur only if the kite hits the 150 kV-transmission line Sei Raya-Siantan, then the profile grid frequency is shown in Fig 6. As shown in the figure, during kite thread disturbance, the grid frequency will increasing follow the loss of electrical load. However, the grid frequency will still in the allowable range of frequency due to the grid code (49.00 Hz – 51.00 Hz in normal condition). Thus, it can conclude there are not any issues in the frequency stability when the kite hits the transmission line, including the 150kV-transmission line Sei Raya – Siantan.

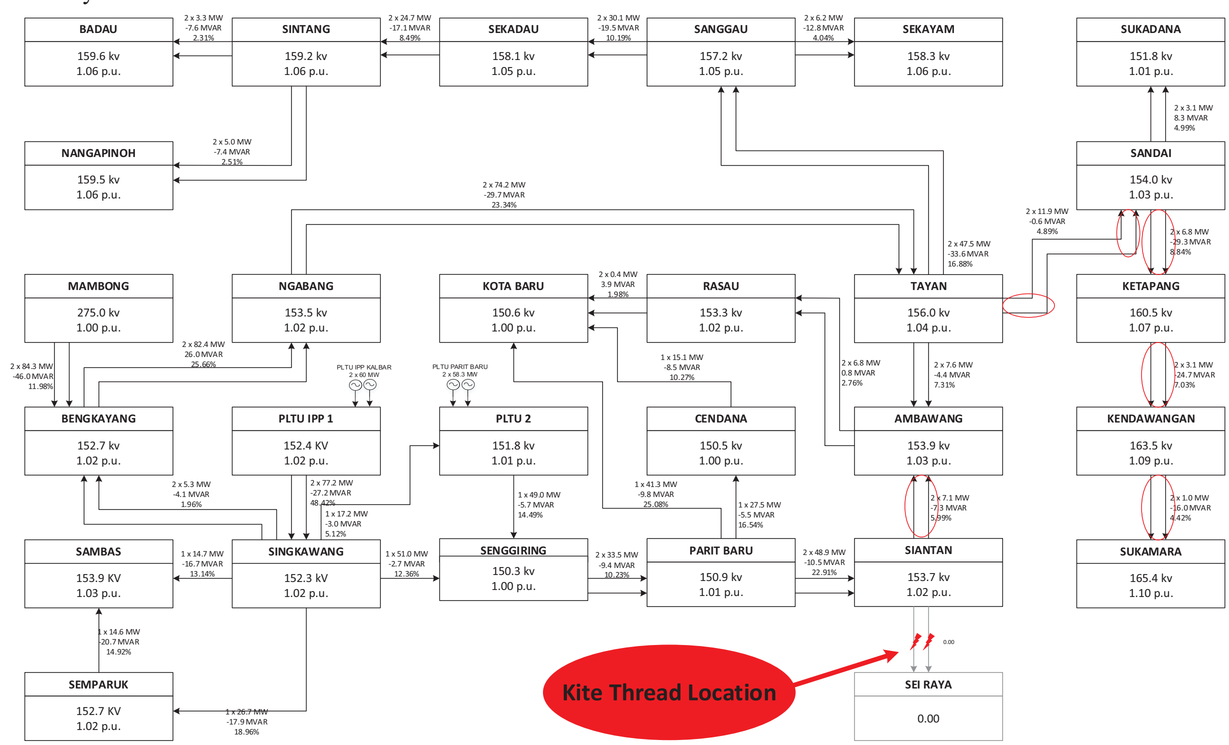

Figure 3 The Result of Load Flow

TABLE IV. TRANSIENT STABILITY

Scenarios		Back to New Stable Condition after Disturbance	
		Rotor Angle	Bus Voltage
Normal Condition		✓	✓
Kite Thread Disturbance	150 kV Line Senggiring-CFPP Bengkayang	✓	✓
	!50 kV Senggiring-Parit Baru Line 1	✓	✓
	150 kV Parit Baru-Siantan	✓	✓
	150 kV Siantan-Sei Raya	✓	✓

- Rotor Angle

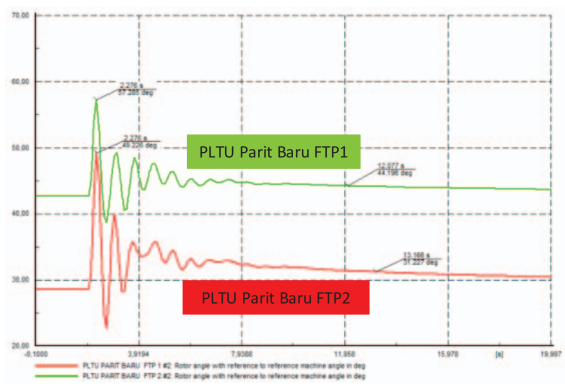

Figure 4 The rotor angle stability during kite thread disturbance in 150 kV transmission line Sie Raya – Siantan

- Voltage

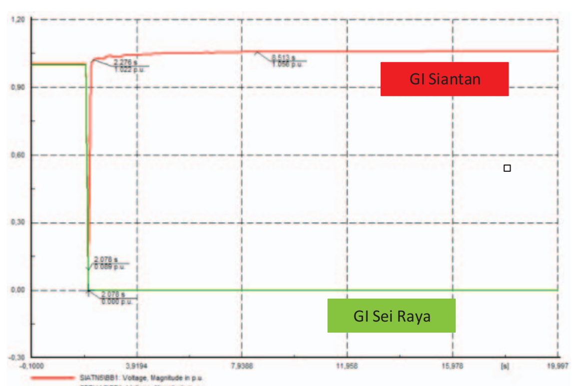

Figure 5 The voltage stability during kite thread disturbance in 150 kV transmission line Sie Raya – Siantan

TABLE V. FREQUENCY STABILITY

Scenarios		Frequency Stability	
		Back to new stability condition	Nadir frequency in the allowable range
Normal Condition		✓	✓
Kite Thread Disturbance	150 kV Line Senggiring-CFPP Bengkayang	✓	✓
	!50 kV Senggiring-Parit Baru Line 1	✓	✓
	150 kV Parit Baru-Siantan	✓	✓
	150 kV Siantan-Sei Raya	✓	✓

- SEI RAYA-SIANTAN

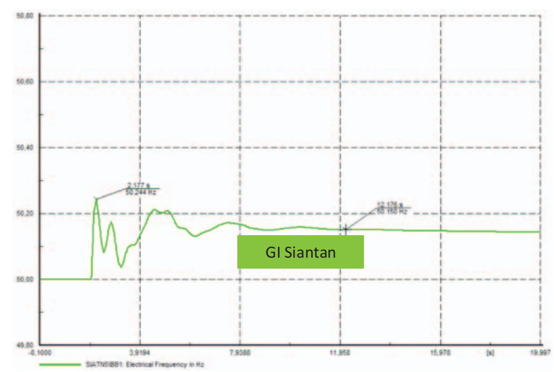

Figure 6 The frequency stability during kite thread disturbance in 150 kV transmission line Sie Raya – Siantan

Thus, the blackout as the impact of the kite thread disturbance in the *Khatulistiwa* Grid will occur when the kite hit 150 kV transmission line Sei Raya – Siantan. Since the transmission line serves 16.84 MW then the blackout will occur in the relatively huge area on West Kalimantan that is equivalent to the *Mempawah* Regency area. Hence, the kite thread disturbance will have a high impact on the grid. Therefore, the kite thread disturbance can be classified as a resilience problem in the grid. The kite thread disturbance is a part of a man-made attack on the grid. It is a specific resilience problem for countries where kite-playing is a cultural activity or a norm.

C. *The Cost of Resilience*

According to the PLN data, the longest recovery time which is equal to disturbance duration in *Khatulistiwa* Grid are 1.35 hours. Whilst the average electricity tariff is IDR 997/kWh or equal to cUSD 6.8/kWh. The ENS_d can be calculated through Equation (1). Therefore, the ENS_d = 22.734

MWh. The cost which is equal to ENS_d is IDR 22,665,798/incident or USD 1,563/incident

D. The Mitigation

Hybrid transmission line kite thread removal robot as a maintenance robot is one of the solutions for increasing the resilience level of the grid from kite thread disturbance. [8]. The constructed robot is shown in Fig.7. While the investment, operation and maintenance costs of the robot are as follows on the Table VI

TABLE VI. COST OF KITE THREAD REMOVAL ROBOT

Component	AUD	Remark
Hardware	$1,515	One time cost
Development software	$ 5,670	Annual licenses of the software used
Development cost (human resources)	$61,300	One year work (one time cost)
Maintenance/Repair	$2,000	Annual
Operation	$1,200	Annual (depending on the number of deployment)

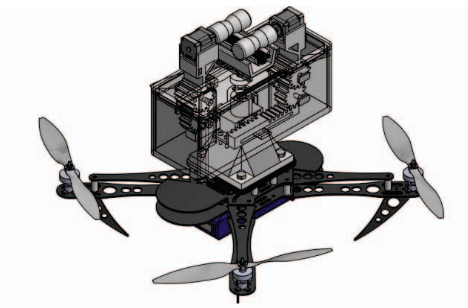

Figure 7 Hybrid transmission line kite thread removal robot [8]

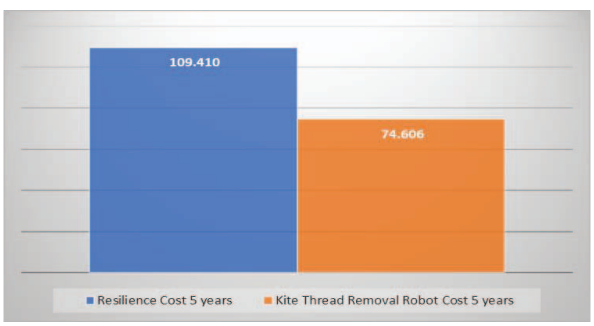

Figure 8 The comparison between resilience cost and kite thread removal robot cost

The lower kite thread accident in 150 kV transmission line Sei Raya – Siantan is 14 incidents per year. It is occurred in 2020. Therefore, the total cost due to these incidents was USD 21,882. This total cost is equal to the resilience cost. The comparison between resilience cost and kite thread removal robot cost for 5 years operation is shown in Fig.7. Since the resilience cost is higher than kite thread removal robot cost, then it can conclude the robot will be solution to increase resilience level of the grid.

IV. CONCLUSION

Since the kite thread disturbance on the high voltage transmission line has a high impact on the grid and a low probability of destructive occurring, then the kite thread disturbance can be defined as a resilience problem in the grid due to a man-made attack. The high impact on the grid is a huge blackout area, and it takes a long time to recover from the disturbance.

The lost cost of the energy not served during kite thread disturbance can be defined as the resilience cost. The level of resilience can be defined by the maximum resilience cost per incident. Any proposed mitigation should have a total investment cost, operation, and maintenance cost lower than resilience cost. Our proposed robotic solution satisfies this requirement.

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