A Field Observation on Lightning Performance Improvement of Overhead Distribution Lines

Reynaldo Zoro*, Ryan Mefiardhi, Syarif Hidayat & Redy Mardiana

School for Electrical Engineering and Informatics, Institute of Technology Bandung, Indonesia

Abstract. Two feeders of 20 kV overhead distribution lines which are located in a high lightning density area are chosen to be observed as a field study due to their good lightning performance after improvement of lightning protection system. These two feeders used the new overhead ground wire and new line arrester equipped with lightning counter on the main lines. The significant reduced of lines outages are reported. Study was carried out to observe these improvements by comparing to the other two feeders line which are not improved and not equipped yet with the ground wire and line arrester. These two feeders located in the nearby area. Two cameras were installed to record the trajectory of the lightning strikes on the improved lines. Lightning peak currents are measured using magnetic tape measurement system installed on the grounding lead of lightning arrester. Lightning overvoltage calculations are carried out by using several scenarios based on observation results and historical lightning data derived from lightning detection network. Lightning overvoltages caused by indirect or direct strikes are analyzed to get the lightning performance of the lines. The best scenario was chosen and performance of the lines were improved significantly by installing overhead ground wire and improvement of lightning arrester installation.

Keywords: *direct and indirect strikes; flashover rate; improved lightning performance; lightning data; lightning outages analysis.*

1 Introduction

Depok and Bogor are two area which are located in the south of Jakarta in West Jawa Province, Indonesia and have a very high lightning density. According to the Guinness Book of Record the highest thunderstorm day in the world is Bogor area which has more than 300 thunderstorm days a year. State Electricity Company of Indonesia reported that this area located in the area with high lightning density and has the highest outages in Indonesia due to lightning strikes to the overhead distribution lines. The latest study of lightning performance on the distribution lines was carried out in year 2002 in this area [1,2]. A lot of outages have been reported and have given the significant

Received August 23rd, 2007, Revised July 19th, 2009, Accepted for publication August 26th, 2009.

*Contact Address: **Power Engineering Research Division,** School of Electrical Engineering and Informatics, Institute of Technology Bandung, Gd. Kerjasama PLN-ITB, Jl Ganesha 10, Bandung 40132, West Java, Indonesia, Tel/Fax. +62 22 2500995, E-mail : zoro@hv.ee.itb.ac.id

problems to the local utility. Installation of the additional grounding system and the use of the earth wire along the line have been done. The result of the study was to recommend the company to improve the lightning protection system on the lines. The significant reduces of the outages was achieved on the two observed lines after improvement. The study is still going on to derive more field data in order to prove the reducing outages is caused by the implementation of the recommendations.

The results of this study can be used by PLN to propose the important guidelines on how to solve the problem due to lightning strikes on the overhead distribution lines. This study has used local lightning data derived from Indonesian Lightning Detection Network operated by High Voltage Engineering Laboratory of Institute of Technology Bandung, Indonesia [3].

The study was carried out by observing several feeders that have high lightning outages on distribution lines by using video camera recorders, lightning event counters and magnetic tapes for measuring lightning peak current [4]. This work was focused on two improved medium voltage 20 kV feeders in Depok area and two other unimproved feeders at the city of Bogor which are located at the east side of Depok area.

2 Overhead Distribution Lines

The objects of the study are to observe four feeder of medium voltage 20 kV overhead distribution lines operated by state electricity company in the region, which are:

a. Kapur feeder and Beton feeder operated by local electricity company. These two feeders supplying urban area, community houses, and several middle scales

This improvement gave the significant result of Lightning Performance in the region. It was achieved by installing the overhead ground wire and line arrester on the main line. It shown in Figure 1. This area was located in the flat and open land.

b. Another two feeder, Hutan feeder and Rimba feeder operated by local electricity company in Bogor area. These two feeders supply the urban area, small city and small-scale industries. The geographical condition is mainly mountainous area. These two feeders are not improved yet.

Figure 1 Typically overhead ground wire installation on the pole equipped with line arrester at Kapur feeder.

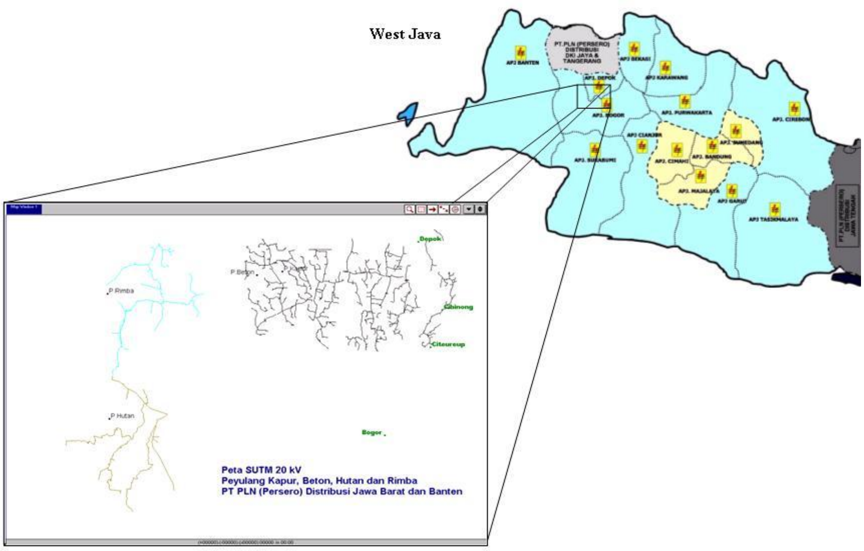

Figure 2 The observed overhead distribution lines: Hutan feeder and Rimba feeder at Bogor and Kapur feeder and Beton feeder in Depok.

2.1 Historical Lightning Data

Local lightning data derived from lightning detection system for more than 7 years were analysed [1]. The data in the area was observed by measuring the latitude and longitude position of -6.5229°S and 106.6817°E as the center of the region to derive local lightning data within the area of 50x50 km^2. This area cover all four feeders as shown on Figure 2. This data was very important to get a better analysis of the lightning performance of the medium voltage 20 kV distribution lines.

Figure 3 shows the distribution of probability of lightning peak current in Depok and Bogor area, and Figure 4 shows flash density map of Kapur Feeder located in Depok Area.

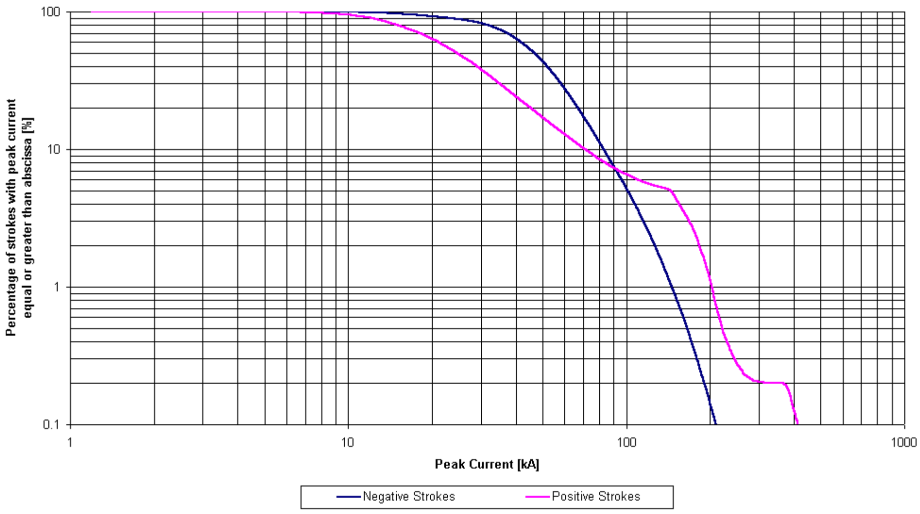

Figure 3 Logarithmic scale of lightning peak current probability.

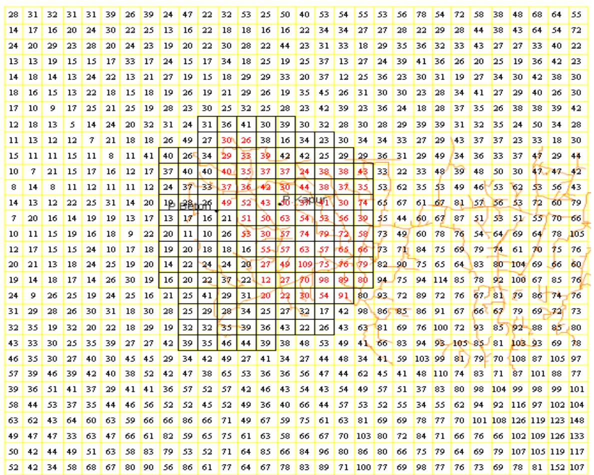

Figure 4 Ground flash density map at Kapur feeder (more than 7 years data).

Table 1 Estimated Ground flash density at Kapur feeder.

Map	Area [km^2]	Ground Flash Density [flash/km^2/year]
Total		
- Average	140	5.24
- Maximum	1	14.9
- Minimum	1	1.36
Circuit w/o OHGW		
- Average	74	3.9
- Maximum	1	6.27
- Minimum	1	1.36
Circuit w/ OHGW		
- Average	66	6.8
- Maximum	1	14.9
- Minimum	1	1.6

Four feeders have almost the same Ground Flash Density. By using this map the area are sectionalized into several group for analysis such as: main distribution line, sub-distribution line, soil resistivity, forest area, building density around the feeders, improved and unimproved lines. The calculation of lightning performance for each feeders are being done by using the data derived from ground flash density map. To make the observation more accurate the work were concentrated only on main distribution lines where the highest lightning density took place or has the highest outages. It reduced also the installation cost for the improvement.

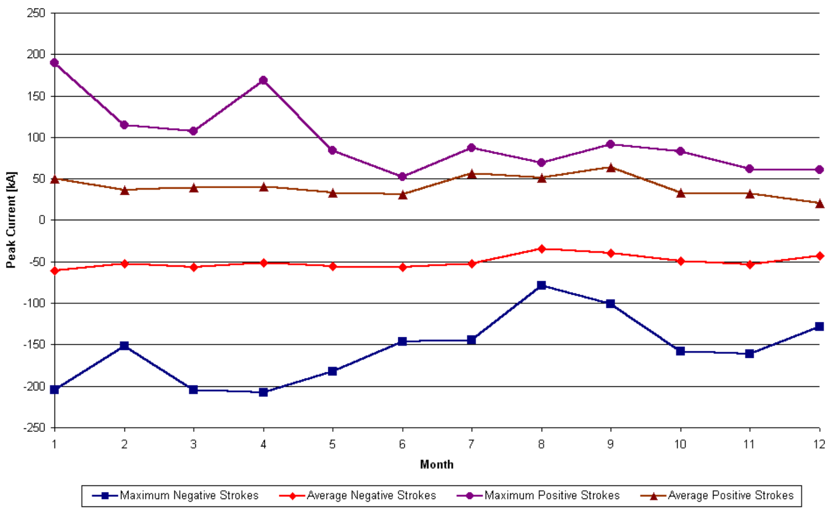

Figure 5 Average and maximum lightning peak current per month in Depok area.

Maximum and average of lightning peak current per month recorded at Depok area are shown on Figure 5 is 70 kA to 160 kA for positive strokes and –100 kA to –200 kA for negative strokes respectively. Maximum of lightning peak current is recorded higher on the first semester and decreasing to the end of the year. The averages data of lightning peak current are more flat than the maximum values which is varies between 35 kA to 55 kA for positive strokes and –39 kA to –56 kA for negatives strokes.

2.2 Lines Data

Distribution lines data of the four feeders are shown on Table 2.

Table 2 Lines Data for Hutan, Rimba, Kapur and Beton Feeder.

Detail	Unit	Name of the feeder			
		Kapur	**Beton**	**Rimba**	**Hutan**
Circuit Length	km	37.294	44.181	66.0	115.0
V_{LL}	kV	20	20	20	20
Insulator CFO	kV	125	125	125	125
Pole Type		**Steel**	**Concrete**	**Concrete**	**Concrete**
Average Wire Configuration					
- Phase R	m	(1 , 10)	(1 , 10)	(1 , 10)	(1 , 10)
- Phase S	m	(0 , 10)	(0 , 10)	(0 , 10)	(0 , 10)
- Phase T	m	(-1 , 10)	(-1 , 10)	(-1 , 10)	(-1 , 10)
- OHGW	m	(0, 11)	(0, 11)	-	-
Pole Grounding Resistance					
- Average	Ohm	3.98	5.59	6.25	5.51
- Maximum	Ohm	12	22	10	8
Overhead Ground Wire (OHGW)					
- Population	%	17.68	16.76	0	0
- Ground at		Every pole	Every 6 span	-	-
Line Arrester					
- Without OHGW	Span	10	11	19	26
- With OHGW	Span	4	5	-	-
Object Near Overhead Lines (mainly trees)					
- Average Height	m	10	10	13	11
- Average Distance from Lines	m	15	14	15	13
- Shielding Factor		0.528	0.492	0.6	0.576

Kapur is the only feeder that use steel type pole. The other three use concrete pole. It assumed that the overhead ground wire (OHGW) at Kapur feeder is grounded at every pole. All systems are solidly grounded. Many of the equipment grounding system are separated to pole grounding, especially at Hutan and Rimba feeders. The existing grounding is pole itself (pole foundation) and some of them use additional grounding rods. Measuring of tower footing resistance were being done by disconnecting the ground wire. In this study most of pole grounding resistance were measured no ground wires. The value of the grounding resistance were vary significantly and it greatly depend on the climate condition at the time when measurement was carried out. In practice the values for deep earth electrodes show variations for about 20% [5].

The recorded line outages is shown in Figure 6, derived from real lightning outages data (stated by the PLN) and the outage data correlated with the lightning such as; bad weather, failed equipment, insulator damaged etc. The data shown that reduced outages were recorded at Kapur and Beton feeder which have already improved at year 2003 since no improvement at Hutan and Rimba feeder yet.

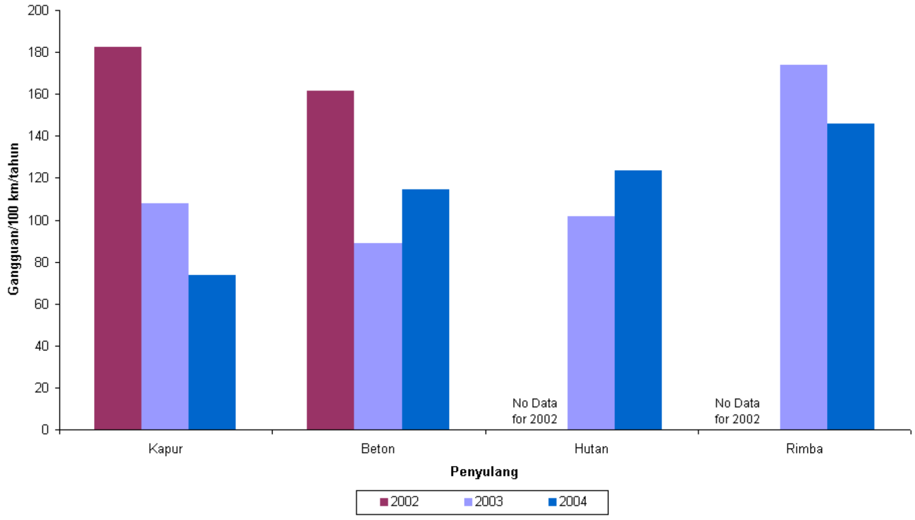

Figure 6 Lightning performance of the lines derived from the PLN outages data.

The earth contour of Depok and Bogor area is flat area at the northern part to the mountainous area at the southern part of the Jawa Island which has over 3000 m height of mountain. This area is influenced by regional monsoon and local wind that flows from mountainous area during night and and from the sea during daylight. Due to this weather condition the thunderstorm activity occurs almost along the year. On the first transition periode on March to May the high lightning activity take place. The second transition periode on September to December the high lightning activity is also recorded. The first periode in this area is higher than the second one. Figure 7 is showing the monthly lightning activities and correlated to the lightning outages on Kapur feeder. It shows that Kapur outages are in good correlated with the lightning activaty in the region.

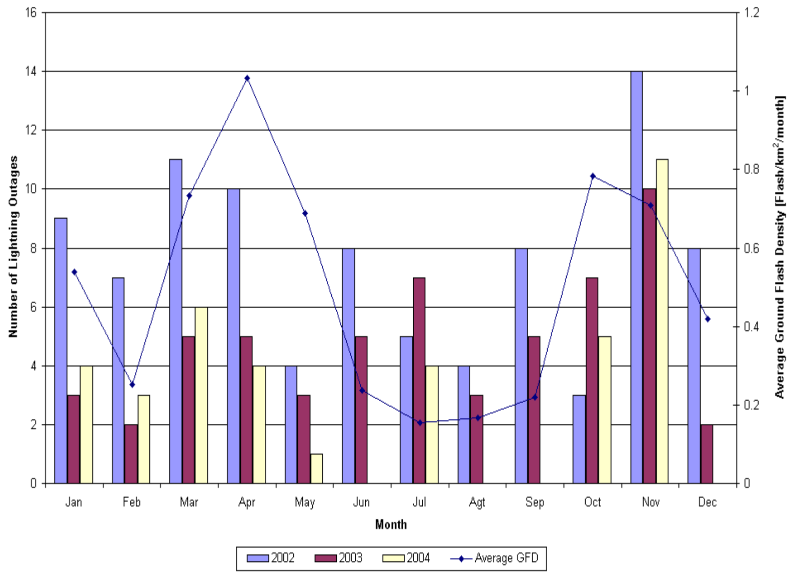

Figure 7 Lightning outages recorded on Kapur Feeder compare with the lightning activity (average GFD) in the region per month.

Statistical analysis of the outages caused by lightning shown on Figure 6 and the and the maximum lightning peak current as shown in Figure 5 is compared and analyzed. The averages values of outages on the first periode are almost the same to the second one which differ from lightning current variation. It was caused by the weather condition that has more wet at the second periode and it increased the outages number on this periode.

2.3 Lightning Performance Calculation

The lightning performance calculation is given at literature [6] with some appropriation with local lightning data. Figure 8 and 9 shown the lightning performance of the lines with flash over rate (FOR) as functions of ground flash density, Critical Flashover (CFO) of the line, grounding resistance etc. The use of Over Head Ground Wire gave a significant reduction of FOR for more than 30% from indirect strikes. Direct strikes to the line without OHGW will result the same FOR for every CFO, while in the line with OHGW will produce back flashover at the insulator and it vary according to the grounding resistance. The arrester span are less effective for distance between them more than 200 meter for direct or indirect strikes.

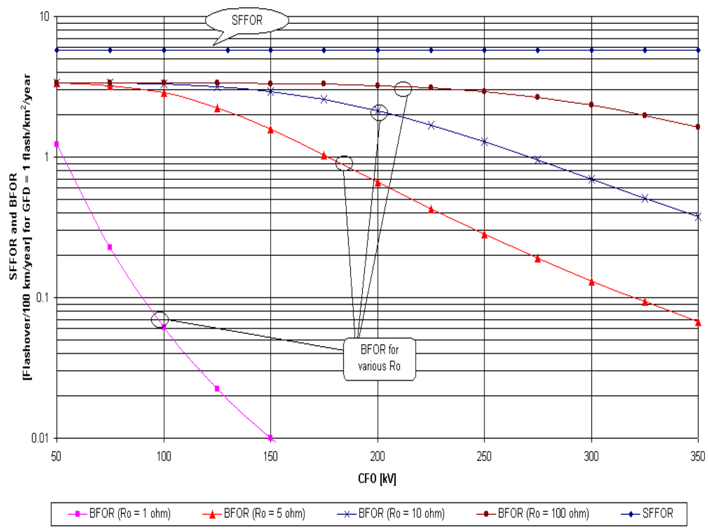

Figure 8 Calculated lightning performance curve for direct strikes: back flashover rate and shielding failures flashover rate.

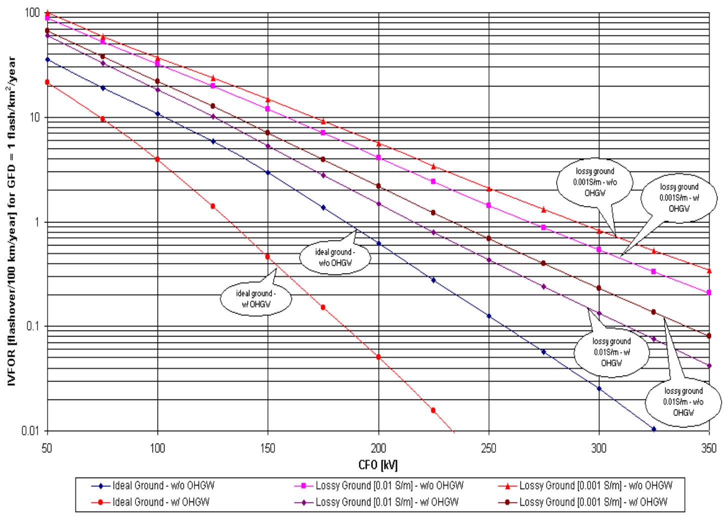

Figure 9 Calculated lightning performance curve for indirect strikes: induced over voltage flashover rate, included lossy ground effect and line with or without overhead ground wires.

This calculation shown that the main source of the outages is indirect strikes, which is more than 10 times FOR than direct strikes.

Table 3 Estimated Flashover rate per 100 km per year for kapur and beton feeders before and after improvement.

FOR [Flashover/100 km/year]		Kapur			Beton		
		Direct	**Indirect**	**Total**	**Direct**	**Indirect**	**Total**
Before	Total	16.62	268.58	285.20	3.13	371.44	374.56
After	Circuit w/o OHGW	12.09	195.41	207.49	2.31	284.15	286.46
	Circuit w/ OHGW	3.06	3.40	6.46	0.89	20.63	21.52
	Total	15.15	198.80	213.95	3.20	304.78	307.98

3 Field Observation

3.1 Video Camera and Recorder

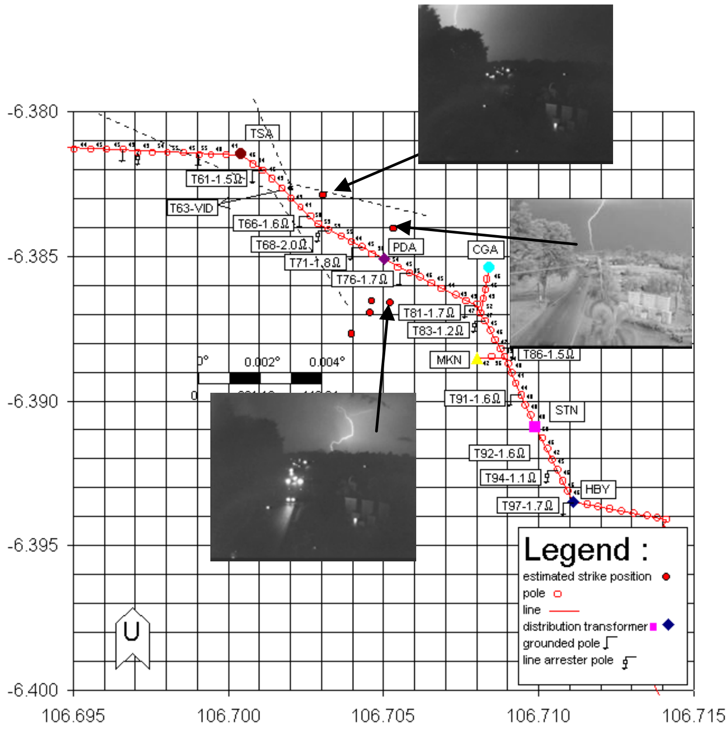

Figure 10 Lightning strikes video frame and its trajectory at the nearby lightning strikes at the observed distribution lines.

A set of video camera is installed at the top of pole, viewing back to back of 20 kV overhead lines. Video recorder is located inside a building near the pole which is operated manually. Based on the lightning data derived from Indonesian lightning detection network [7] shows that lightning activity start at 11.00 to 21.00 hour where the most incident was taken place at 16.00 to 19.00 hour. Most of lightning stroke are recorded on video frame. It was recorded that on the area of observation has a very high lightning incident in month January to April 2005 [3]. During the observation more nearby strike from cloud to ground hit trees and other structures near the lines compare to the lightning direct strike to 20 kV lines. Some of the photos of the lightning strikes are shown in Figure 10.

3.2 Outages Reduction

The reduction of the outages are very significant for the two improved feeders in Depok. On the first year after the installation of overhead ground wire and line arrester on the feeder at main distribution line the outage has reduced for more than 40% as shown in Figure 11.

3.3 Magnetic Tape Measurement System and Lightning Event Counter

A peak current measurement system using magnetic tape (APM) consist of three different type of commercial magnetic tape which are IEC type I Normal, type II Chorm and type IV Ferro. These tapes were filled with 315 Hz sinusoidal signal and laid on yellow fiber plate and attached to the arrester grounding lead [1].

Figure 11 Magnetic tape measuring system and lightning event counter installation on arrester grounding lead.

The measurement unit installed in several pole with different type of arrester installation such as ; arrester lead on distribution transformer, arrester lead on the line and arrester lead on cable at dead end tower. The magnetic tape measurement system (APM) and lightning event counter (LEC) are placed in a box attached to the tower. Minimum current of 2 kA can trigger the LEC. The lead grounding of arrester is using single core N2XSY 1x50 mm^2 cable to allow lightning current flows undisturbed to the ground trough the LEC and APM.

One of the research results of this observation is explained as follows:

On January 18, 2005 a lightning hit the line nearby and triggered the LEC. The counter had changed from 002 to 003 positions. At the same time it was reported that the outage take place and the relays on the substations recorded 2 phases over current and also 2 phase’s ground faults. The magnetic tape reading of this evidence is shown in following Figure 13.

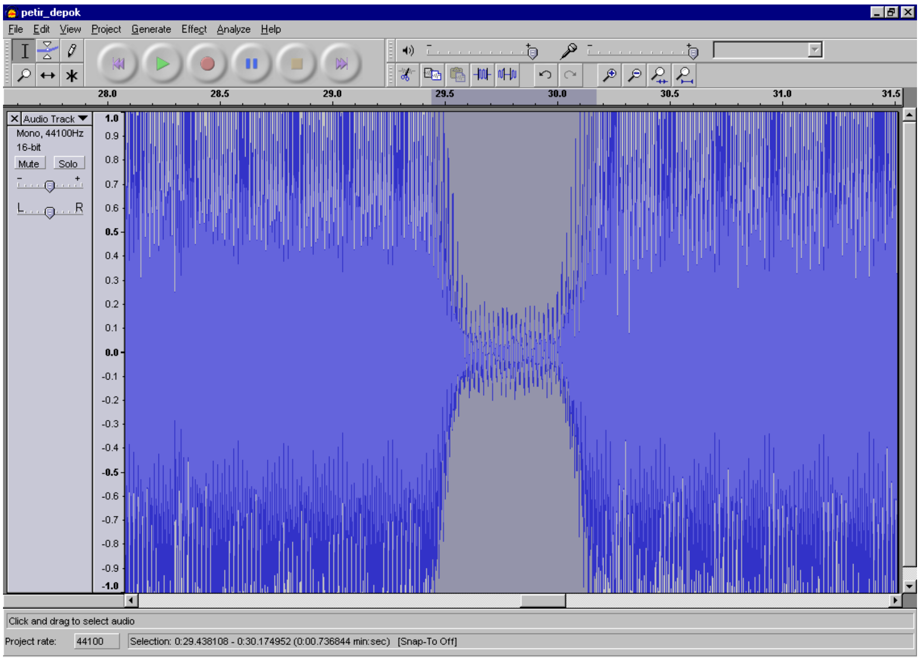

Figure 12 The result of magnetic tape reading using free audio analyzer software. It shows the erased 315 Hz signal on IEC type I Normal commercial tape by lightning impulse. The length of erasement is about 3.5 cm or equivalent with 8.9 kA of lightning current.

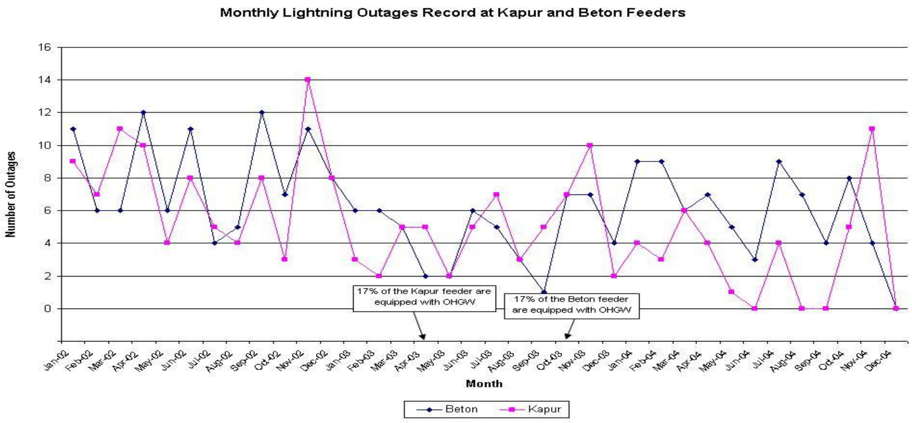

Figure 13 Outage curves of Kapur and Beton feeders shown outages reduction after the installation of OHGW.

4 Discussion

This study was carried to observe the results of the improvement that has been made by electricity company from the previous study which was completed on year 2002. Several improvements have been made and gave the significant results in reducing line outages. Improvements are not done yet for the other feeders at city of Bogor.

Bogor is suffering more outages due to lightning strikes than Depok while Bogor has higher Ground Flash Density and located in mountainous area with a lot of trees nearby 20 kV lines.

Some of the installations on the existing overhead lines need to be repaired and cleaned such as fungi on the insulators, trees touch the wire, etc. and it produced outages not caused by lightning. Some of the arrester grounding lead was not yet properly installed. The lines used the different type of insulators that has different Basic Impulse Insulation Level. Some of the lines have too low span distance and improper installation of grounding system was also found.

As the result of the observation stated that the improvement which has been carried out on Depok’s feeder have decreased the outages significantly and improved the lightning performance of this overhead distribution lines.

Based on this results the same improvement will be done for Bogor’s feeder and other distribution lines in Indonesia. The installation of grounding wire and the improvement of grounding system gave significant outages reduced than installation of line arrester on the lines. Installation of one overhead ground wire reduced more than 30% induced voltages to the lines caused by indirect strike.

5 Conclusion

Improvement was carried out by installing ground wire and installation of lightning arrester give a significant outages reduction of the distribution lines in the region.

The others medium voltage 20 kv lines in the same region could be protected according to the installation that has already been done in Beton and Kapur two feeders.

The cost of protection and to improve the performance of the medium voltage 20 kV lines can be reduced by installation of ground wire along the line and the improvement of the arrester location to get optimal protection distance. It could be done by utilizing the local lightning data derived from lightning detection network.

Acknowledgment

The authors gratefully thanks for the contributions of Institute for Research and Community Service of Institute of Technology Bandung and PT. PLN (Persero) Distribusi Jawa Barat dan Banten for their support technically and financially to this research programs.

References

[1] Zoro, et al., *Studi Sistem Pengaman Jaringan Listrik PT PLN (Persero) Unit Bisnis Distribusi Jawa Barat dan Banten Cabang Depok - Final Report*, PT. Lapi Elpatsindo, December 2002.

[2] Zoro, R. & Suhana, H., *Improvement of Lightning Protection System on Distribution Lines: A Case Study at South-Jakarta, Indonesia*, in Proc. of Seminar Nasional Ketenagalistrikan, 2004, SN-112.

[3] Zoro, et al., *Studi Pengaman Terhadap Sambaran Petir PT. PLN (Persero) Distribusi Jawa Barat dan Banten di APJ Depok dan APJ Bogor – Final Report*, LPPM ITB, May 2005.

[4] Sirait, K.T. & Zoro, R., *Application of Lightning Peak Current Measurement System at Mnt. Tangkuban Perahu*, Asian Conference on Electric Discharged (ACED), Bandung, 1990.

[5] *IEEE Guide for Improving Lightning Performance of Electric Power Distribution Lines*, IEEE Standard 1410-1997, IEEE Power Society, New York, 1997.

[6] Hoidalen, Hans Christian, *Analitycal Formulation of Lightning Induced Voltage on Multiconductor Overhead Lines Above Lossy Ground*, IEEE Transaction on Electromagnetic Compability, **45**(1), February 2003.
[7] Zoro, R., Bambang, N. & Mefiardhi, R., *Evaluation and Improvement of Lightning Protection on Transmission and Distribution Lines Using Lightning Detection Network*, in Proc. of 27^{th} International Conference on Lightning Protection, 2004, 6p.13.