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RELIABILITY ANALYSIS OF ADSS CABLES USING DRY BAND ARCING TEST

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ABSTRACT

In this study, we determined the dry-band arc resistance of three ADSS fiber optic cables. The cables were manufactured by different companies. The tests were performed according to the description given in IEEE 1222 ADSS Electrical Test. The basic concept of the test is that the energized cable is sprayed by salt water for few minutes. This produces conducting wet layer on the cable surface and initiate leakage current. This current causes to decrease the lifetime of the cable. Using the statistical tools, presented the lifetimes of the cable is investigated the pdf, reliability, failure rates.

Keywords: *Dryband Arcing, ADSS Cable, Aging, Reliability Analysis.*

1. INTRODUCTION

All-dielectric selfsupporting (ADSS) optical fiber cables are progressively being installed on overhead lines since 1979 [1], [2]. ADSS optical cables have so far shown an acceptable performance on lines up to 150 kV [1]. Nonetheless, failures have occurred with ADSS cables installed on lines with a higher voltage. These failures are caused by electrical phenomena, such as corona, sparking and dry band arcing, since the cables are exposed to the strong electrical field environment [3], [4]. Previous studies show corona can be mitigated by installing grading devices and the impact of micro-sparking can be reduced by attaching electric field reducing hardware to towers[5]. Discussions in an IEEE workshop [6] indicated that the failure of ADSS cables caused by dry band arcing in high electric field environments is potentially an industry wide problem[7].

The basic concept of the arc resistance test is that the energized cable is sprayed by salt water for few minutes. This produces conducting wet layer on the cable surface and initiate leakage current. The current is limited to few milliamps by a RC circuit. The current dries the surface, produces dry bands and initiates arcing. The arcing lasts for 5-20 minutes. This process is repeated till the jacket is punctured. The level of the arc resistance value is dependent on the number of cycles needed to puncture the jacket[8].

The pollution level is determined by the RC limiting impedance and the voltage is the maximum space potential that the cable can tolerate. We specified both the voltage (25kV)

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and the pollution level medium , which corresponds to an R = 13.1 MΩ and C = 200 pF[9].

The mean time is a statistical value and is meant to be the mean over a long period of time. For constant failure rate systems, MTTF(Mean time to failure) is the inverse of the failure rate or can be calculated using the

$$MTTF = \int_0^{\infty} tf(t)dt$$ equation[10].

In this study cable lifetimes are calculated using statistical tools such as probability density function, reliability function and failure rate curves are obtained and MTTF.

2. TEST SAMPLES AND FACILITY

Ten about 18” long samples were prepared from each of the submitted ADSS cables. The total numbers of samples were 30. The ends of each sample were sealed to prevent water penetration. Two electrodes, made out of aluminum foil were placed on the sample. The distance between the two electrodes is 4”. Figure 1 shows a test sample.

Figure 1: Test sample

The tests were performed in high voltage ADSS cable test facility.

Figure 2 shows the electrical connection diagram of the ADSS Cable Test Facility The samples were suspended in a stainless steel chamber and periodically sprayed by salt water. Simultaneously the samples are energized up to 25 kV by a high voltage test transformer rated 150V/42000V, 5kVA.

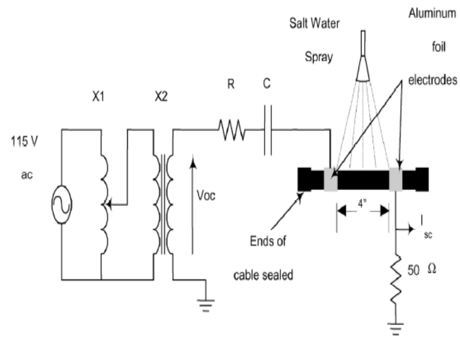


Figure 2 : Circuit diagram[7]

The voltage of the transformer is regulated by an autotransformer. The current through each sample is limited by an RC circuit, connected in series. The circuit parameters are shown in Table 1.

Table 1: Circuit parameters

Parameters	Actual value	Unit
Voc	25	kV
Isc	1.363	mA
R	13.1	MΩ
C	200	pF

The required resistance and capacitance are built by connecting several units in series and few in parallel. The values in the table can vary by 5%. A 50 ohm resistance is connected in series with each sample. The current flowing through the sample is proportional to the voltage across the 50 ohm resistance. This voltage can be measured or recorded using a digital oscilloscope.

Figure 2 shows the physical arrangement of the test facility. The main component is a stainless steel tank (101,6cm 76,2cm 40,64cm). The three test samples are suspended in the tank. The RC limiting impedances, one per test sample, are installed on a board at the side of the tank. Insulators are placed at the top of the metal tank. Bare wires or insulated cables connect the transformer to the limiting impedances and to the test samples.

The samples are periodically sprayed by salt water. Figure 3 shows the flow diagram of the spraying system.

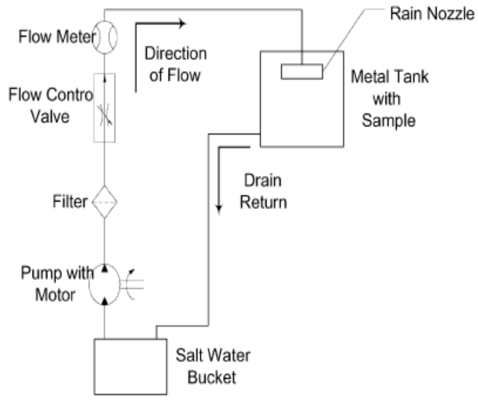


Figure 3: Flow diagram of the salt water spraying system[7]

The components of the spraying system are a salt water storage bucket, pump, control valve, filter, flow meter, rain nozzles, and metal tank with test samples. Salt water is mixed in a plastic bucket and pumped through a control valve, filter, flow meter and 3 parallel connected spray nozzles. The flow rate is adjusted by the control valve. Both the flow rate and water salinity are kept constant during the test. Water with 1% salinity is used for spraying the cables. The flow rate per nozzle of the spraying water is 0.5–0.8 gpm. The energized samples are sprayed by salt water for 2 minutes and allowed to dry for 28 min. During the drying period, the high voltage produced arcing on the samples. Voltage and current signals can be observed and recorded during testing for analysis.

It is observed that when the cable is new, the water forms discrete droplets on the hydrophobic surface of fiber optic cable. The high voltage produces sparking between the water droplets. After several cycles the surface of the sample becomes hydrophilic; a continuous water layer appears on the jacket surface and current, which flows through the conducting layer forming dry bands. The flashover of the dry band produces dry-band arcing which can damage the cable. Figure 4 shows the typical current waveform of a dry band arc. If the arc is visible, the level of arc current is determined by the RC impedance, but if the arc is extinguished (not visible), the current is near zero due to the high impedance of the dry band.

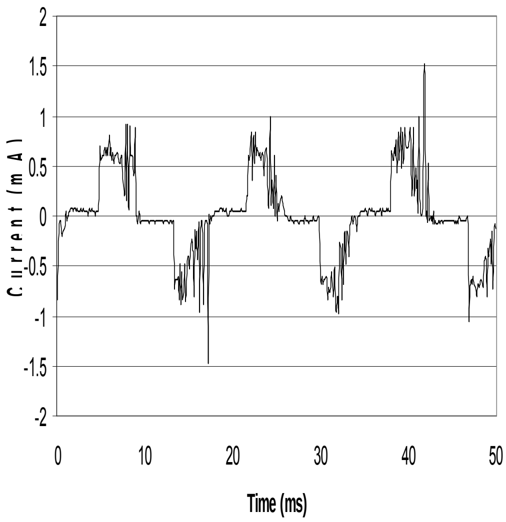


Figure 4: Typical current waveform during the dry band acing

The technical data of the Test cycle is presented in Table 2.

Table 2: Technical data of the test cycle

One Cycle Data	
Salinity	1%
Total Duration	30 min
• Spray duration	2 min
• Non-spray duration	28 min
Nozzles flow rate	0.5-0.8 g/m

3.TEST PROCEDURE

The test was performed under normal room temperature and humidity conditions. The procedure was as follows:

1) A sufficient quantity of the salt solution was prepared 24 hours prior to the test start-time. This allowed the salt to be completely dissolved.

2) Three different test samples were cut, each of length 18-inch and their ends were sealed.
3) Aluminum foil electrodes was affixed on the sample 4 inch apart, centered at the middle of the cable.
4) The cable samples were installed in the test fixture and made the required electrical connections.
5) The control valve was set to attain the desired flow rate from the nozzles.
6) The cables were energized to 25 kV.

7) The on and off times for the pump was set. The energized cables were wetted for 2 min and allowed to dry for 28 min using the time-controlled pump. Dry-band arcing was observed mostly during the drying period.
8) Periodically the cables were observed visually for detecting failure. In addition, we took a photo the test samples after each cycle. The cable failed if the jacket was punctured.
9) Some of the cables were ignited during the test. Once the cable catches fire, the test was stopped and the destroyed cable was removed. But experiment was continued. The remaining cables were re-energized.
10) The number of on/off cycles to failure was recorded.
11) The current (voltage on 50-ohm resistor) was periodically checked to verify proper operation and recorded.
12) After each test, the cable location in the chamber was changed. The cables were swapped among the different locations in the chamber. Consequently each cable was tested all the 3 locations[8].

4.TEST RESULTS

Each of the same ten cables was tested. Each time the number of cycles to failure was recorded. The average number of cycles and standard deviation were calculated.
Table 3 shows all test results. The test are marked set#1….set#10. The test results were shown in table 3 showing the number of cycles to failure in each set for each cable, average number of cycles to failure for each cable, and standard deviation for each cable.

Probability density function(pdf) of the three types of the cables are extracted. Firstly it is assumed that the pdf of the lifetime is exponential, normal, Weibull 2, gamma distributions. Loglikelihood values are calculated with Weibull++ 7 programme and the values are seen in Table 4.

Table 3: Test Results

	Cable A	Cable B	Cable C
Set # 1	27	32	19
Set # 2	44	61	2
Set # 3	57	15	5
Set # 4	55	78	13
Set # 5	64	76	7
Set # 6	52	83	6
Set # 7	39	46	31
Set # 8	41	64	9
Set # 9	33	51	5
Set # 10	34	22	9

Table 4: Likelihood values of distributions.

Distributions	**Cable A**	**Cable B**	**Cable C**
Exponential	-48,410	-49,852	-33,612
Normal	-38,653	-45,529	-35,209
Weibull-2	-38,522	-45,795	-32,722
Gamma	-38,777	-46,107	-32,461

The lifetime distribution function is detected using the likelihood values. Which likelihood value is the nearest to zero that is our lifetime distribution.

If the likelihood values are close to each other we can choose any of them. It is seen that distribution is Weibull-2. And probability-weibull curves are seen in Figure 5.

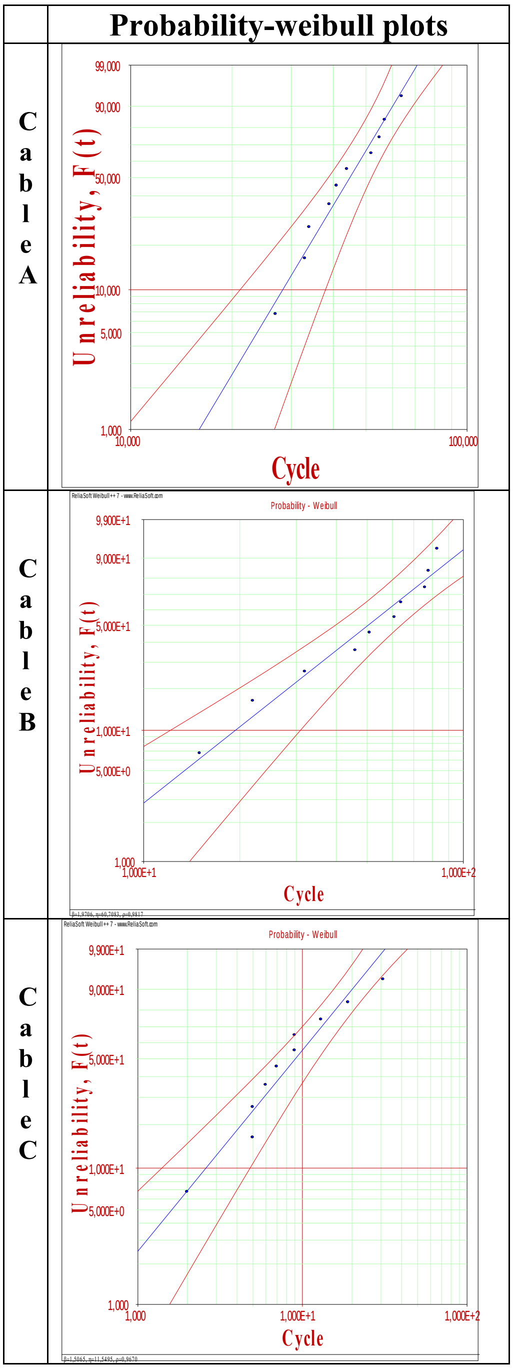
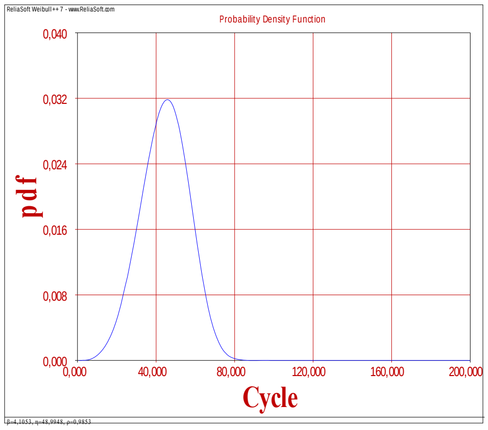


Figure 5: Probability-weibull plots for cables.

Lifetime distributions of the cables are presented in Figure 6.



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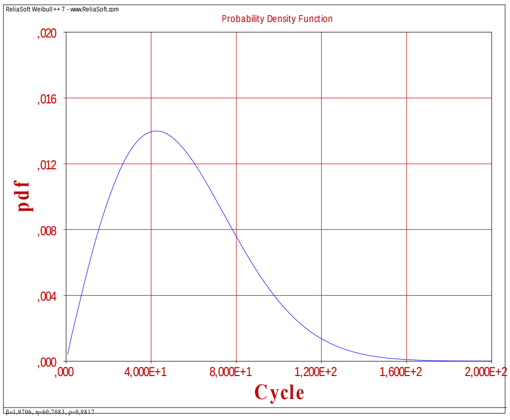

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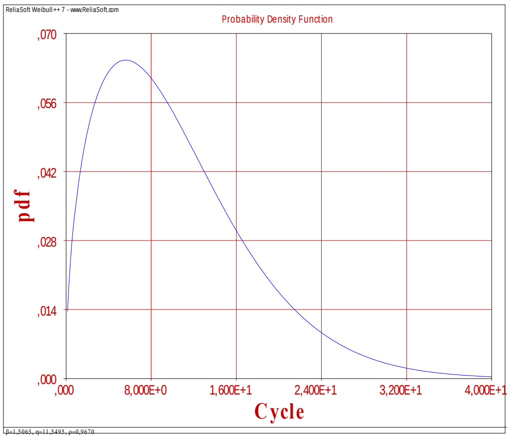


(c)

Figure 6: The lifetime distibutions of the cables. a:Cable A, b:Cable B, c:Cable C

The Weibull distribution depends mainly on two parameters, β the 'shape' and α the 'scale' parameters. The Weibull shape parameter, β, is also known as the Weibull slope. This is because the value of β is equal to the slope of the line in a probability plot. Different values of the shape parameter can have marked effects on the behaviour of the distribution. Confidence intervals(CI) are used to indicate the reliability of an estimate. For example, a CI can be used to describe how reliable survey results are. All other things being equal, a survey result with a small CI is more reliable than a result with a large CI. In this study 95 % of reliability is used to find the confidence interval[11].

For Weibull-2 distribution cdf, pdf, reliability and the failure rate equations are seen in Equation 1-4.
Cumulative Weibull distribution F(t) can be shown as,

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right] \qquad \text{Eqn (1)}$$

By taking the derivative of cumulative Weibull distribution(cdf) function we have the probability density function, pdf as,

$$\frac{dF(t)}{dt} = f(t) = \left(\frac{\beta}{\alpha}\right)\left(\frac{t}{\alpha}\right)^{\beta-1} \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right] \qquad \text{Eqn (2)}$$

Reliability function R(t) can be expressed as,

$$R(t) = 1 - F(t) \qquad \text{Eqn(3)}$$

$$R(t) = \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right] \qquad \text{Eqn(4)}$$

The weibull parameters are seen in Table 5. The mean life function, which provides a measure of the average time of operation to failure, is given by:

$$\mu = m = \int_0^\infty t.f(t)dt \qquad \text{Eqn(5)}$$

It should be noted that this is the expected or average time-to-failure and is denoted as the *MTBF* (Mean-Time-Before Failure) and is also called *MTTF* (Mean-Time-To-Failure) by many authors. MTBF is used for repairable systems and MTTF is used non-repairable systems. Experimental lifetimes are seen in Table 3 and In Table 6 statistical lifetimes can be seen.

Table 5: Weibull parameters for all cables.

Cable A		
Lower	Alfa	Upper
44,1588	48,9948	54,3604
Lower	Beta	Upper
2,9747	4,1053	5,6655
Cable B		
Lower	Alfa	Upper
48,4993	60,7083	75,9906
Lower	Beta	Upper
1,3837	1,9706	2,8064
Cable C		
Lower	Alfa	Upper
8,6945	11,5495	15,3419
Lower	Beta	Upper
1,1226	1,5065	2,0215

Table 6: Statistical Lifetimes of cables.

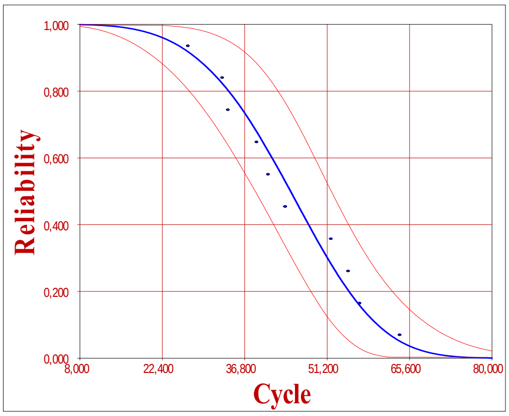
	Cable A	**CableB**	**CableC**
Statistical Lifetimes(MTTF)	44,4748	53.81	10.42

It is seen that the Cable B is the most durable cable. Reliability curves of the cables with upper and lower limits of the Weibull-2 parameters are shown in Figure 7.

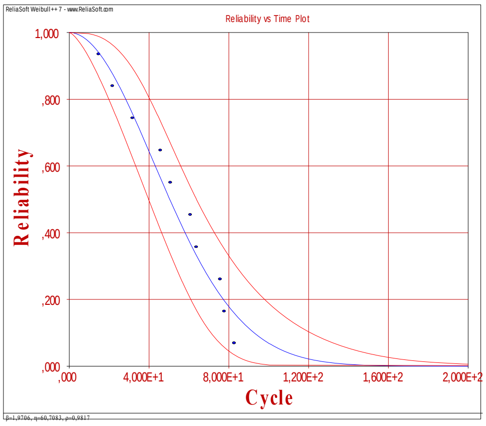
The pdf and the reliability equations for all cable are seen in Table 7.

Table 7: pdf and the reliability equations.

	PDF(f(t))
Cable A	$0{,}0838\left(\frac{t}{48{,}9947}\right)^{3{,}1053}\exp\left[-\left(\frac{t}{48{,}9947}\right)^{4{,}1053}\right]$
Cable B	$0{,}0324\left(\frac{t}{60{,}7083}\right)^{0{,}9706}\exp\left[-\left(\frac{t}{60{,}7083}\right)^{1{,}9706}\right]$
Cable C	$0{,}1304\left(\frac{t}{11{,}5495}\right)^{0{,}5065}\exp\left[-\left(\frac{t}{11{,}5495}\right)^{1{,}5065}\right]$
	Reliability(R(t))
Cable A	$R(t)=\exp\left[-\left(\frac{t}{48{,}9947}\right)^{4{,}1053}\right]$
Cable B	$R(t)=\exp\left[-\left(\frac{t}{60{,}7083}\right)^{1{,}9706}\right]$
Cable C	$R(t)=\exp\left[-\left(\frac{t}{11{,}5495}\right)^{1{,}5065}\right]$



(a)



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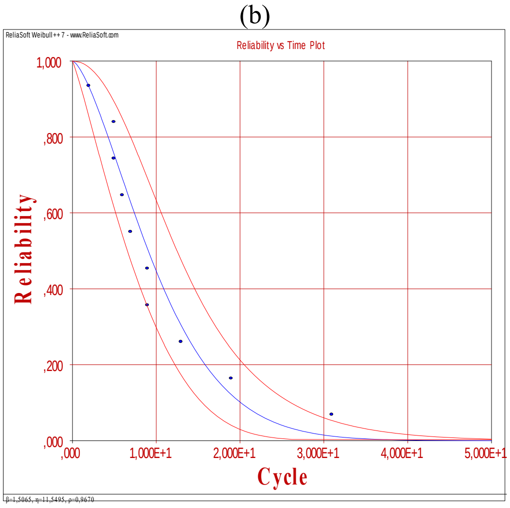
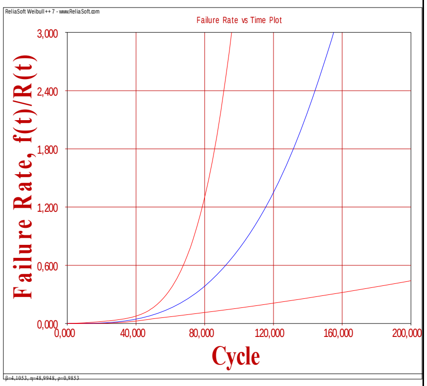


(c)

Figure 7: Reliability curves of Cables. a:Cable A, b:Cable B, c:Cable C

The engineers and researchers can be use the failure rates of the cables during the design of a system. The failure rates are seen in Figure 8.

Failure rates, after the 40 cycles , are 0.044, 0.021, 0,244 for Cable A,B,C respectively. It is also seen by using the failure rates that the cable B is the most durable.

<table>
<tr><th></th><th>Failure rates</th></tr>
<tr><td>Cable
A</td><td>
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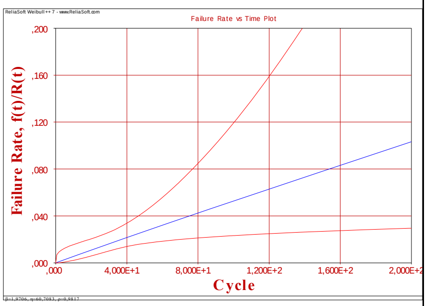
B</td><td>
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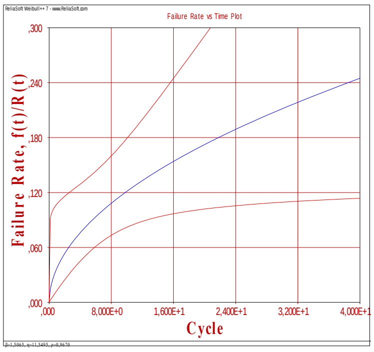
C</td><td>
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Figure 8: The failure rates for cables.

5.CONCLUSION

The dry band arcing is a statistical phenomena, where the location and intensity of the arcing depend on the surface conditions, which are changing rapidly through the wetting and drying cycles. This is the result of the observed significant difference between the maximum and minimum number of cycles that caused failure of a sample. We investigated the cable dryband arching statistically. Test and investigation results showed that Cable B is the most durable. Pdf and reliability equations are presented for all cables. Failure rates are presented .

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