Turk J Elec Eng & Comp Sci, Vol.19, No.1, 2011, © TÜBİTAK
doi:10.3906/elk-1001-384

Analysis of frequency characteristics of electrical arcs on the insulating sheath of the ADSS fiber optic cables

Cengiz Polat UZUNOĞLU, İbrahim GÜNEŞ, Mukden UĞUR
Department of Electrical & Electronics Engineering, Faculty of Engineering,
İstanbul University, 34320, Avcılar, İstanbul-TURKEY
e-mail: polat@istanbul.edu.tr, gunesi@istanbul.edu.tr, mugur@istanbul.edu.tr

Abstract

The insulating outer-sheath of ADSS (All dielectric self supporting) cables used on high voltage transmission lines are often subjected to various environmental effects. The ageing process of cable sheath can be investigated by using the dry-band arcing test method under laboratory conditions. Dry-band arcing is the most common technique to determine the ageing period of insulating materials. Environmental effects such as rain, humidity, dew and ice produce various amounts of wet regions on the cable surface. Electrical arcs and hence degradations are occurred on the cable surface due to the enhanced electrical field with formation of wet regions. In this study, the ageing process of ADSS cables was investigated by using the dry band arcing test method (IEEE 1222 Electrical surface degradation). Rainfall intensity determines the wet regions on the cable surface which affects the ageing process of the cable. During tests electrical arc signals were investigated by analyzing wet region scope versus amplitude and frequency spectrum variations via the FFT method. It is possible to claim that the proposed FFT analysis clearly identifies the ageing period of the ADSS cable which was subjected to different rainfall intensities by monitoring frequency spectrum of the arc signals.

Key Words: *ADSS cable, dry-band arcing, frequency spectrum, ageing process*

1. Introduction

ADSS cables installed on high voltage transmission lines are subject to a high electrical fields. In turn, the high electrical field can induce failure on the cable surface [1]. Most cable failures occur by dry band arcing, a common problem in industry. Cable life-time depends mostly on the surface degradation of the cable. Dry-band arc testing, a IEEE 1222 test standard, can help determine the relationship between life-time and electrical arcing in the cables [2, 3].

According to the test standard the region between the electrodes located on the cable sample surface was subjected to salt-water spray and hence wet regions were obtained. In our study, different numbers of spray nozzles were used to obtain different levels of wet regions on the cable surface. Characteristics of wet region and the density of the electrical arcing change under different artificial rainfall intensities. Under the IEEE 1222 test standard, the surface between electrodes is assumed to be completely wet; but in this study, in order to simulate different amount of rainfall intensities, different number of sprays nozzles were selected to achieve the same effect.

Test samples are 45 cm long and the ends of each sample were sealed to prevent water penetration. Two electrodes, made out of aluminum foil were placed on the sample, space 10 cm apart. The cable jacket is made from HDPE (High-density polyethylene).

The electrodes on the test samples were connected to the terminals of an AC high voltage transformer. The transformer was grounded. In order to simulate real world conditions, the test standard voltage was set to 25 kV AC. Current was limited via a series RC circuit. The electrical arcing signals were derived from a 50 Ω resistance connected in series with the electrode [2, 4, 5]. A Fluke 199CS scope meter is used to collect data. The block diagram of the test setup is given in Figure 1.

To arrange different rainfall intensities, the spray system can operate with one, two and three nozzles in the test setup. The tests were conducted at 1 atm pressure (sea level) and 22 °C temperature. The electrical resistance of the pollution changes the leakage current's magnitude flowing along the cable's sheath. In our study we assumed that the cable pollution level is medium ($10^6\Omega$/m) which simulates an industrial environment [6]. A medium pollution level was simulated with a 13.1 MΩ resistor (R) and 200 pF capacitor (C). The observed dry band arcing signal is shown in Figure 2.

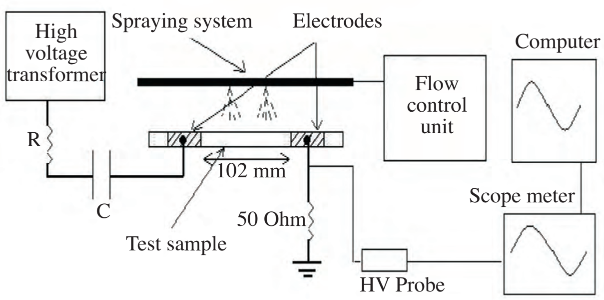

Figure 1. The block diagram of test setup.

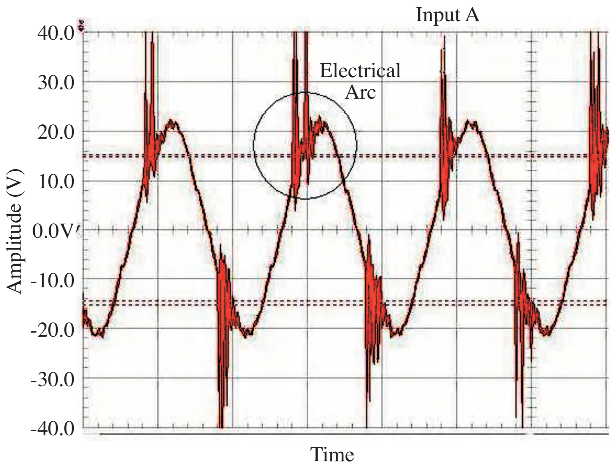

Figure 2. Dry band arc signal.

Systems with one, two and three spray nozzles were chosen in order to obtain different rainfall intensities on the test sample surface. Spray water contains about one percent salt, which corresponds to 17.2 mS conductivity. In our study this conductivity level is constant for each spray system case. Initially, test samples were sprayed with salt-water for 2 minutes, then were allowed to dry for 28 minutes by shutting down the spray system. Total time of 30 minutes was denoted one cycle [7, 8]. In order to prevent failure on the cable surface the electrical arc signals for each test sample were analyzed at the first cycle. FFT of the electrical arc signals were used to identify the ageing period of the cable insulation [9, 10, 11]. The arc signal characteristics were investigated for three different time periods, such as during spray, transition period just after the spray system shut down, and during dry band arcing after the shut down. For each stage, the arc signal and the corresponding frequency spectrums were obtained and the relationship between ageing process and the electrical arc signal variations were determined.

2. Experimental studies

In this study dry-band arcing test system is used to test the life-time of the cable. In order to fulfill IEEE 1222 standard, the test setup in Figure 3 was established in the laboratory.

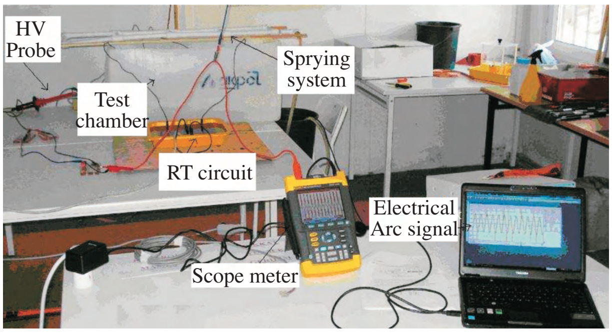

Figure 3. Test facility based on IEEE 1222 standard.

In previous studies, the lifetime of ADSS cables were measured and the experimental results are given in Table 1 [12]. We tested five samples for each spray system. Life-times reported in Table 1 are accelerated test results. In industrial regions life-time of the ADSS cables is approximately 15 years [13].

Table 1. Life-time versus spray system.

	Life Time (Cycle)		
Sample No	Set 1	Set 2	Set 3
1	37	24	20
2	29	27	24
3	35	27	21
4	32	25	21
5	35	31	27
Average	33.6	26.8	22.6

Set 1: Spraying with one nozzle; Set 2: Spraying with two nozzles;
Set 3: Spraying with three nozzles.

Lifetime of a cable depends mostly on the electrical arcs that occur on its surface. When full degradation occurs between electrode surfaces, the life-time of the test sample is assumed to be over (i.e., the test procedure should be terminated) [12]. In the proposed method, the relation between arc characteristics and the life-time has been explained via spray systems employing one, two and three spray nozzles. Three different wet layer models are given in Figure 4.

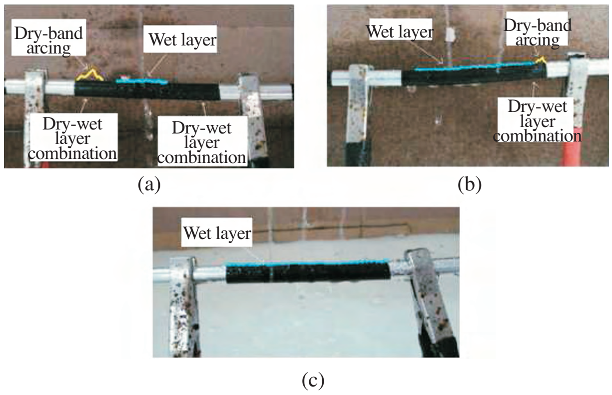

Figure 4. Different wet layer models: (a) single-nozzle, (b) two-nozzle, (c) three-nozzle spraying.

3. Results

3.1. Spray system with one nozzle

Low rainfall intensity was simulated by using a single spray nozzle, from which the wet layer model in Figure 4(a) was obtained. In this model, a wet region (3–4 cm) was formed in the middle of the test sample. Remainder of the test surface had partially dry regions. The arc signal associated with single-nozzle spray was characterized and correlated with the periods of spray, transition and dry band time.

3.1.1. Spraying period

The test samples were continuously sprayed for two minutes with salt water. The corresponding electrical arc signal and frequency spectrum are shown in Figure 5.

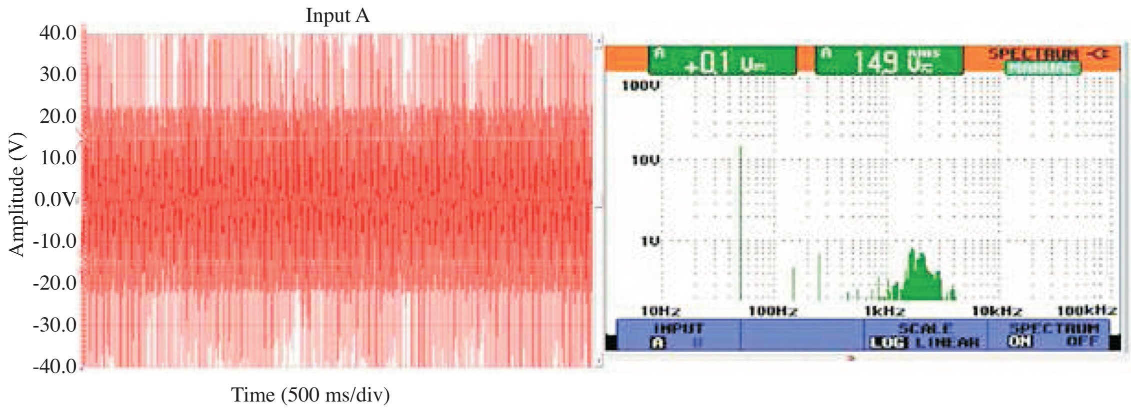

Figure 5. The Arc Signal and frequency spectrum for one nozzle system (spray period).

With a single-nozzle spray system the surface of test samples cannot get completely wet; hence for two minutes dry and wet layer combinations occurred on the surface of the test sample. As shown in Figure 5, the frequency spectrum of the arc signal varies mostly between 1 kHz and 4 kHz, where 3^{rd} and 5^{th} harmonics of the main frequency have also high output values. Experiments clearly indicate that the main reason of the ageing of the cable sheath is the heat produced by arcs; hence in the spray system with one nozzle, ageing of the test sample was limited by the spraying period.

3.1.2. Transition period

According to the test procedure, the spray system shut down after two minutes after initiation. Just after shutting down the spray, the number of electrical arcs rapidly decreased, since wide dry band areas established on the surface. The transition period of the electrical arc signal is given in Figure 6. The frequency spectrum of the signal obtained in this period has only main frequency component (50 Hz) due to the lack of electrical arcs.

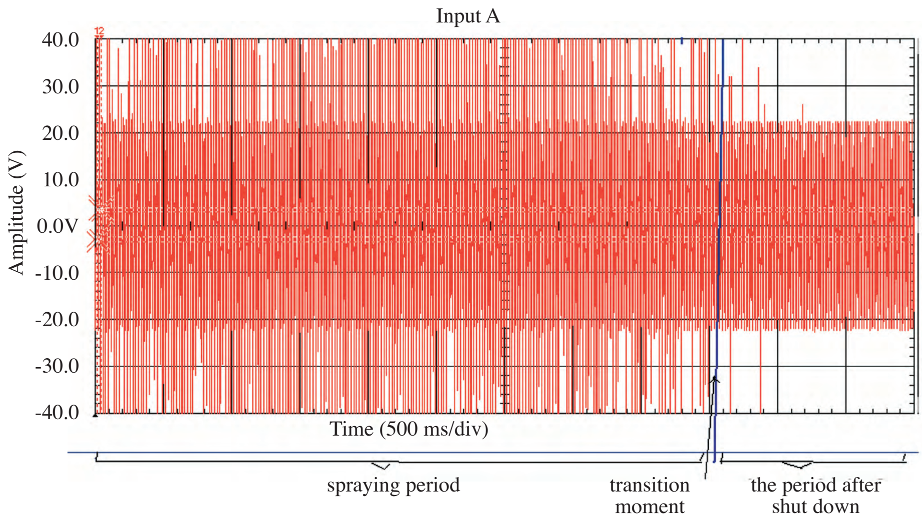

Figure 6. The transition moment of the electrical arc signal with single-nozzle spraying.

3.1.3. Dry band arcing period

This period lasts twenty-eight minutes following spray shut down. During this period no considerable electrical arcs were monitored except for small oscillations just after the transition moment (maximum one minute). It is possible to claim that the ageing process of the test sample for the spray system with one nozzle is limited within the two minutes spraying period.

3.2. Spray system with two nozzles

The wet layer model for the two-nozzle spray system shown in Figure 4(b) was developed in order to simulate an average amount of rainfall. In this model, a wet layer of length of 6–7 cm was formed on the cable surface. A couple of dry-wet layer combinations (1.5–2 cm long) were observed between the electrodes and the wet layer. The arc signal characteristics for two nozzle spray system were identified by using the procedure performed for one nozzle spray system.

3.2.1. Spraying period

The electrical arc signal and corresponding frequency spectrum for the two-nozzle spray system are given in Figure 7. In this spray system, a wider wet layer was formed on the surface of the cable than had occurred during single-nozzle spray. The distance between the wet layer and the electrodes was shorter and the frequency spectrum of the electrical arc signals were found mostly in the 1–4 kHz range, but the frequency spectrum distributed was more widely distributed over 10 Hz to 4 kHz. Under the two-nozzle spray system, irregular dry and wet layer regions were detected. Since electrical arcs occur due to dry bands, frequency components of the electrical arcs distributed over a wide range due to the irregularities of dry layer regions.

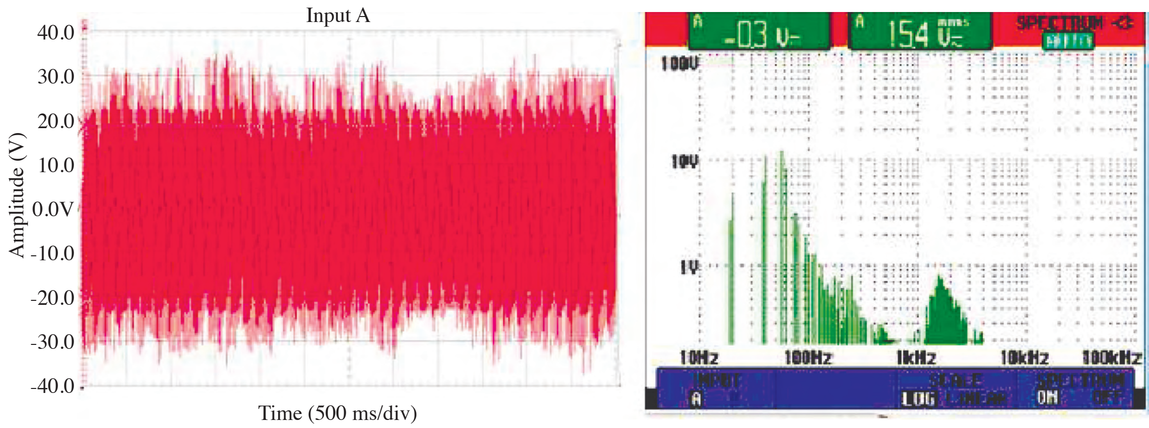

Figure 7. The Arc Signal and frequency spectrum while two-nozzle spray system is on.

3.2.2. Transition period

The transition period of the electrical arc signal for the two-nozzle spray system is given in Figure 8. In this wet layer model, wider wet layer and dry-wet layer combinations produced electrical arcs while the spray system was on.

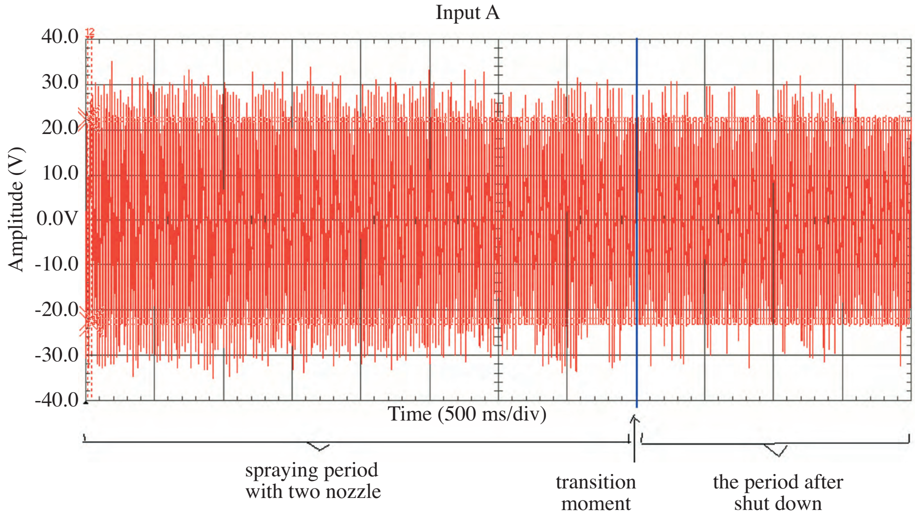

Figure 8. The transition moment of the electrical arc signal with two-nozzle spraying.

3.2.3. Dry band arcing period

In this wet layer model electrical arcs were monitored approximately for fifteen minutes from the beginning of the test cycle. The frequency spectrum and the amplitude of the electrical arc signal are given in Figure 9. After the transition moment, the dry band arcing period of test surface started due to the heat caused by electrical arcs. The number and amplitude of arc signals decreased with time following the transition period. The distribution and power of the frequency components were found to reduce.

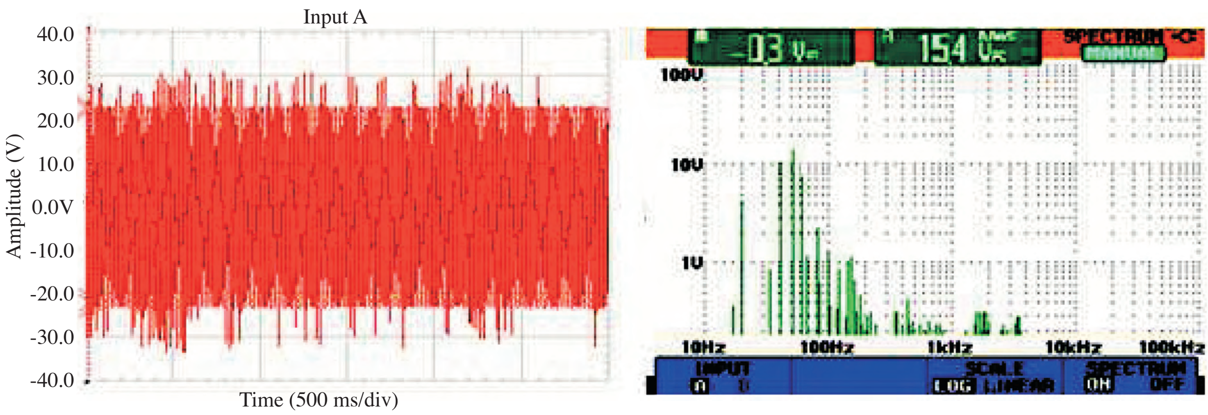

Figure 9. The Arc Signal and frequency spectrum while two-nozzle spray system is off.

3.3. Spray system with three nozzles

The wet layer model for the spray system with three nozzles is given in Figure 4(c). In this wet layer model, completely wet layer region was observed between the electrodes. The test sample was subjected to the spray system with three nozzles in order to simulate excessive rainfall intensity.

3.3.1. Spray period

In this wet layer model, the completely wet region between electrodes produced a short circuit effect on the cable surface; the corresponding electrical arc signal and frequency spectrum are given in Figure 10. During this period no electrical arcs were detected due to the excessive leakage current on the cable surface. Base band frequency of 50 Hz is the maximum component of the frequency spectrum, and the other two components can be ignored. It is possible to claim that the electrical signal is pure sinusoidal with 50 Hz base band frequency (no electrical arc). In the spray system with three nozzles, spraying period for two minutes not have any effect on the ageing process of cable sheath.

3.3.2. Transition period

Electrical arc signals during the transition period, for the three-nozzle spray system, is given in Figure 11. After the transition moment, rapid decrease of the wet region on the cable surface led to the formation of dry band regions. The electrical arcs were observed on these dry band regions just after the spray system was shut down. The number of dry band regions and the number of arcs increased over time.

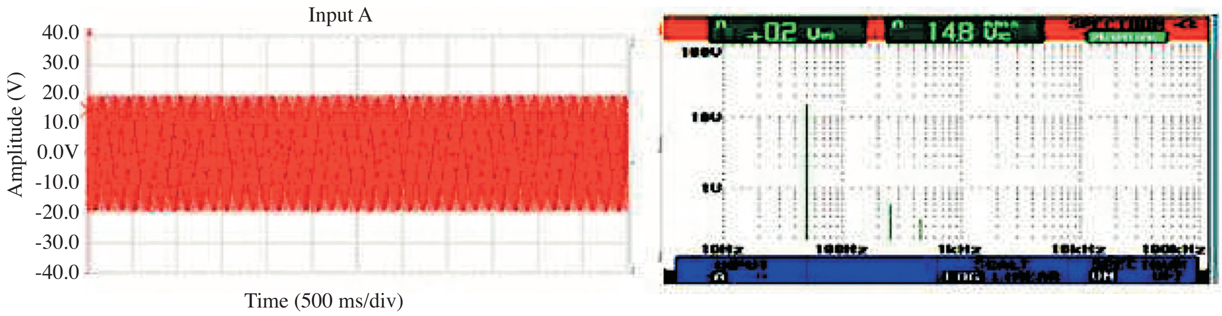

Figure 10. The Arc Signal and frequency spectrum while three-nozzle spray system is on.

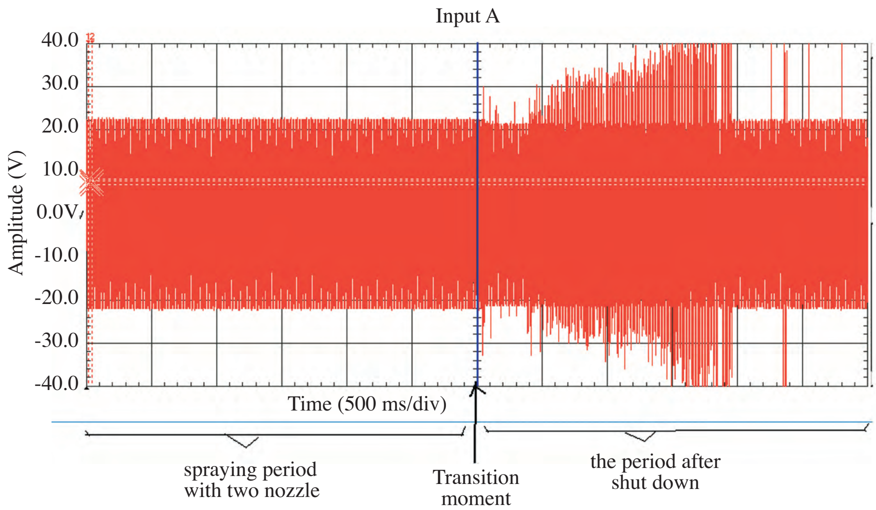

Figure 11. The transition moment of the electrical arc signal with three-nozzle spraying.

3.3.3. Dry band arcing period

In this wet layer model the number and amplitude of the electrical arc signals increased compared with the one- and two-nozzle spray systems. Electrical arcs have been observed until the 25^{th} minute of the cycle. The electrical arc signal and corresponding frequency spectrum are given in Figure 12.

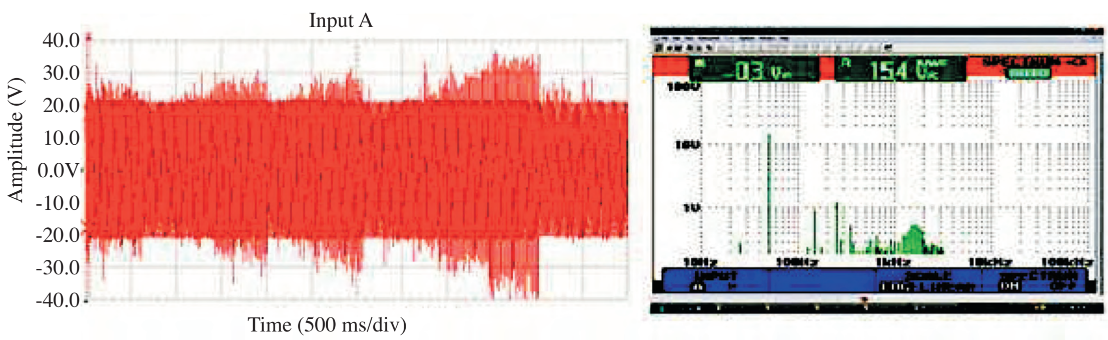

Figure 12. The Arc signal and frequency spectrum while three-nozzle spray system is off.

4. Conclusion

In this study the characteristics of electrical arc signal on insulating sheath of the ADSS cable was investigated for different wet layer models, via FFT analysis. Different numbers of spray nozzles were employed to simulate different levels of rainfall. The ageing process of the test sample for spray system with one nozzle mainly depends on the spraying period of two minutes of test sample. Heavy degradation was seen with two-nozzle spray exposure, with the dry band arcing period occurring thirteen minutes after the transition period. In the three-spray case, arcing had been observed up to the 25th minute of the cycle.

According to the test results, it is possible to claim that the ageing process of cable insulation can be investigated by using the frequency spectrum and the amplitude of the arc signal. The environmental factors associated with rainfall can considerably deteriorate the cable insulation and hence accelerate the ageing process. A linear relationship between the rainfall intensity and the level of deterioration is hard to evaluate, however an arc signals can be reliable indication of the damage level on the polymeric insulator.

Acknowledgement

This work is supported by Istanbul University Scientific Research Fund. No:UDP-7171.

References

[1] G. Karady, G. Besztercey, and M. W. Tuominen, “Corona caused deterioration of ADSS fiber-optic cables on high-voltage lines,” *IEEE Transactions on Power Delivery*, vol. 14, no. 4, pp. 1438–1447, Oct. 1999.

[2] G. Karady, E. Al-Ammar, B. Shi, and M. W. Tuominen, “ Experimental verification of the proposed IEEE performance and testing standard for ADSS fiber optic cable for use on electric utility power lines”, *IEEE Transactions on Power Delivery*, vol. 21, no. 1, pp. 450-455, Jan. 2006.

[3] IEEE 1222 Standard for All Dielectric Self Supporting Fiber Optic Cable, 2004.

[4] W. DeWitt, S. Neogi, B. Risch, and G. Karady, “High voltage ADSS reliability modeling: Environmental and climatologically effects on advanced jacket material selection”, *Proceedings of the 49th International Wire and Cable Symposium*, pp. 337-346, Nov. 2000.

[5] G. Karady and D. Srinivasan, “Algorithm to predict dry-band arcing in fiber-optic cables”, *IEEE Transactions on Power Delivery*, vol. 16, no. 2, pp. 286–291, Apr. 2001.

[6] C.N. Carter, J. Deas, N.R. Haigh, and S.M. Rowland, “Applicability of all-dielectric self supporting cable system to very high voltage overhead power lines,” *Proceeding of the 46th International Wire and Cable Symposium*, pp. 622-631, 1997.

[7] G. Karady, Y. Lei, D. Srinivasan, M. Tuominen, and B. Risch, “Experimental investigation of aging effects of dry-band arcing on ADSS fiber-optic cables”, *IEEE/PES Transmission and Distribution Conference and Exhibition Technical Proceedings*, vol. 3, pp. 898- 903, Sept. 2003.

[8] B. Risch, S. Neogi, G. Karady,Y. Lei, and B. Shi, “Evaluation of ADSS jacketing compounds and environmental exposure effects using a new dry-band arc test methodology”, *Proceedings of the 51stInternational Wire and Cable Symposium*, pp. 551-560, Nov. 2002.

[9] X. Zuoming, W. Xiong, C. Yong, L. Yunpeng, Y. Tao, "Study of the flashover process on ice-covered insulator string", *Proceedings of the 9th International Conference on Properties and Applications of Dielectric Materials*, pp.186-191, July 19-23, 2009, Harbin, China.

[10] F. Meghnefi, C. Volat, and M. Farzaneh, "Temporal and frequency analysis of the leakage current of a station post insulator during ice accretion," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 14, no. 6, pp. 1381-1389, Dec. 2007.

[11] G. Karady, G. Besztercey, and M. W. Tuominen, "Corona caused deterioration of ADSS fiber-optic cables on high-voltage lines", *IEEE Transactions on Power Delivery*, vol. 14, no. 4, pp. 1438–1447, Oct. 1999.

[12] I. Gunes and M. Ugur, "The effects of different rainfall intensities on the ageing process of ADSS cables", *EVK 2009*, Kocaeli, Turkey, 21-22 May 2009.

[13] G. Karady, and J. Madrid, " Assessing deterioration of ADSS fiber optic cables due to corona discharge", *Final project report, Power Systems Engineering Research Center*, May 2002.