Measurement and Denoising of Partial Discharge Signal in High Voltage Cables using Wavelet Transform

S. Madhupriya, R. V. Maheswari, B. Vigneshwaran

Abstract: A huge amount of exploration propagated over the past decade investigates the characterization of Partial Discharge (PD) inception in cable ideology. Underground cables are passed down as surrogate for over hauling in congested areas. The intention of this research is to examine the feasibility of exploring insulation defects present in High Voltage (HV) Cable setup by employing PD disclosure under alternating current (AC) Voltage. Study of PD characteristics has a congregate of predictable distinguished contraption to prove the probity and the affirmation of electrical insulation of Power System. In this work, the cable is exposed into the measurement of PD signal under artificially conceived defects. PD signal parameters are mainly depends on the size of void and applied voltage. In general, the measured PD signal is depraved with interferences. To identify the exact characteristics of PD distinctive and its severity, the PD signal is subjected to Wavelet Transform (WT) for denoising. Different types of WT families with various level is used for de-noising. To identify the effectiveness of the WT for de-noising guidelines like Signal to Reconstruction Error Ratio (SRER) and Reduction in Noise Level (RNL) are used.

Keywords: Partial discharge, Wavelet transform, Signal to Reconstruction Error Ratio (SRER) and Reduction in Noise Level (RNL)

I. INTRODUCTION

Partial discharge (PD) assessment is an crucial symptomatic contrivance for insulation systems as retrieve culminate can be worn to compute the accustom of high voltage farm. PD unremarkably materialized at defeatists like voids, dent, breach, juncture and delamination [1]. These will manifest in solids, liquids and aerosolized dielectrics. The injury because of the discharge may be calculable looking on the kind of discharges; for instance, internal or surface discharge, termination discharge, corona, electrical treeing, etc., [3]. Cables are extensively pre-owned in potential dispersion and transmittal channel in debt its excellent electrical, mechanical and thermal features. Deficiency might be imported in the operation of carry or established, although cable accomplishing is upgraded. In an empirical working situation, electric field laceration throughout these defects is reshape, exceeding unfavorable possessions upon the XLPE insulation disintegration [2].

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Therefore, as PD audit has incline a cardinal device in estimate the attainment of insulation materials, the designing of PD is valuable in supposing a excelling recognition of PD development [5]. So the artificial defects such as cylindrical void is created in cables will provide a better perception of PD characteristics and also prevent a cables from failure [4]. The connotation of PD on the vigor of insulation has been diagnosed. In PD estimation, eruption can appearing virtue of various species of origin and can span with the structure in contrastive techniques and with contrastive visage. In view of the peradventure to miniature domain of PD beacon it is veridicality to demise them. Therefore, it's necessary to denoise by many techniques. Because of the prevalence of various interferences within the Partial discharge signal, it's necessary to extract those original signals from creaky signal. Within the previous couple of years, many techniques were spring with denoise the PD signals cogently. However it can be complete either the time domain or within the frequency domain. Once the signal method is completed at intervals the frequency domain, the time domain information is lost. Newer the Wavelet Transform (WT) is sanctioned as a powerful tool for PD process as a result of it preserves each time and frequency domains data.

II. SAMPLE, EXPERIMENTAL SETUP AND PROCEDURE

A. Cylindrical Void

Cylindrical Void with 2mm and 5mm depth and constant diameter 4mm is created in low tension cable by using drilling machine. The depth of the void is measured by using vernier caliper.

B. Experimental Setup

Partial Discharge measure by using coupling capacitor, testing transformer. The power supply is given as per Fig 1. Fig 1 shows the PD testing connection having merging capacitance, high voltage test transformer, and establish to detain a XLPE cable. The transformer ranked voltage is $2\times0.22/100/0.22$kV, ranked current $2\times22.8/0.1$A, ranked output is 10kVA. Measuring transformer is worn to composed Alternating Current, Direct Current, and impulse voltage. Electric source is given to cable bits by means of transformer. Fig 2 shows a control desk is worn to curb and perform high voltage AC test furnishings. Test arrangement is composed by means of control desk. The PD audit can be eminent from the curb desk, PD meter and computer.

Fig.1. Experimental setup

Fig.2. Control panel

C. Samples

The investigated cable mainly consisted of a stranded aluminium conductor, an insulation of XLPE, an inner sheath layer and armouring and cable outer sheath. XLPE cable samples have length 1feet. Before test the cable sheath and insulation were carefully peeled. Fig. 3, 4 and 5 shows a test samples of cables.

Low Tension Cable: 1.1 kV
Cross sectional Area: 35 square mm
Insulation thickness: 0.9 mm (XLPE) [R-Y-B-N]
Number of conductor: 6 (Aluminium)
Minimum outer sheath Thickness: 1.4 mm (PVC)
Minimum inner sheath Thickness: 0.3 mm (PVC)
Armouring: Galvanized steel, flat strip

Fig.3. Pure cable

Fig.4. Cylindrical void with 2mm depth

Fig.5. Cylindrical void with 5mm depth

D. Procedure

The transformer output terminal is connected to the Cable. Before that 2mm and 5mm void is created on the cable. Voltage is applied on the cable. PD waveform is captured by partial discharge meter. Fig. 6 shows a Schematic diagram of the test object.
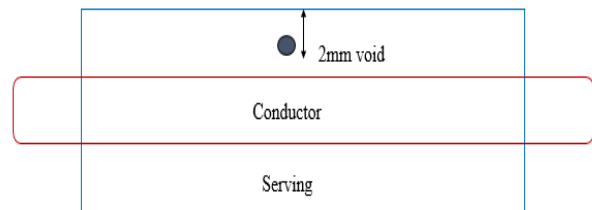

Fig. 6. Schematic diagram of the test object

III. PARTIAL DISCHARGE

In engineering, partial discharge (PD) could be a localized dielectric failure (which doesn't fully form the bridge the distance between the 2 conductors) of limited low portion of a solid or fluid electrical insulation scheme under high voltage (HV) emphasis[6].In paper-insulated high-voltage power phases, partial discharges establish as trifle pricks ingoing the paper windings that are beside to the electrical conductor or outer sheath [7].

As Partial discharge bustleimprovement, the monotonouspardon eventually create durable chemical variance at parenthesis the troubled paper tiers and infuse dielectric fluent [8]. Additional time, partly escort carbonized branches are forged. This places preeminent emphasis on the tarrying insulation, emerging in additional progress of the broken region, renitentsteaming on the tree, and additional scorching invoked to as trailing [9][10]. This ultimatelyterminate within the complete material failure of the cable and, typically, an electrical fulmination.Partial discharges lavish energy within the variety of heat, sound, and light. Localized heating from PD cause thermicdeterioration of the insulation.The purity of insulation in high voltage instruments will be accepted by observance of the PD activities that occur through the equipment's life.

IV. SIGNAL DENOISING

In general PD doesn't cause instant breakdown. It express the existence of a defect inside the insulation which might have an effect on its performance in an exceedingly long run. In the chapter explains regarding the denoising techniques that are secondhand to denoise the Partial discharge signals in an efficient manner. The noise is especially generate by pours and exposes that WTstrategies displays best results compared to different filtering procedure by the signal to reconstruction error ratio (SRER) and reduction in noise level (RNL).

A. Wavelet Transform

In virtual signal processing and picture compression, wavelet is used and wavelet is a mathematical function. Firstly Wavelet compression is analysing a picture or image and secondly set of mathematical expressions is formed and then the receiver is used for decoded purpose. In recent years, Wavelet Transform (WT) has been adopted as an alternative algorithm for the analysis of non-stationary PD waveform. Comparing frequency/time-based filters, WT is more suitable for de-noising PD signals. In Wavelet, both time and frequency domains are used for analyse the signal and high and low-frequency components are used for analyse the sharp spikes in a signal and regains the originality of the signal.

B.Types of Wavelet Transform

• Daubechies Wavelet
• Coiflet Wavelet
• Biorthogonal Wavelet
• Symlet Wavelet
• Fejér-Korovkin Wavelet

IV. EVALUATED PARAMETERS

A.Signal to Reconstruction Error Ratio (SRER)

It is defined as the ratio of the power of the signal to power of the noise. Equation (1) shows a SNR value,where $s(i)$ is the PD signal, $n(i)$is the noise signal and N the number of sampIes.

$$SRER(dB)=10\log_{10}\frac{\sum_{i=1}^{N} s^2(i)}{\sum_{i=1}^{N} n^2(i)} \quad (1)$$

B. Reduction in Noise Level (RNL)

RNL is determined by,

$$RNL=10\log\frac{1}{n}\sum_{i=1}^{n}\big(Z(i)-Y(i)\big)^2 \quad (2)$$

Where, $Z(i)$is the noisy signal acquired, $Y(i)$is the denoised signal and n is the number of samples. Equation (2) shows a RNL value.

V. RESULT DISCUSSION

In this section, the results obtained within the limited period for completion of the project. Different type of defects are created in low tension cable. PD waveform is obtained from Partial Discharge meter. Normally PD signal contains noise, so this must be reduced because obtaining exact signal. The wavelet signal de-noising method is used for de-noising the PD signal with the help of MATLAB. The Signal to Reconstruction Error Ratio (SRER) and Reduction in Noise Level (RNL) are compared in different types of mother wavelets.

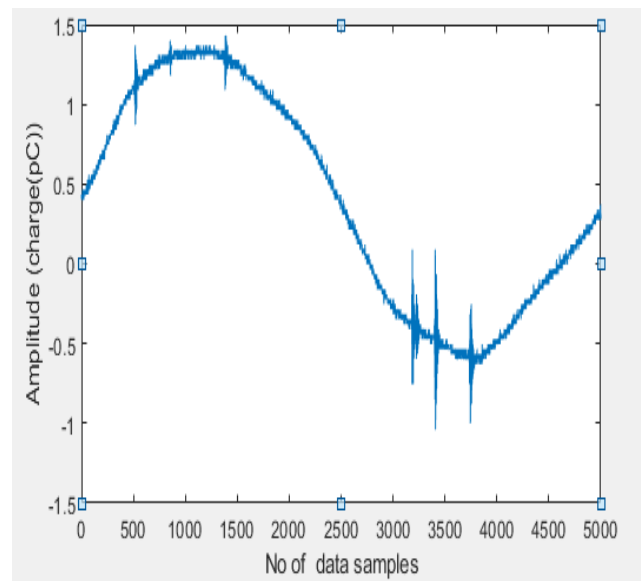### A. Partial Discharge Waveform in Pure Cable

Fig.7. PD waveform for pure cable

Fig. 7 shows a PD waveform for pure cable. Fig. 8 shows 3D image of pure cable. This PD waveform contains PD magnitude and noise signal. This noise signal must be eliminated to obtain the exact PD waveform. It can be done by different mother wavelets. Table.I– VI shows a SRER and RNL values for different mother wavelets.
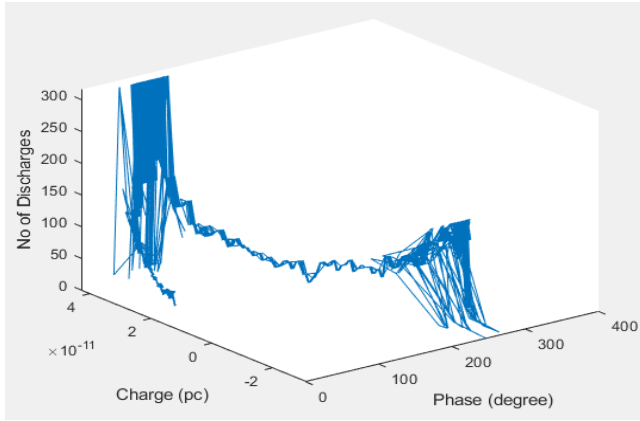
Fig.8. 3D plot of pure cable

Table-I: SRER and RNL in SYM wavelet for pure cable

SYMLET	SRER	RNL
2	30.5154	-64.5154
3	30.5944	-64.5831
4	30.6982	-65.0393
5	30.6121	-64.7995
6	30.8418	-65.0619
7	30.8353	-65.5532
8	30.9579	-65.6880

Table- II: SRER and RNL in COIF wavelet for pure cable

COIF	SRER	RNL
1	30.5474	-64.5074
2	30.7885	-65.2702
3	30.9288	-65.7569
4	30.9947	-65.8069
5	31.0573	-65.9337

Table- III: SRER and RNL in FK wavelet for pure cable

FK	SRER	RNL
4	28.8955	-62.1604
6	30.5802	-64.3063
8	30.8378	-65.0967
14	31.0779	-65.8317
18	31.1380	-65.9012
22	31.1290	-65.865

Table- IV: SRER and RNL in BIOR wavelet for pure cable

BIOR	SRER	RNL0
1.1	28.2424	-61.1567
1.3	28.4479	-64.7975
1.5	28.6229	-65.6319
2.2	30.8686	-65.1237
2.4	30.9755	-65.4383
2.6	31.0571	-66.2663
2.8	31.1252	-66.3126
3.1	29.7921	-66.7652
3.3	30.8946	-65.9157
3.5	31.0747	-66.4418
3.7	31.1755	-66.6615
3.9	31.2537	-67.1663
4.4	30.7733	-64.9053
5.5	30.5481	-64.6345
6.8	30.9686	-65.4784

Table- V: SRER and RNL in DB wavelet for pure cable

DB	SRER	RNL
1	28.2424	-61.5167
2	30.3516	-64.5154
3	30.5944	-64.5831
4	30.5826	-64.5672
5	30.7446	-64.9545
6	30.8093	-65.3544
7	30.8209	-65.1979
8	30.8631	-65.1739
9	30.8943	-65.3601
10	30.9541	-65.7902

Table- VI: Comparison of all mother wavelets for pure cable

Mother wavelet	SRER	RNL
SYM 8	30.9579	-65.6880
COIF 4	30.9947	-65.8069
FK 18	31.1380	-65.9012
BIOR 3.9	31.2537	-67.1663
DB 10	30.9541	-65.7902

Biorthogonal 3.9 gives a higher Signal to Reconstruction Error Ratio (SRER) and Reduction in Noise Level (RNL) comparing all the mother wavelets levels. Denoising PD waveform shown in Fig 9.
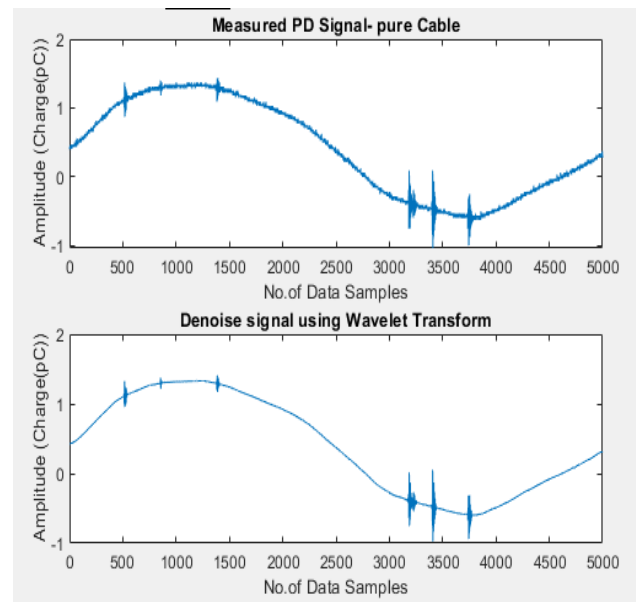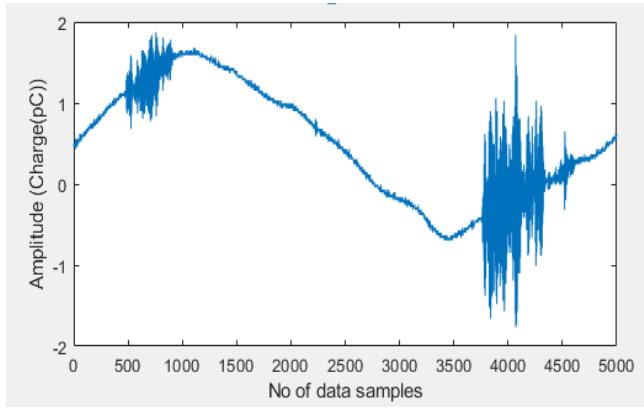

Fig.9. Denoised PD waveform for pure cable

B. Partial Discharge Waveform in 2mm Cylindrical Void Cable

Fig.10. PD waveform for 2mm cylindrical cable

Fig. 10 shows a PD waveform for 2mm cylindrical cable. Fig. 11 shows a 3D image of 2mm cylindrical cable. This PD waveform contains PD magnitude and noise signal. This noise signal must be eliminated to obtain the exact PD waveform. It can be done by different mother wavelets. Table. VII - XII shows a SRER and RNL values for different mother wavelets.
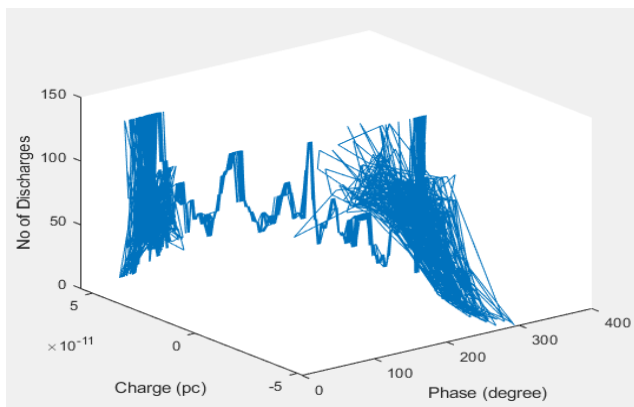
Fig.11. 3D image of 2mm cylindrical cable

Table- VII: SRER and RNL in SYM wavelet for 2mm cylindrical cable

SYMLET	SRER	RNL
2	25.1162	-43.6249
3	25.8268	-44.8245
4	25.9971	-45.1695
5	25.5768	-44.7508
6	26.5681	-46.1530
7	26.6364	-46.3606
8	26.8183	-46.6292

Table- VIII: SRER and RNL in COIF wavelet for 2mm cylindrical cable

COIF	SRER	RNL
1	26.0327	-44.7475
2	26.5524	-45.8373
3	26.7766	-46.4333
4	26.8967	-46..7712
5	27.1552	-47.1554

Table- IX: SRER and RNL in FK wavelet for 2mm cylindrical cable

FK	SRER	RNL
4	24.0197	-42.3679
6	26.2398	-45.4070
8	26.4576	-45.9490
14	27.5437	-47.6539
18	27.4337	-47.4388
22	27.6052	-47.6383

Table- X: SRER and RNL in BIOR wavelet for 2mm cylindrical cable

BIOR	SRER	RNL
1.1	23.5206	-41.5877
1.3	23.8639	-42.9348
1.5	24.1337	-43.3952
2.2	27.4788	-46.6830
2.4	27.8261	-47.6237
2.6	27.9752	-48.2761
2.8	28.1743	-49.0619
3.1	25.6263	-49.0624
3.3	26.8594	-46.2554
3.5	27.3555	-47.3379
3.7	27.5307	-48.3457
3.9	27.6372	-48.8992
4.4	26.7306	-46.0028
5.5	25.7715	-44.7542
6.8	27.1963	-47.0455

Table- XI: SRER and RNL in DB wavelet for 2mm cylindrical cable

DB	SRER	RNL
1	23.5206	-41.5877
2	25.1162	-43.6249
3	25.8268	-44.8245
4	25.5973	-44.6529
5	25.9294	-45.2433
6	26.3976	-46.0303
7	26.4096	-45.9432
8	26.5532	-46.2111
9	26.7201	-46.6542
10	27.1088	-47.0654

Table- XII: Comparison of all mother wavelets for 2mm cylindrical cable

MOTHER WAVELET	SRER	RNL
SYM 8	26.8183	-46.6292
COIF 5	27.1552	-47.1554
FK 22	27.6052	-47.6383
BIOR 2.8	28.1743	-49.0619
DB 10	27.1088	-47.0654

Biorthogonal 2.8 gives a higher Signal to Reconstruction Error Ratio (SRER) and Reduction in Noise Level (RNL) comparing all the mother wavelets levels. Denoising PD waveform shown in Fig.12.
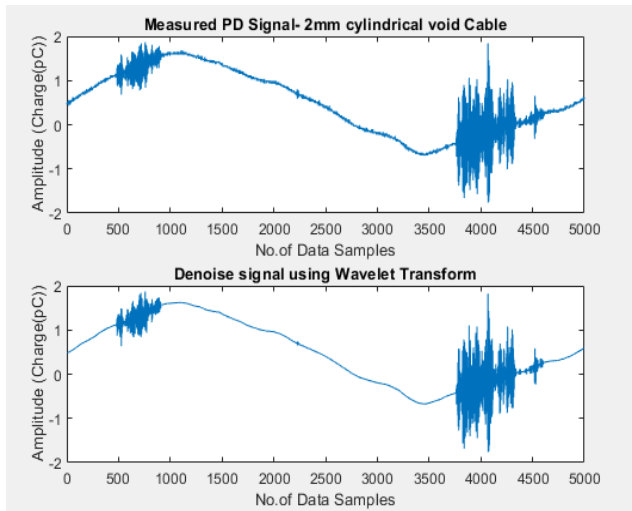
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Fig.12. Denoised PD waveform for 2mm cylindrical void cable

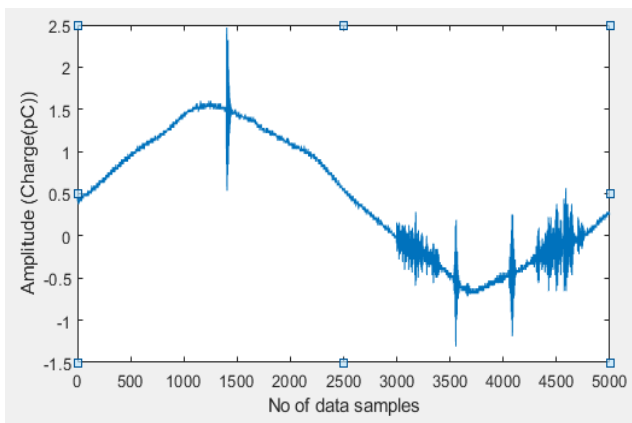## C. Partial Discharge Waveform in 5mm Cylindrical Void Cable

Fig.13. PD waveform for 5mm cylindrical cable

Fig. 13 shows a PD waveform for pure cable. Fig. 14 shows a 3D image of 5mm cylindrical cable. This PD waveform contains PD magnitude and noise signal. This noise signal must be eliminated to obtain the exact PD waveform. It can be done by different mother wavelets. Table. XIII - XVIII shows a SRER and RNL values for different mother wavelets.
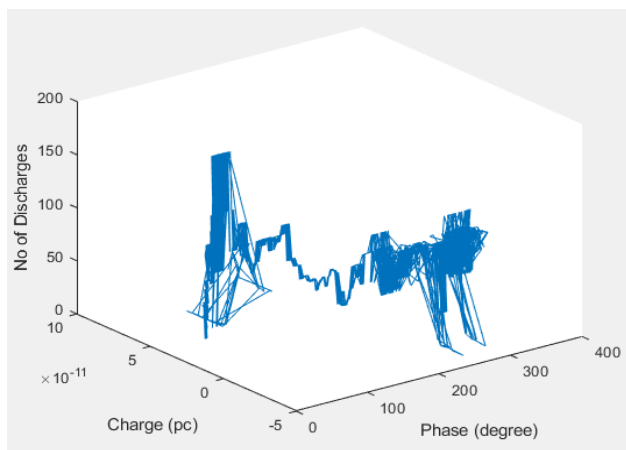

Fig.14. 3D image of 5mm cylindrical cable

Table- XIII: SRER and RNL in SYM wavelet for 5mm cylindrical cable

SYMLET	SRER	RNL
2	27.1424	-52.7675
3	27.6807	-53.7615
4	27.8171	-54.0651
5	27.5537	-53.8638
6	28.4060	-54.7979
7	28.2737	-54.6908
8	28.6812	-55.1839

Table- XIV: SRER and RNL in COIF wavelet for 5mm cylindrical cable

COIF	SRER	RNL
1	27.4997	-53.3687
2	28.0916	-54.3746
3	28.4693	-54.8485
4	28.7301	-55.1695
5	28.9346	-55.4211

Table- XV: SRER and RNL in FK wavelet for 5mm cylindrical cable

FK	SRER	RNL
4	25.4136	-51.0291
6	27.8380	-54.0548
8	28.0647	--54.4072
14	29.1857	-55.7715
18	29.3049	-55.9937
22	29.1518	-56.0307

Table- XVI: SRER and RNL in BIOR wavelet for 5mm cylindrical cable

BIOR	SRER	RNL
1.1	29.3400	-56.1901
1.3	25.2965	-52.0608
1.5	25.4715	-52.3467
2.2	28.4657	-54.7439
2.4	28.8515	-55.6651
2.6	28.9915	-56.1389
2.8	29.1951	-56.7561
3.1	27.3290	-54.7122
3.3	28.5797	-55.0712
3.5	28.8279	-55.7775
3.7	29.0894	-56.6805
3.9	29.2191	-56.9328
4.4	28.3285	-54.5797
5.5	27.4553	-53.4232
6.8	28.9055	-55.3686

Table- XVII: SRER and RNL in DB wavelet for 5mm cylindrical cable

DB	SRER	RNL
1	24.8076	-50.1707
2	27.1424	-52.9675
3	27.6807	-53.7615
4	27.1056	-53.1968
5	27.6866	-53.9358
6	28.2244	-54.6420
7	28.3649	-54.7991
8	28.7259	-55.2119
9	28.6055	-55.1314
10	28.8486	55.4171

Table- XVIII: Comparison of all mother wavelets for 5mm cylindrical cable

MOTHER WAVELET	SRER	RNL
SYM 8	28.6812	-55.1839
COIF 5	28.9346	-55.4211
FK 18	29.3049	-55.9937
BIOR 3.9	29.2191	-56.9328
DB 10	28.8486	55.4171

Biorthogonal 3.9 gives a higher Signal to Reconstruction Error Ratio (SRER) and Reduction in Noise Level (RNL) comparing all the mother wavelet levels. Denoising PD waveform shown in Fig. 15.
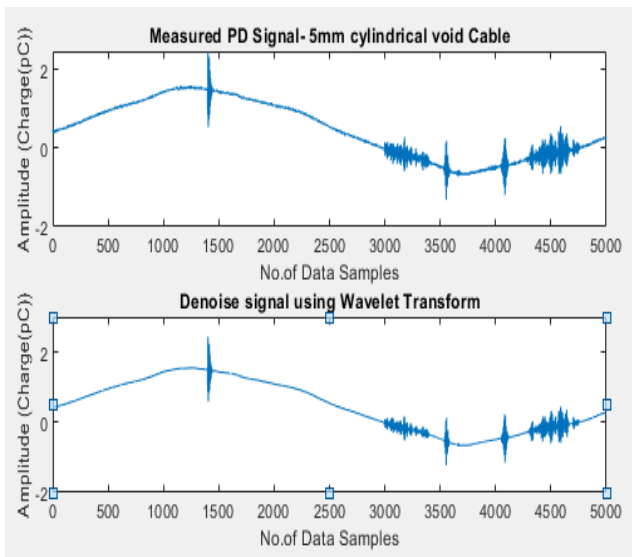
Fig.15. Denoised PD waveform for 5mm cylindrical void cable

The proposed method WT which overcomes the problem (i.e) noise present in the measured PD signal. Wavelet Transform approach is used for noise reduction goal, it recovers the novelty of the signal after denoising. To evaluate the effectiveness of the PD signal denoising Wavelets. The statistical parameters like SRER and RNL are computed, compared and tabularized in Tables VI, XII, XVIII for all cases. Biorthogonal Mother Wavelet produces the better result among other Mother wavelets.

VI. CONCLUSION

In this work, cylindrical defects is imported into a 1.1 kV XLPE cable. The PD characteristics of cylindrical cavities with various void diameter have been experimentally investigated. In this planned technique, Wavelet Transform (WT) is employed to denoise the PD signal in a very more practical manner. By evaluating the two totally different parameters it's clearly shows that the suggested denoised technique has a worthy SNR and RNL values. The noise existence within the signal ought to be low solely within the case that the SNR worth ought to be higher. The RNL shows high worth, that describes however expeditiously the noise is eliminated from the PD signal. Among the five different mother wavelets, Biorthogonal (Bior) shows a better result to denoise the PD measured signal.

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