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Effects of Common In-Service Defects of Different Insulators on Radio Frequency Interference Emission from 765 kV Insulators String

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Abstract

Worldwide utilities are preferring Ultra-High Voltage (UHV) transmission lines for transmitting electric power from generating stations to load centres. This long-distance UHV transmission line uses porcelain, glass and composite insulators. Fault-free operation of these insulators is vital to provide reliable service to consumers. Any defects on these insulators may lead to outages and affect the reliability of the supply system. To ensure reliability, utilities are continuously monitoring the condition of transmission line insulators. Nowadays in addition to providing reliable and quality power to the consumers, the utilities are keen on measuring and reducing The Radio Frequency Interference (RFI) from transmission lines. Under normal operating conditions, the RFI of the insulator string may be less than the specified limit. However, evolving in-service defects and deposition of pollutants on the surface of the insulator may increase the RFI level, sometimes it may exceed the specified limit also. This higher emission may affect the operation of nearby other electronic equipment. In this present work, an attempt is made to measure and compare RFI from healthy and defective 765 kV single I suspension string in the shielded indoor laboratory. It was observed that defects and pollutants deposited on insulators have induced corona/spark or gap discharges at the operating voltage level, which in turn increases the intensity of RFI.

Keywords: Electromagnetic Compatibility, Impact of In-Service Defects on RFI Emission, In-Service Defects, Radio Frequency Interference (RFI), RFI Measurement, RIV Emission

1. Introduction

Utilities all over the world employ either AC or DC transmission lines for transmitting electric power from generating stations/energy surplus places to load centres to meet ever-increasing energy demand. This long-distance UHV transmission line uses porcelain, glass and composite insulators. Any damage/defects on insulators may lead to an energy outage and consequently impacts the reliability of the supply system. To ensure reliable service to consumers, in addition to regular/preventive maintenance, utilities are keen on monitoring RFI from insulator strings too. In general, before putting into service, using laboratory test methods, the Radio Interference Voltage (RIV) of the insulator or string of insulators is measured and ensured that the RIV level is less than the permissible limit of utility and customer. To transmit large quantities of power over long distances economically, worldwide utilities are preferring Ultra-High Voltage (UHV) transmission lines. In India, these 765 kV UHV transmission lines use porcelain, glass and composite insulators. All over the world, 40% of insulators used in transmission lines are composite insulators and the remaining are ceramic, viz. porcelain and glass insulators.

Literature reported that corona and spark or gap discharges are responsible for RFI emission of transmission lines[1]. Spark or gap discharges from insulators depend on surface area and type of insulators. Hence, in this work, an attempt is made to measure the interference of strings consisting of porcelain, glass and composite insulators independently. Many times, under normal operating conditions, the emission from insulator strings will be within acceptable limits specified by the utilities. However, when these insulators are exposed to outdoor ambient atmospheric conditions, pollutants are getting deposited on the surface of the insulators. With these pollution deposits, when the string is subjected to

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high voltage, which leads to surface discharges and if the surface is wet due to humidity, the intensity of discharges may be higher. In addition, under the influence of pollutants, the corona discharges may occur at lower voltages than that of normal operating voltage. The intensity of spark/corona discharges is depending on surface area and type of insulators. High-frequency pulse current resulting from these discharges emits higher radio interferences and it may disturb the operation of neighbouring delegate electronic equipment. As a comparative measure, the Radio Frequency Interference spectrum from three different 765 kV single I suspension strings under polluted conditions is measured. Insulator string is erected in the indoor laboratory using a loop antenna and EMI receiver the spectra are recorded.

In addition to the deposit of pollutants on insulators, there are possibilities of evolving common in-service defects on the string, viz. breakdown of glass or porcelain discs, bird pecking and/or rodent damage. To record the influence of these common defects on RFI emission, some discs on the 765 kV porcelain single I suspension string are deliberately damaged. Upto 12.5% of total discs, i.e., 5 discs on a 40 discs insulator string deliberately damaged and RFI is recorded. The amount of damage may vary from 30% to 70%. Similarly, the RFI from 765 kV glass disc insulators with 5 damaged glass discs was also recorded. The percentage of damage in toughened glass insulators is 100% because once the disc is broken only the stub will be present. To record the effect of birds pecking/rodent damage, some sheds on the composite long rod insulator are deliberately damaged and subjected to normal operating voltage as per utilities. RFI under high voltage excitation is recorded. Equipment used for RFI measurement along with the arrangement of strings in the laboratory is discussed in Section II. The influence of in-service defects and pollution on RFI emission is presented in Section III.

2. Test Facility, RFI Measuring Equipment, Insulator Strings and Common Defects of Insulator String

2.1 HVAC Test Facility

CPRI, UHVRL is equipped with 2400 kVA, 1200 kV, 2A continuous current rated HVAC test source. It is placed in a double shielded 50 m (length) X 40 m (breath) X 38 m (height) indoor test facility. The test source and its measuring instrument are in compliance with IEC 60060-1[2] and IEC 60060-2[3], respectively. Double shielding of the laboratory effectively attenuates the ambient interference during measurement and the background interference at 1000 kHz (fixed frequency) was found approximately 15 to 18 μV. The same on the outdoor facility may be roughly 300 to 350 μV. This source placed in the indoor laboratory is used for test voltage application on the string. A photograph of a 765 kV glass disc insulator with 5 broken discs erected in the shielded laboratory for interference measurement is shown in Figure 1. Spectra are recorded in the span of 150 kHz to 30 MHz using a loop antenna placed laterally at 12 m from a string.

Figure 1. 765 kV glass disc insulator string with 5 damaged discs erected at double shielded indoor test facility for interference measurement.

2.2 Equipment used for RFI Measurement

CISPR compliance EMI test receiver, ESR3, used for the recording of RFI. This receiver is capable to record/ measure RFI spectra up to 3.6 GHz in conjunction with suitable antennas viz, loop (9 kHz to 30 MHz), bi-conical (30 to 300 MHz) and logarithmic (300 to 1000 MHz). The specifications of the antenna also comply with the requirement of CISPR 16-1[4]. Figure 2 shows the schematic arrangement of interference measurement up to 30 MHz using a loop antenna.

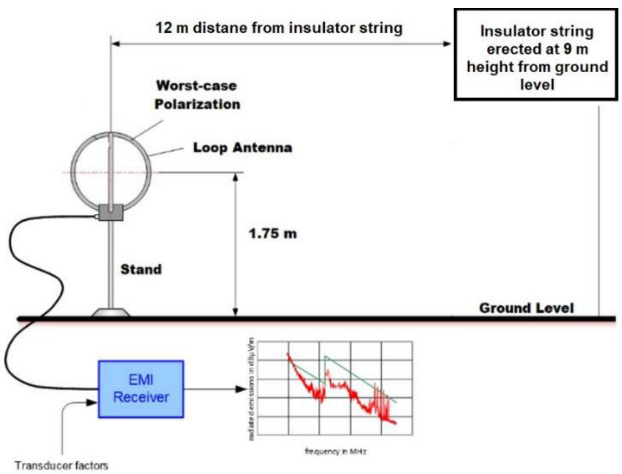

Figure 2. Recording of interference using loop antenna and EMI receiver.

2.3 Method of RFI Measurement

RFI spectra of different 765 kV single I suspension strings with and without excitation of HVAC test voltage, 508 kV, i.e., 1.1 X 800 kV/√3 is recorded independently up to 1 GHz using three different antennas. Interference recorded without application of HVAC is considered ambient RIV at that instant. A noticeable difference in RFI spectra is observed particularly in the lower frequency range, i.e., up to 30 MHz. At higher frequencies, no such distinct difference was found. Observed differences in spectra at lower frequencies may be due to discharges[1]. In the present work, for comparative studies, as suggested in CISPR 18-2, authors have measured interference to 30 MHz. Interference was measured at 9 kHz bandwidth and reported as frequency (kHz) and interference magnitude spectra (*dBμV/m*). In many cases, the magnitude of interference recorded in the lower frequency range is deciding factor for Electromagnetic Compatibility (EMC) compliance and hence required to measure accurately. To record the interference precisely, measurement is performed at the worst-case polarization/orientation of the loop antenna.

In addition to polarization, detectors used to acquire the spectra also decide the accuracy of interference recorded. As per CISPR guidelines, in general, one among these four detectors, viz. peak (P), Quasi-Peak (QP), RMS and Average (AVG) are used for measurement. Each detector has its characteristics. Utilities prefer to use QP detectors. But measurement with a QP detector is time-consuming, to record RFI to 30 MHz with 9 kHz bandwidth in the linear scale of frequency from 150 kHz requires approximately 90 minutes. But the peak detector records the interference faster compared to that the QP detector. Moreover, CIGRE 391 recommends using a combination of Peak and QP detectors for faster and more precise measurement of interference[5]. Hence, the measurement is performed with a peak detector and on the measured spectrum, peak search is performed with a QP detector. Identified Quasi- peaks are represented with red colour '+' mark on the spectra. A screenshot of RFI measured using an EMI test receiver and loop antenna oriented at worst-case polarization in the frequency sweep from 0.15 to 30 MHz inside a shielded laboratory is shown in Figure 3.

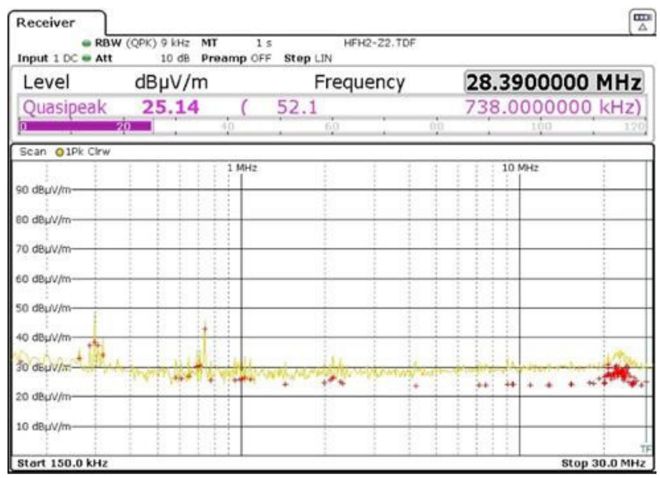

Figure 3. Ambient RFI measured from double shielded indoor test facility.

2.4 Test Sample – Insulator Strings

A single I suspension insulator string with hardware fittings suitable for quadruple ACSR moose conductors is chosen for comparative studies. The photograph of the 210 kN porcelain disc insulator used for comparative analysis is shown in Figure 4. Chosen porcelain disc insulator has a diameter of 280 mm and 41 discs are connected in series. As shown in Figure 1, an arcing horn with a ball diameter of 50 mm is used on the ground side and a corona control ring of 600 mm diameter is used on the HV side. The tube diameter of chosen corona control ring is 60 mm. Similarly, a photograph of chosen 210 kN glass disc insulator is shown in Figure 5 and the diameter of this disc is also 280 mm. Similar hardware like porcelain insulator string is used for this string too. On the contrary, a 210 kN long rod composite silicone rubber long rod insulator as shown in Figure 6 is chosen for comparative studies. Two composite insulators connected in series form a 765 kV single I suspension composite insulator string with hardware fitting suitable for quadruple ACSR moose conductor. In composite insulator string, in addition to the corona control ring, 2 numbers 300 mm diameter tube grading rings are also used.

Figure 4. 210 kN porcelain disc insulator.

Figure 5. 210 kN Glass disc insulator.

Figure 6. 210 kN composite silicone rubber long rod insulator.

2.5 Common Defects of Insulator String

Rodent damage or bird peaking is a common in-service defect in composite insulators. Birds usually peak insulator shed portion along the entire length of the insulator. However, to record the impact of rodent damage/bird peaking, some sheds on both the line and ground end are deliberately damaged as shown in Figure 7. Both rodent-damaged long rod insulators are arranged in series to form a single I suspension string. Damage to porcelain or glass disc insulators due to various reasons is the major in-service defect in the ceramic insulator strings. To study the influence of the damaged disc insulator on RFI, five discs are deliberately damaged as shown in Figure 8 and placed at equally spaced intervals along the entire length of the string from line end to tower end. As the glass insulators are made up of toughened glass, after damage only the stub is present and the stub is placed at equally spaced intervals on the sting from HV end to ground end. Inclusive of damaged insulators, the number of discs on each string in 41.765 kV, 210 kN glass single I suspension insulator string with 5 damaged insulators (only stub) is shown in Figure 1.

Figure 7. Deliberately damaged composite insulators like rodent/bird peaking damage.

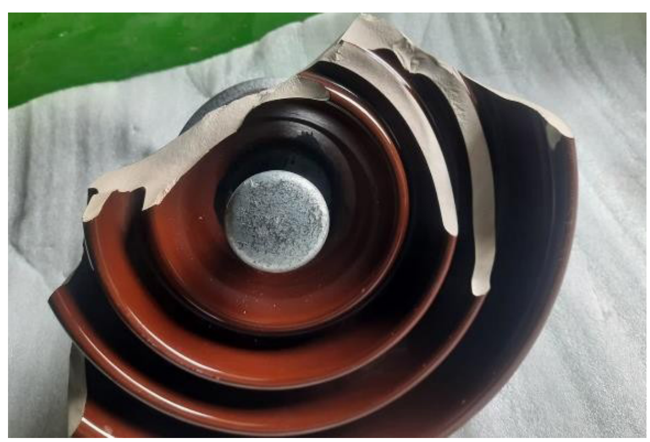

Figure 8. Deliberately damaged porcelain disc insulator.

3. RFI Spectra Recorded

3.1 RFI Emission Recorded from Healthy Composite, Porcelain and Glass Insulator String

In general, utilities measure conducted radio interference voltage level from insulator string in the laboratory using coupling capacitors at a fixed frequency, i.e., at 1000 kHz at a test voltage of 1.1 X highest system voltage/√3. For the 765 kV system, the test voltage is 1.1 X 800/√3 = 508 kVrms. For this comparative analysis, 508 kVrms is used as the test voltage. The test sample is excited at this voltage and maintained for 300 seconds before recording RFI. As stated earlier in section II, the test sample, 765 kV, 210 kN single I suspension string with 41 number of healthy porcelain disc insulators are erected as in Figure 1 and the loop antenna is located at 12 m. As per measurement guidelines, before the application of test voltage, the worst-case orientation of the loop antenna is identified and RFI is recorded at that orientation only. Screenshot of interference recorded from a healthy porcelain insulator string at 508 kVrms after preconditioning at 300 seconds is shown in Figure 9. It is evident from Figure 9 that, compared to the ambient/background shown in Figure 3, few spikes are found between 2 to 23 MHz frequency. Spikes around 10 MHz are due to spark or gap discharges and spikes recorded around 5 to 10 MHz is from corona discharges. RFI recorded from 765 kV healthy glass disc and composite single I suspension string is shown in Figures 10 and 11. More-or-less same trend of RFI was observed from both glass and porcelain disc insulators. However, spectra from glass disc insulator string are different from others. In that, the contribution of corona discharges on interference was found minimum.

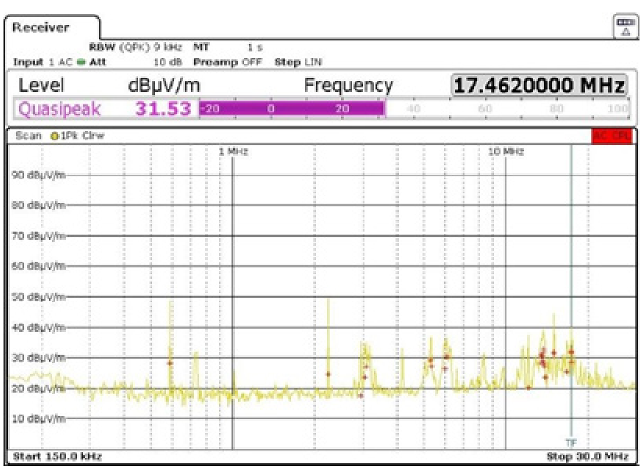

Figure 9. RFI emission of 765 kV healthy porcelain disc insulator string.

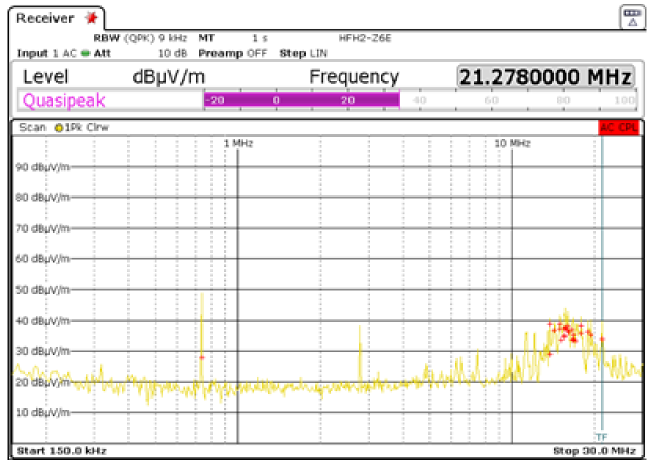

Figure 10. Measured RFI emission of 765 kV healthy glass disc insulator string.

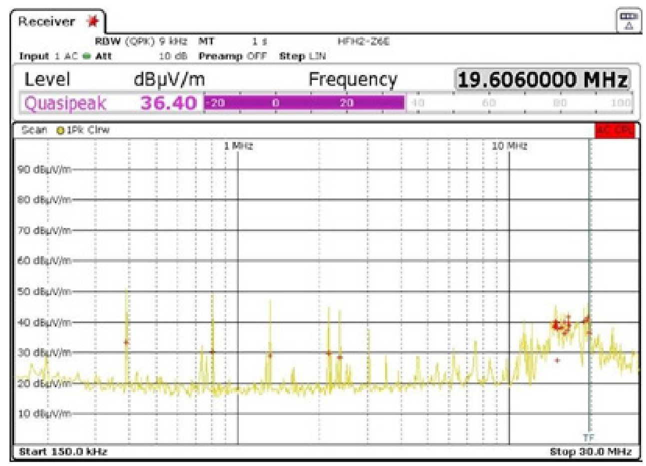

Figure 11. Interference was measured from a 765 kV healthy composite insulator string.

3.2 RFI Emission Recorded from Damaged Composite, Porcelain and Glass Disc Insulators

As stated in section II.E, three 765 kV, 210 kN single I suspension insulator strings were chosen. Ceramic insulator strings consist of 5 numbers of damaged disc insulators placed at equally spaced intervals from the line end of the string to the ground end. Interference was recorded at a test voltage of 508 kVrms after preconditioning for 300 seconds. Interference of string consisting of damaged porcelain and glass disc insulators are shown in Figures 12 and 13 respectively. It is evident from Figures 9 and 12 that a distinct difference in recorded spectra was found on healthy and damaged porcelain disc insulator string. Particularly, the intensity of interference is higher in the 4 to 6 MHz range. Corona is the contributing factor for interference emission at this frequency range and hence this higher magnitude of interference from string consists of a broken disc insulator. A similar trend is observed from glass disc insulator string consisting of healthy and broken glass disc insulators also. The magnitude of interference measured is lesser, this may be due to the presence of only stub on the string. Moreover, rodent damaged/bird-peaked composite insulator string is shown in Figure 14. Compared with RFI recorded from healthy composite insulator string, no major difference is observed, except for a few spikes on the low-frequency region.

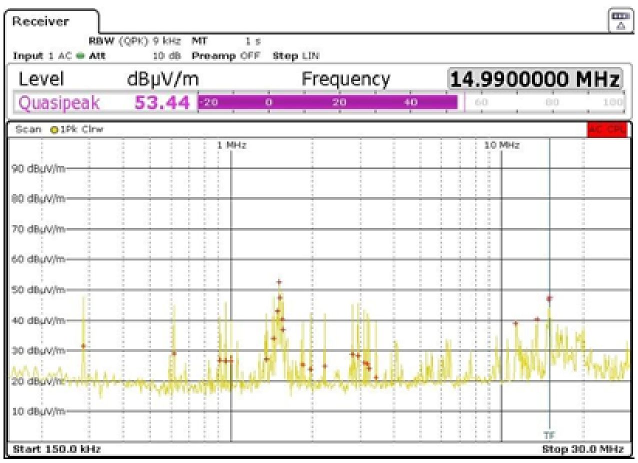

Figure 12. RFI recorded from 765 kV porcelain disc insulator string consisting of 5 damaged discs.

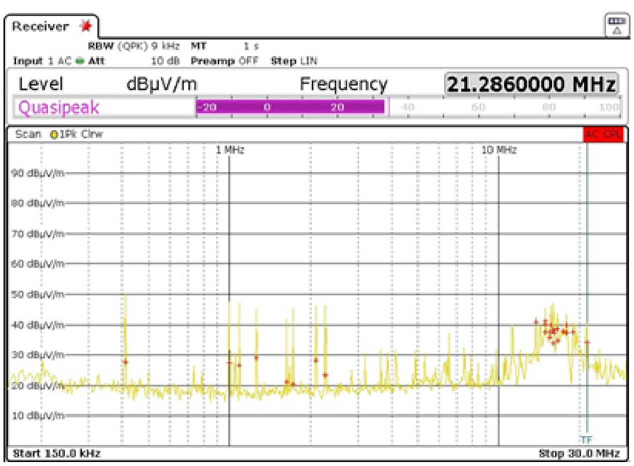

Figure 13. RFI recorded from 765 kV glass disc insulator string consisting of 5 damaged discs.

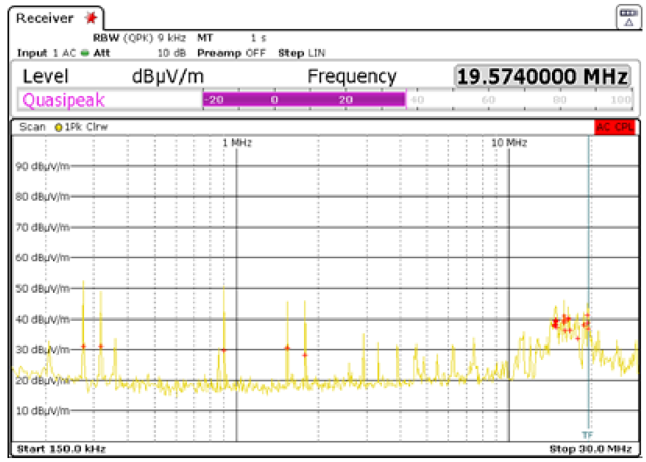

Figure 14. RFI rodent/bird peaking damaged composite long rod insulator string.

3.3 RFI Emission Recorded from Pollutant Deposited and Damaged Insulators

To assess the impact of surface pollution on radio frequency interference emission, on the chosen ceramic disc insulator string, salt water having a salinity of 160 kg/m^3 is sprayed using a commonly available commercial water sprayer. A photograph of salt pollution deposition on the surface of a porcelain disc insulator is shown in Figure 15. Similarly, the salt water sprayed composite disc insulator is shown in Figure 16. RFI recorded at 508 kVrms from both insulator strings with salt water sprayed is given in Figures 17 and 18. A distinct change in the trend and magnitude of RFI is due to corona and spark discharges.

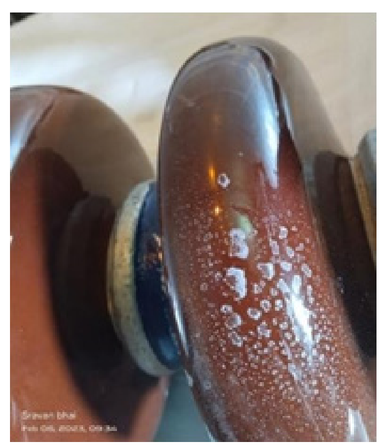

Figure 15. Porcelain disc insulator with salt water pollution applied on the surface.

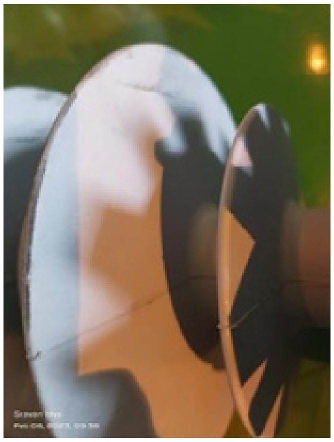

Figure 16. Composite insulator with salt water pollutants sprayed on the surface.

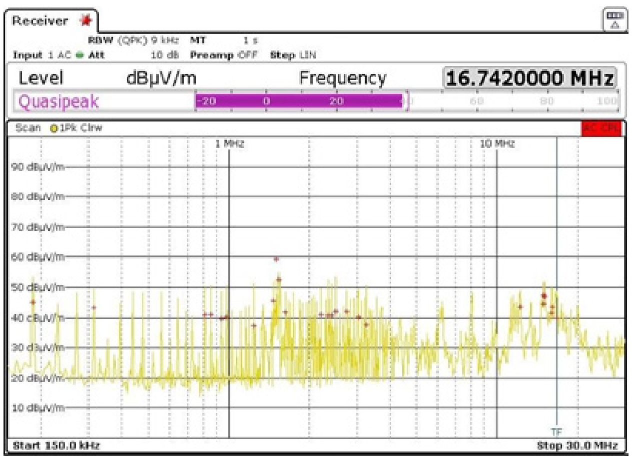

Figure 17. RFI of 765 kV porcelain disc insulator string coated with salt pollution spray.

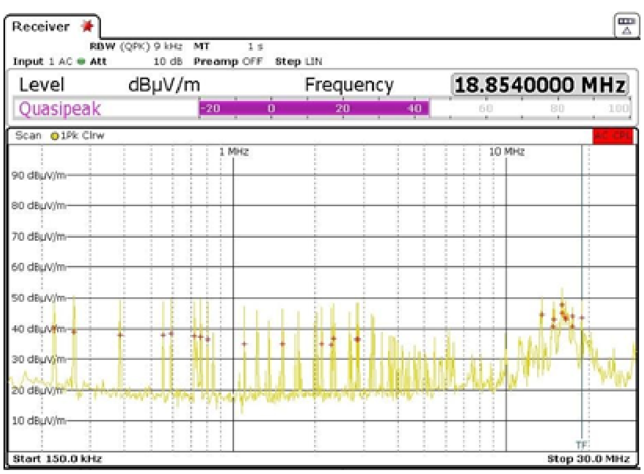

Figure 18. RFI of 765 kV polluted composite long rod insulator string.

4. Conclusions

RFI of 765 kV single I suspension ceramic and composite insulator string with healthy and damaged insulators were measured. It was observed from recorded spectra that, in-service defects on ceramic insulator string have a significant impact on the interference emission due to corona and spark discharges. However, minimal trend and magnitude change is observed on recorded interference of healthy and rodent/bird peaking damaged 765 kV composite insulator string.

5. Acknowledgment

The Authors would like to thank CPRI management for permitting them to publish this comparative study.

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